sciendo

Civil and Environmental Engineering
Vol. 18, Issue 2, 551-564, DOI: 10.2478/cee-2022-0053

IMPACTS OF CLIMATE CHANGE ON THE ENVIRONMENT, INCREASE IN RESERVOIR LEVELS, AND SAFETY THREATS TO EARTHEN DAMS: POST FAILURE CASE STUDY OF TWO CASCADING DAMS IN MICHIGAN

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Abstract

Climate change has received significant attention lately as it has adverse environmental impacts. Among them, rising water levels in the reservoirs are of key concern for infrastructures such as dams. Dam officials are compelled to reconsider dam safety with the increment in catastrophic floods and accelerated dam failure issues. Relatedly, there are numerous earthen dams in the US that may not be up to the current design standards as these dams are aging. They possess a higher risk of failure due to various factors such as defects in design geometry, geologic materials, and hydrologic deficiency due to extreme storms associated with changing climate. Hence, this study focuses on evaluating the impacts of climate change on earthen dams and spillways by conducting a post-failure analysis of the two cascading dams, Edenville Dam and Sanford Dam, located in Michigan, USA, that failed in series in May 2020. The study aims to accomplish three main objectives: 1) to identify the role of climate change on recent dam failures of Edenville and Sanford, 2) to perform a Windows Dam Analysis Modules (WinDAM) C simulation for the failure analysis of the two dams, and 3) to perform Hydrologic Engineering Center - River Analysis System (HEC-RAS) simulation for the failure analysis of both dams by observing downstream propagation of flood with the detailed evaluation of depth and velocity. The overall results show that extreme storms and flooding are associated with the increase in temperature and precipitation rates, impacting overall dam safety. Careful precautions should be undertaken before any of these catastrophic dam events occur. The analysis is useful for the dam agencies as they reconsider their guidelines and policies for future updates.

Keywords:

Climate change;
Environment;
Reservoir levels;
Flood;
Dam failure in the US.

1 Introduction

US dams are aging. They are at risk of failure due to numerous factors, including the defects in design geometry, the nature of geologic materials, changing climate, and the adverse environmental impacts thereafter. Climate change contributes to increased risk of dam failure by changing the patterns of extreme storms and precipitation, impacting the overall environmental phenomena. These changes contribute to an increase in rainfall intensities, triggering the dams for fatal collapse. Hence, this study evaluates the impacts of climate change on dams and spillways by focusing on increasing water levels that could lead to catastrophic failure. In that regard, the study conducts a post-failure analysis of the two cascading dams, Edenville Dam and Sanford Dam, located in Michigan, USA that failed in series in May 2020 when their reservoirs activated due to extreme flooding.

To understand the extent to which increasing water levels in reservoirs can influence dam breaches, it is important to understand the issue of climate change. Evidence shows that the planet's average surface temperature has increased by about 0.9 ^{o}C between the 1950s and the 2000s decade [1]. The rise in temperature is a result of the anthropogenic emissions of greenhouse gases, including carbon dioxide, methane, nitrous oxide, etc. [2-3]. The rise in the earth's temperature is expected to accelerate throughout the 21st century [4]. Temperature rise will result in increased water levels, especially in the higher latitudes or the earth poles [5]. The temperature-induced changes result in shorter snow seasons and high amount of snowmelt causes peak streamflow sooner than predicted. The changing precipitation patterns because of temperature rise involves in extreme flooding, erosion, and heavy riverine sediment transport [3, 6]. Relatedly, the sensitivity analysis performed by Ghimire et al. [7] concluded that the inflow hydrograph in the dam reservoir is the most influential parameter when it involves dam erosion cases. While there are other methods to identify dam condition such as seismic response, slope stability, and soil mechanics of the foundation [8-10], the main focus of this paper is to analyze the impacts of climate change and the resulting inflow hydrograph that reveal the potential safety threat to the earthen dams, by observing previously failed dams.

The remainder of the paper is organized as follows. Section 2 presents a summary of existing literature; Section 3 presents the methodological framework; Section 4 provides the overview of study location; Section 5 provides a description of the data; Section 6 discusses the results; and finally, Section 7 provides the conclusion of the study.

2 Literature review

It is evident that climate change will bring unprecedented numbers of extreme floods and droughts as global warming issues continue to rise. Dam officials are compelled to reconsider dam safety as they are more worried about the catastrophic floods and accelerated failure of dam infrastructures. Although some dam agencies in the US are developing guidance for including climate change in their policies, the information remains scattered and challenging for its application for overall dam safety in general, as shown by Bahls and Holman [11] and Fluixá et al. [12]. Furthermore, the assumptions of stationary climatic baselines may not be appropriate for long-term dam safety project management [13]. As such, incorporating climate change studies into dam safety practices is still limited to quantifying the frequency and intensity of future rises in water levels and flooding. Hence, the main objective of the proposed research is to evaluate the impacts of climate change on Edenville Dam, located at the confluence of the Tittabawassee River and Tobacco River, and Sanford Dam, located in the Tittabawassee River channel downstream of Edenville Dam.

Existing research on climate change and dam safety identify various factors such as precipitation, inflow design flood, outflow flood, and probable maximum flood (PMF) [14]. Sutton [15] determined how the changes in a 100-year flowrate may impact dam design criteria for the existing dam in West Virginia. The paper examined if the emergency spillway remains adequate for high-hazard dams, despite changing climate by analyzing peak annual flowrate data compiled from existing United States Geological Survey – National Water Information System (USGS-NWIS) stream monitoring stations. Azimi Sardari et al. [16] studied the soil erosion in the watershed area of Minab Dam in Iran and sediments accumulated in the dam reservoir due to climate change. They observed that the adverse effects of climate change could bring a rise in land degradation, soil erosion, increment in reservoir sedimentation, etc., and suggested careful application of watershed land use policy and reservoir management. Similarly, Fluixá et al. [12] presented a global and comprehensive review of the impacts of climate change that could affect dam safety. The authors provided valuable insights into dam safety from various aspects of hazards associated with climate change on flood consequences and the population at risk.

In contrast to the previous studies, this paper attempts to analyze the impacts of climate change by comparing the before and after failure phenomena of outflowing water discharged through the dams.

3 Methodology

Given the large number of dams in the US, it is difficult to screen the individual dams involving rigorous site investigation in a relatively short time. Also, it is costly to perform a case-by-case analysis with individual dam site visits. In that light, we adopt an automated screening technique developed by

Ghimire and Schulenberg [17] using Windows Dam Analysis Modules (WinDAM C) software to identify risky dams and spillways where multiple dams and spillways can be flagged as risky in a single simulation. The technique helps rapidly assess the expected level of dam and spillway erosion when the reservoirs are activated. Although the screening helps target the dams for further study, it does not necessarily allow examination of the impacts of climatic and environmental changes or the factors that trigger dam failure. However, in this paper, Ghimire and Schulenberg's screening technique helped identify potential drivers of dam failure, like internal erosion and overtopping. Similarly, the paper also utilizes the Hydrologic Engineering Center - River Analysis System (HEC-RAS) simulation to study the patterns of downstream floods once the dams fail. In sum, the paper examines the impact of climate change on dam safety and evaluates various failure mechanisms of the proposed dams using the following methodology:

1) First, identify the role of climate change in recent dam failures of Edenville and Sanford by studying the effect of change in temperature, precipitation, and Probable Maximum Flood (PMF), by comparing the data from the years 1994 and 2020.

2) Second, perform the WinDAM C simulation for the potential non-risk drivers of dam failure, like internal erosion (for Edenville Dam) and overtopping (for Sanford Dam), both being compatible for the WinDAM analysis with the available data.

3) Third, perform the HEC-RAS simulation for the failure analysis of both dams by observing downstream propagation of flood with the evaluation of depth and velocity.

This study is essential in the context of climate change effects that ultimately questions the storage capacities of reservoirs and overall dam safety, especially for those dams that are identified as potentially risky and hazardous, like Edenville and Sanford.

4 Overview of study location

There are four dams in the Tittabawassee River channel from upstream to downstream in series: Secord, Smallwood, Edenville, and Sanford; however, the focus of the study is Edenville and Sanford Dams. As shown in Fig. 1, Edenville Dam has two sources for its reservoir: Tittabawassee River as the primary source of the reservoir forming Wixom Lake and Tobacco River impoundment converging to the Wixom Lake. The Tittabawassee River in the downstream of Edenville Dam is the source of the Sanford Lake, forming the reservoir for Sanford Dam. This research studies mechanisms of failure triggered due to the change in stream stage and streamflow patterns in and around both of the Tittabawassee River and Tobacco River watershed area from the upstream basin boundary to the Sanford Dam in the downstream, Fig. 1. The Edenville dam was made of sand, and it breached due to the massive inflow of heavy flooding in May 2020, prompting over 11,000 people to evacuate. As the Edenville Dam collapsed, unleashing its reservoir into the downstream Tittabawassee River, the floodwater began gushing over the Sanford Dam, which suffered failure due to overtopping, and the heavy sediment load washed away by the upstream dam breach.

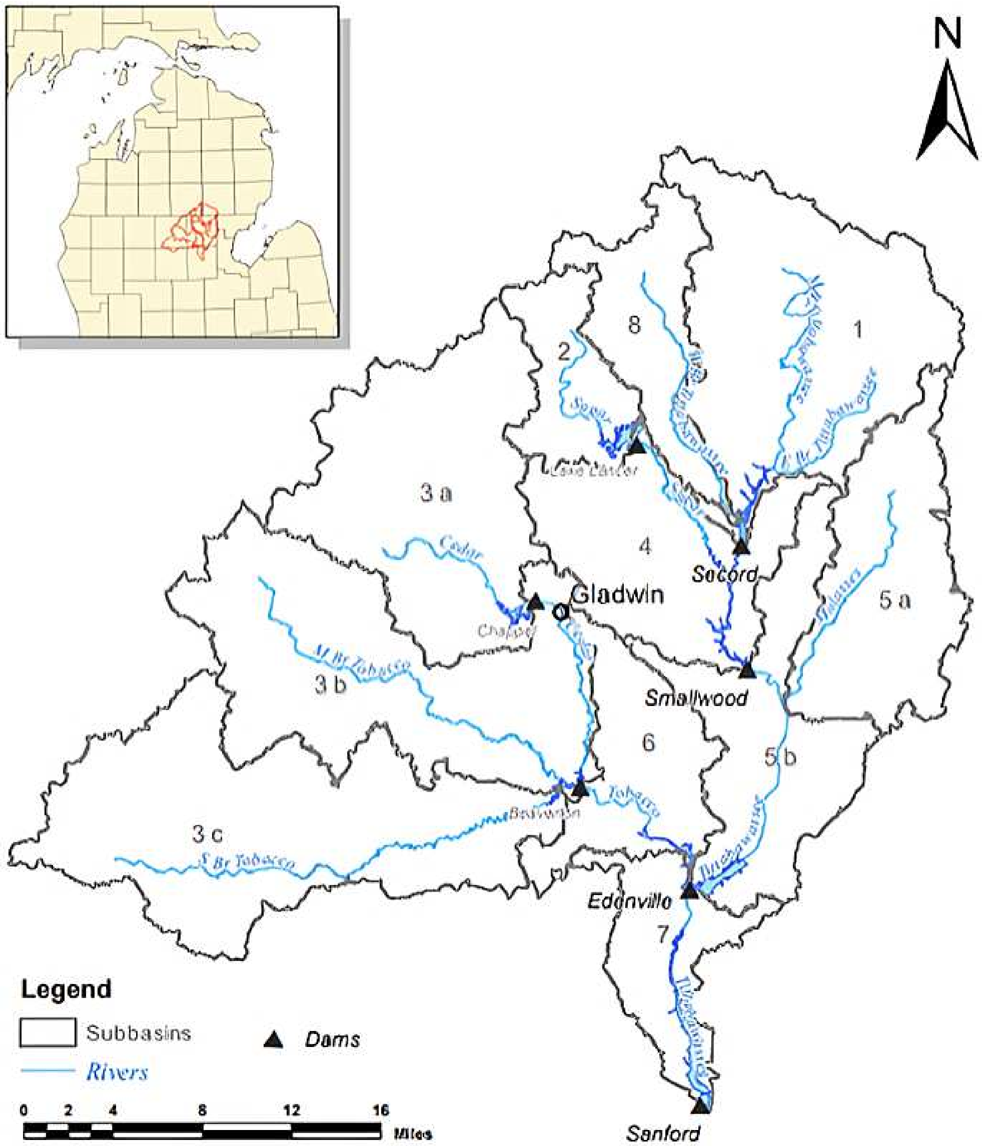


Fig. 1: Tittabawassee and Tobacco River watershed from the upstream basin boundary to Edenville Dam and Sanford Dam in the downstream series (Ayres Associates, 2020).

Fig. 2 represents the after-failure scenario of the dams when they experienced heavy flood. The top half of the figure shows the location of the two dams in series (Edenville Dam in the upstream and Sanford Dam in the downstream) and the flooded area during the time of failure. Similarly, the lower half of the figure shows the dam breach and flood water of the dams individually. The figure is generated in the Geographic Information System (GIS) software using Environmental Systems Research Institute (ESRI) imagery.

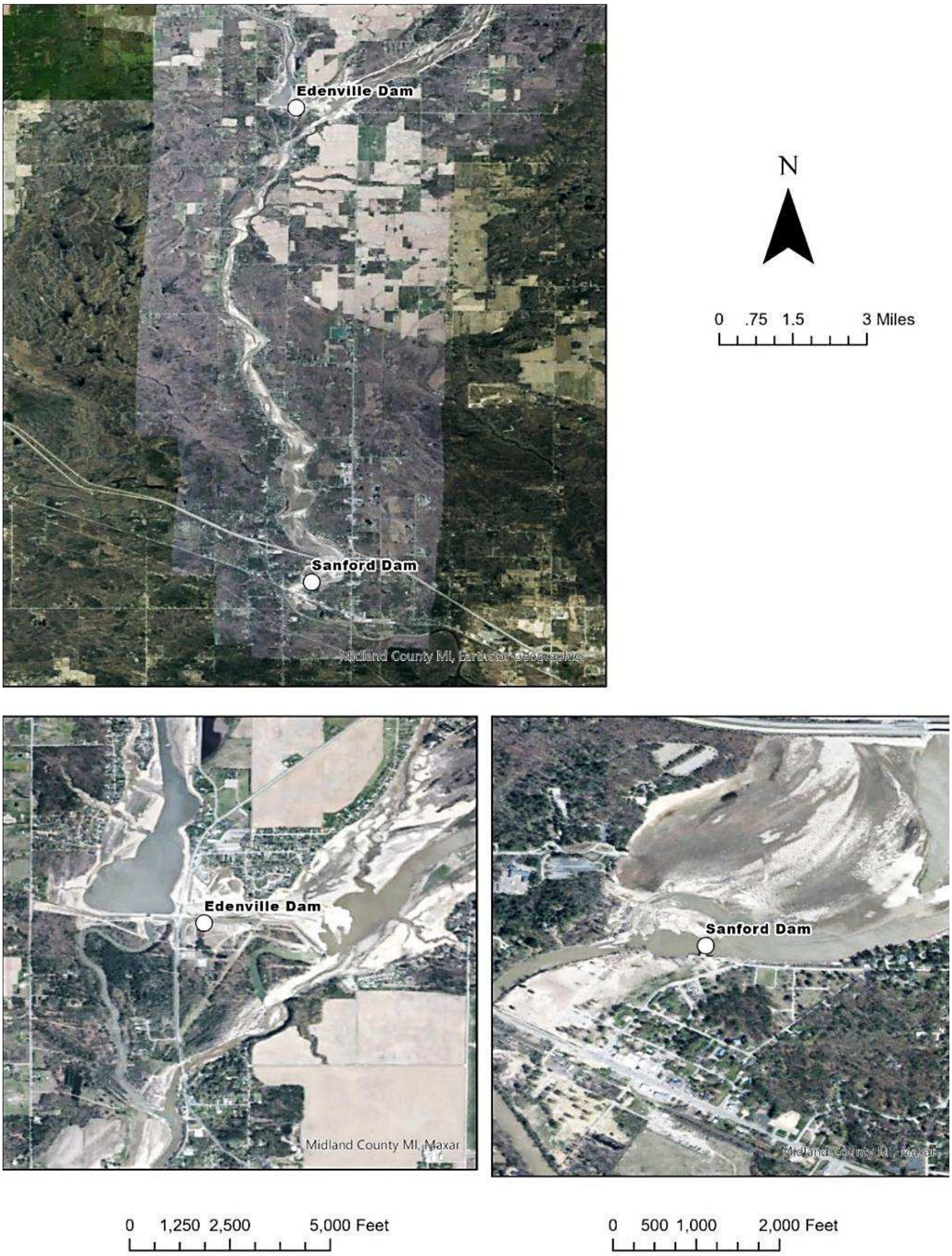


Fig. 2: Edenville Dam and Sanford Dam experiencing a heavy flood in May 2020 (Images created using ESRI Imagery in (GIS)). Note: although the scales represent the US units, all the measurements are referenced using SI units throughout the paper.

According to the forensic report published by ASDSO in May 2022, the most recent failure of the 16.46 m tall Edenville Dam occurred mainly due to static liquefaction leading to instability of saturated and loose sands in the downstream section of the embankment [18]. The conclusion of static liquefaction is supported by the movement of existing loose and uniform fine sand in the embankment. Furthermore, the water level at the reservoir at the time of the failure and the duration of high-water levels contributed to the static liquefaction instability failure. Although the major cause of failure was identified as static liquefaction leading to slope instability, this paper focuses on the examination of other potential modes of failure such as internal erosion and overtopping, both being compatible with the WinDAM analysis with the given data.

5 Data summary

The study uses various data, including the peak flow, streamflow and stream stage, temperature, and precipitation data available from sources like the National Oceanic and Atmospheric Administration (NOAA), USGS-NWIS, etc.

This section summarizes the historical data on temperature and precipitation from the US and the study area – Midland County in Michigan. As the paper's goal is to see how the change in the temperature and precipitation is associated with the water level, we show the growth in the Tittabawassee River flow and the reservoir inflows for the two dams located in the river channel. These data are collected from various sources, including the peak flow data from Ayres Associates [19], streamflow and stream stage data from USGS-NWIS, and temperature and precipitation data from NOAA [6].

5.1 Temperature and precipitation history in the US

Global warming is causing some regions to become wetter and increasing the frequency of extreme storms, according to the latest National Climate Assessment [20]. The trends are expected to continue as the world gets even warmer, and these events will have a severe impact on dams and spillways with increased precipitation rates. The following graphs in Fig. 3 and Fig. 4 show the US's contiguous average annual temperature and precipitation data from 1895 to 2020. The average yearly temperature seems to be rising by + 0.1 ^{o}C per decade, and the average annual precipitation appears to be rising by + 5.8 mm per decade.

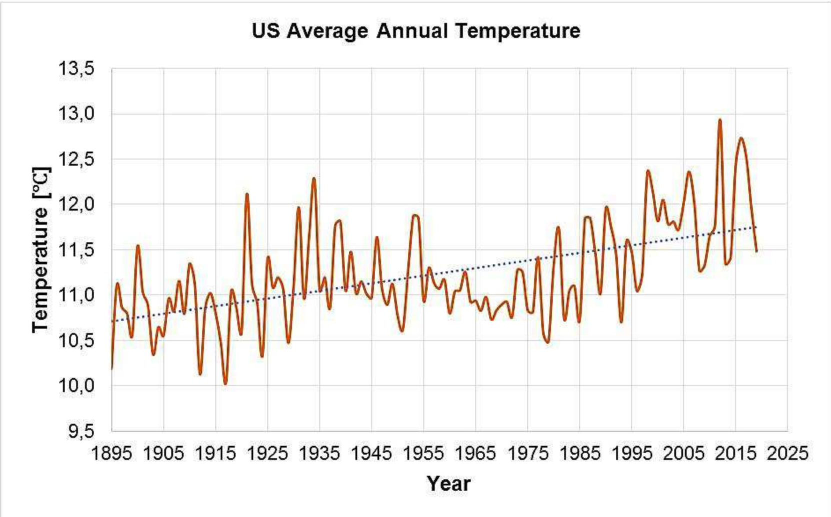


Fig. 3: US annual average temperature (Source: (NOAA, 2020)).

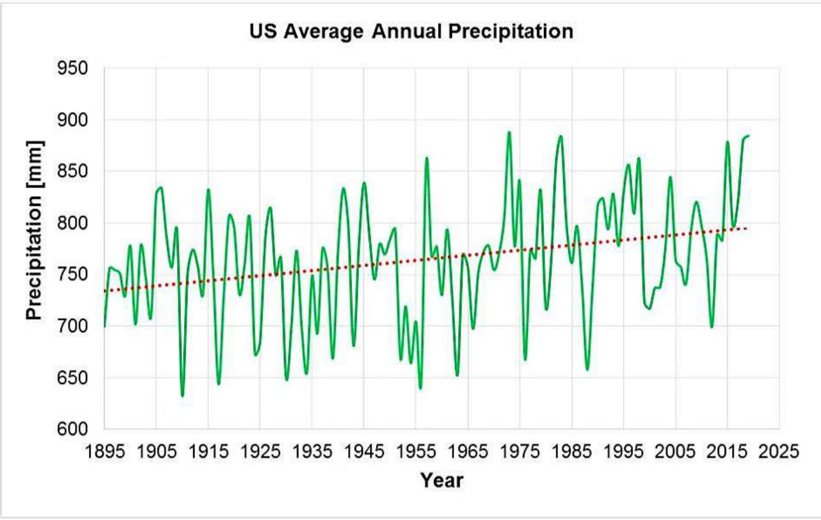


Fig. 4: US average annual precipitation (Source: (NOAA, 2020)).

5.2 Temperature and precipitation history in Midland County

It is not only the country-level data; the local statistics pertaining to the study area show a similar pattern. Fig. 5 and Fig. 6 show the average annual temperature and precipitation data in Midland County in Michigan. In both graphs, the trendlines for temperature and precipitation appear to be increasing.

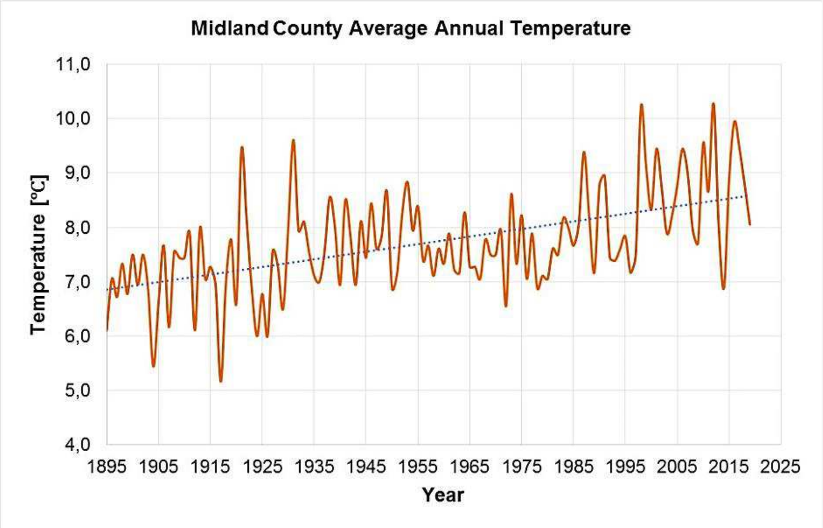


Fig. 5: Average annual temperature in Midland County (NOAA, 2020).

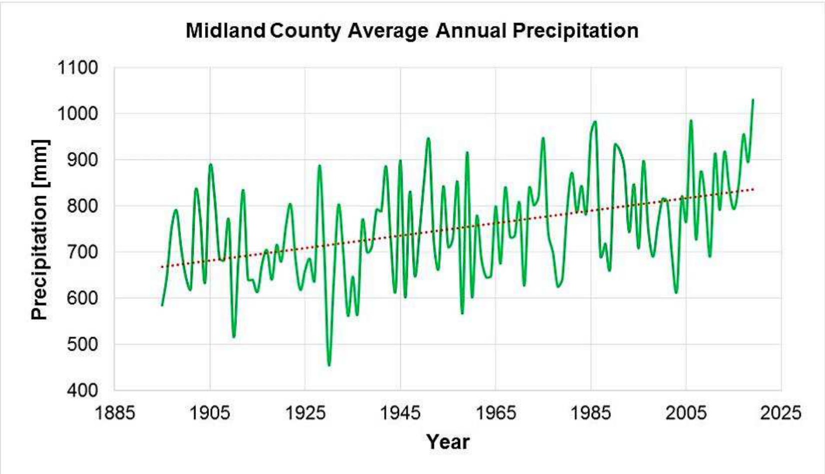


Fig. 6: Average annual precipitation in Midland County (NOAA, 2020)..

5.3 Change in Tittabawassee River flow and reservoir inflows

The Ayres Associates conducted a PMF study to provide engineering and design services to Federal Energy Regulatory Commission (FERC) regarding dam safety compliance for Edenville and Sanford Dams. As the data required for dam performance analysis are limited, this paper focuses on the publicly available data for 1994 and 2020. The PMF inflows and outflows for these two years are listed in Table 1. According to the reports, more intense storm oriented on the upstream basin of Edenville increased the PMF values at both Edenville and Sanford. The data shown in Table 1 is taken from the study conducted by Ayres, where they evaluated the PMF at Tittabawassee River facilities using precipitation, streamflow, and watershed data. The calculated PMF peak inflows to the Edenville and Sanford reservoirs are 2290.81 m^3/s and 2282.32 m^3/s, respectively, in 2020. These represent 30 percent and 7 percent increases over the previously accepted values. According to Ayres Associates, these increases can be attributed primarily to a decrease in simulated hydrologic loss rates in 2020. The disproportionately large increment at Edenville Dam is also attributed to a more critical storm position than was previously evaluated. It can be said that the increase in temperature and precipitation in Gladwin and Midland counties have prompted these flows to rise and eventually collapse the dams. In this study, the inflow values provided in Table 1 are used for the comparison of WinDAM analysis for the year 1994 and are compared with the inflow of 2020 to see the erosion phenomena of these dams. For the Edenville Dam, an internal erosion analysis is conducted, whereas, for the Sanford Dam, an overtopping analysis is undertaken. The required input parameters for WinDAM analysis, such as dam geometry, inflow hydrograph, and geologic properties available at the dam location, are calculated and entered accordingly. A sample of input parameters required for WinDAM analysis for Edenville and Sanford Dams is provided in Table 2.

Table 1: Tittabawassee River probable maximum flood (PMF) in 1994 and 2020, respectively (Ayres Associates, 2020).

Dams	1994 Peak Flows [m^3/s]		2020 Peak Flows [m^3/s]	
	Inflow	Outflow	Inflow	Outflow
Edenville	2106.75	2092.60	2290.81	2268.16
Sanford	2137.90	2072.77	2282.32	2239.84

Table 2: Sample of input parameters required for the WinDAM analysis.

Dam details	Edenville dam	Sanford dam
Dam length [m]	2011.58	487.66
Dam height [m]	16.46	10.97
Max. inflow [m^3/s] - 1994	2106.75	2137.90
Max. inflow [m^3/s] - 2020	2290.81	2282.32
US State	Michigan	Michigan

Similarly, the USGS streamflow for Tittabawassee River, in the downstream is analyzed in detail to observe the flood propagation by using HEC-RAS software. The USGS streamflow data for the month of May (peak season of flow, as seen from the data) for the years 1994 and 2020 are compared and analyzed simultaneously to visualize the climatic impact in the increment of depth and velocity of the flood. Fig. 7 and Fig. 8 show the graph of streamflow data for May 1994 and May 2020, respectively. For further analysis, the 26 years of continuous streamflow data from 1994 to 2020 is collected, and the flow patterns are observed accordingly. The peak flow value recorded in May 2020, when the dams collapsed, was the highest of all time. According to the National Weather Service (NWS), the Tittabawassee River had peaked at 10.68 m, which was 3.045 m above flood levels, beating the previous record of 10.33 m set in 1986, which is also named as "catastrophic" flood in history, Fig. 9.

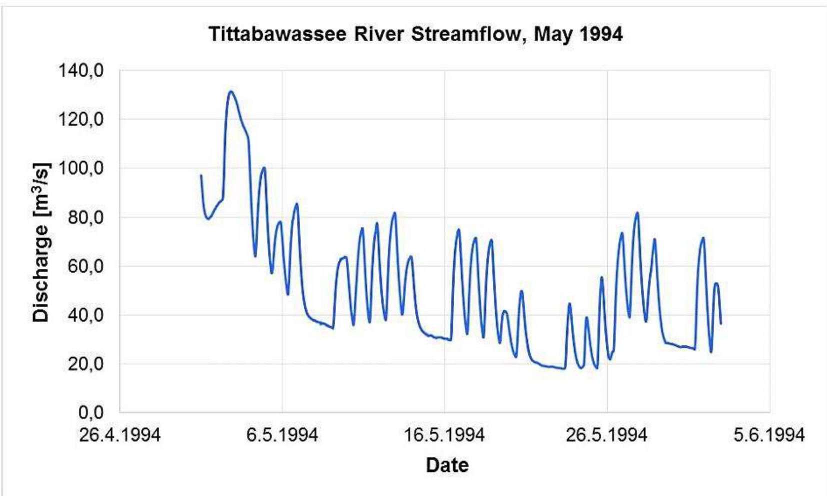


Fig. 7: Tittabawassee River streamflow recorded in May 1994.

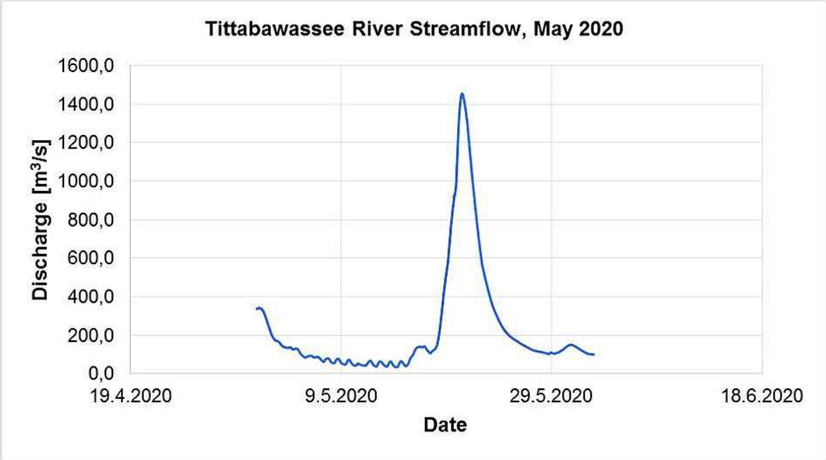


Fig. 8: Tittabawassee River streamflow recorded in May 2020.

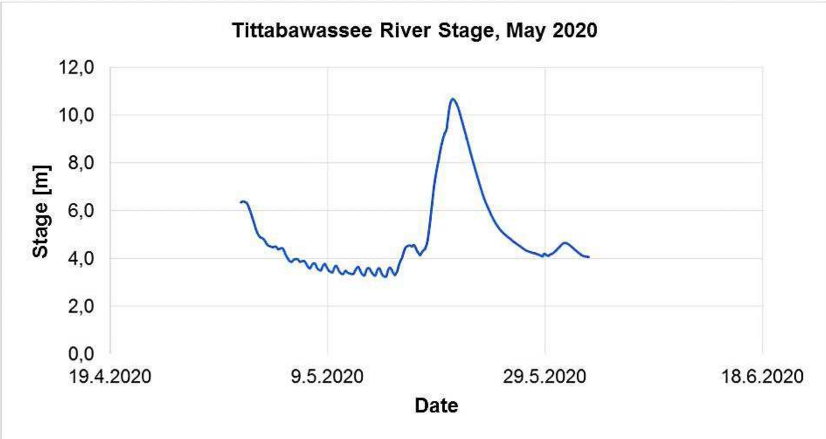


Fig. 9: Tittabawassee River stream stage recorded in May 2020.

5.4 HEC-RAS simulation

The USGS inflow discharge data from 1994 and 2020 are used for the HEC-RAS simulation for the dam breach analysis in Edenville Dam, and its consequences are visualized in the Sanford Dam and the downstream Midland County. The data are compared to observe how the flood propagates in the downstream area with the change in the inflow hydrograph. The terrain data, hydrologic inputs, and boundary conditions are used to develop an unsteady flow model for dam breach analysis. In HEC-RAS, a projection file (prj file extension) is required as an ESRI projection to access the base maps available in RAS Mapper. Digital Elevation Model (DEM) files are used for extracting the elevation values of a particular location.

The following steps are applied to conduct the HEC-RAS simulation:

1) Draw the geometry of the storage area upstream and the perimeter downstream of the dam as required for mapping purposes.
2) Set the boundary downstream and generate mesh for 2D flow area computation points.
3) Enter the dam station and elevation details.
4) Set the boundary conditions and initial conditions for the storage area and perimeter.
5) Input the lateral inflow hydrograph and set the simulation time.
6) Run the unsteady flow analysis.
7) Open the RAS mapper to view the results of flood depth, velocity, water surface elevation, etc.

6 Results and discussion

This section compares the results observed from the WinDAM simulation for the flood data from 1994 and 2020. Similarly, it also discusses the HEC-RAS simulation, the flood propagation on the downstream area, and the variation in depth and velocity of flood in Midland County.

6.1 WinDAM simulation results

To analyze how the rising water level in the Tittabawassee river impacted the water flow in the two dams, WinDAM simulation is conducted for both Edenville and Sanford Dam failure analyses. Internal erosion of Edenville Dam and an overtopping erosion of Sanford Dam is visualized for both 1994 and 2020 PMF data, as provided in Tables 1 and 2. The results samples are presented in Fig. 10 and 11, which show the beginning phase of internal erosion in Edenville Dam in 1994 and 2020, respectively. As expected, in Fig. 11, the dam erosion is more significant with the higher water level than in Fig. 10. Similarly, Figs. 12 and 13 show the overtopping erosion in Sanford Dam in 1994 (if there had been one at the observed water level) and 2020, respectively. It is observed that in Fig. 13, the overtopping begins faster with higher erosion than that of Fig. 12, as expected. Both of these results only represent a portion of erosion. The overall analysis concluded that with an increment in flood level in 2020, the dams had higher water levels and higher outflows than that of 1994, the reason for both of the dams to collapse. In each of the following figures, the top half represents the dam cross-section, and the bottom half represents the plan view.

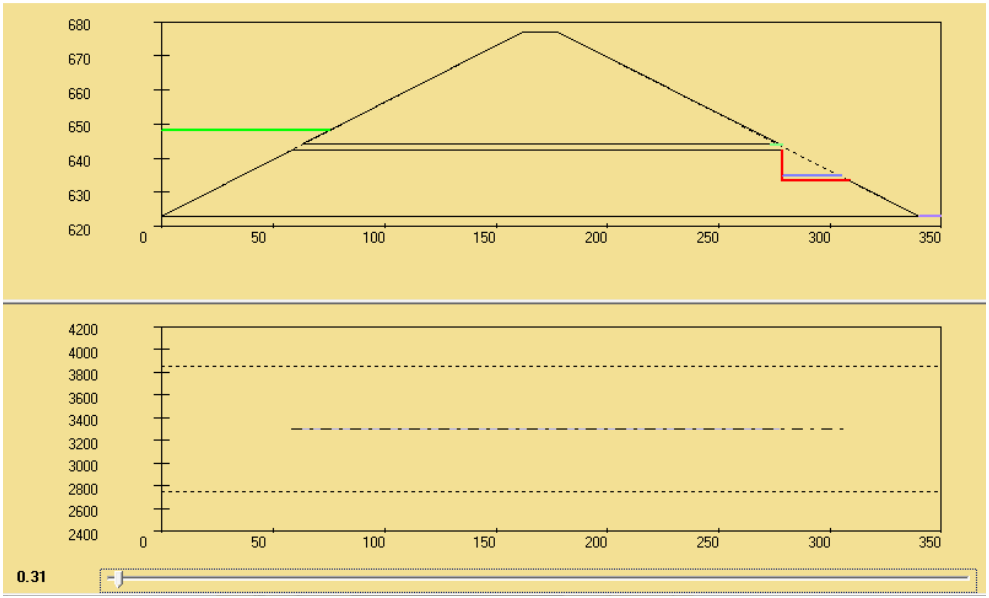


Fig. 10: WinDAM simulation for internal erosion analysis for Edenville Dam with 1994 inflow.

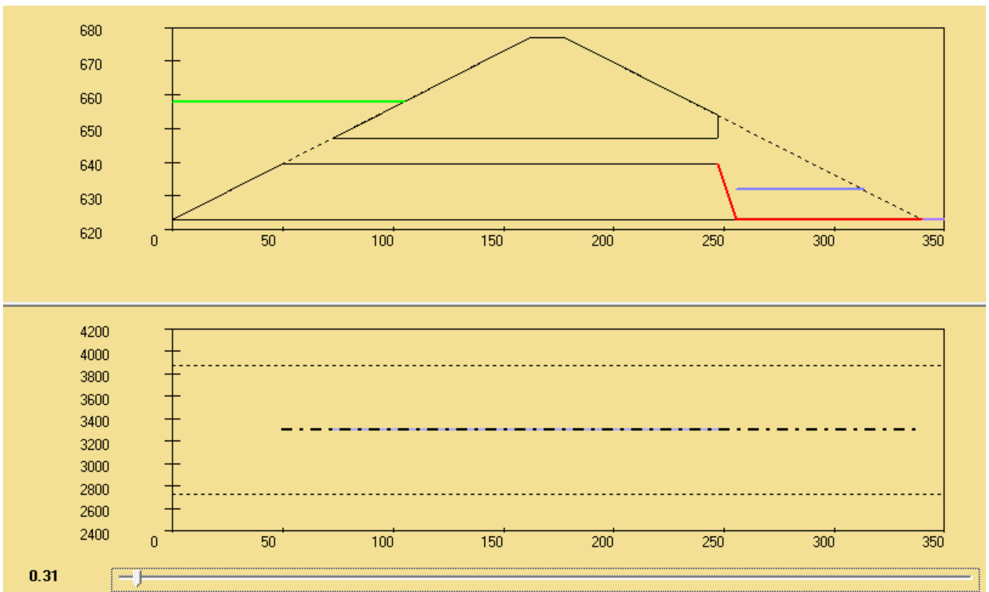


Fig. 11: WinDAM simulation for internal erosion analysis for Edenville Dam with 2020 inflow.

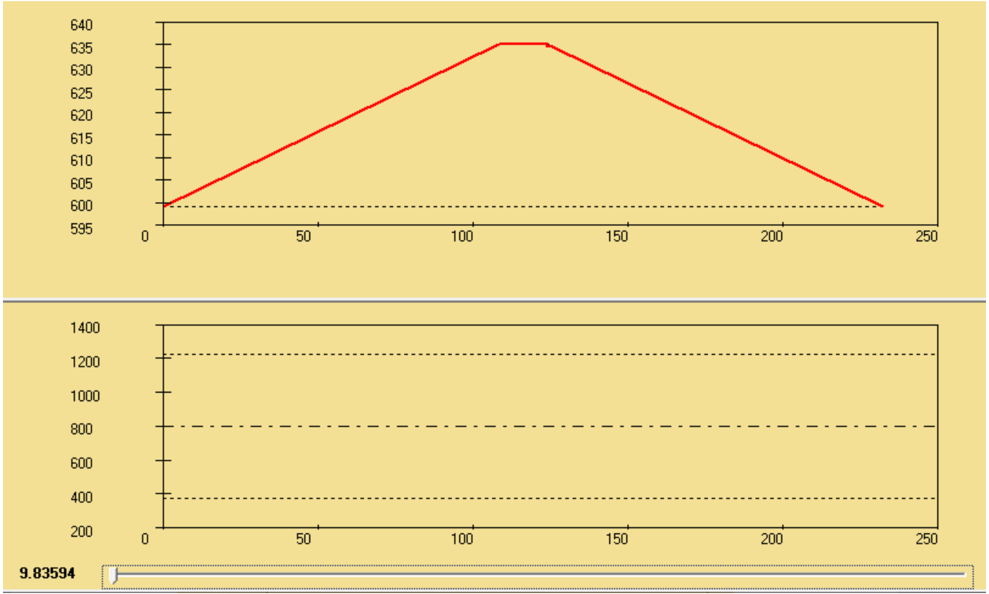


Fig. 12: WinDAM simulation for overtopping analysis for Sanford Dam with 1994 inflow.

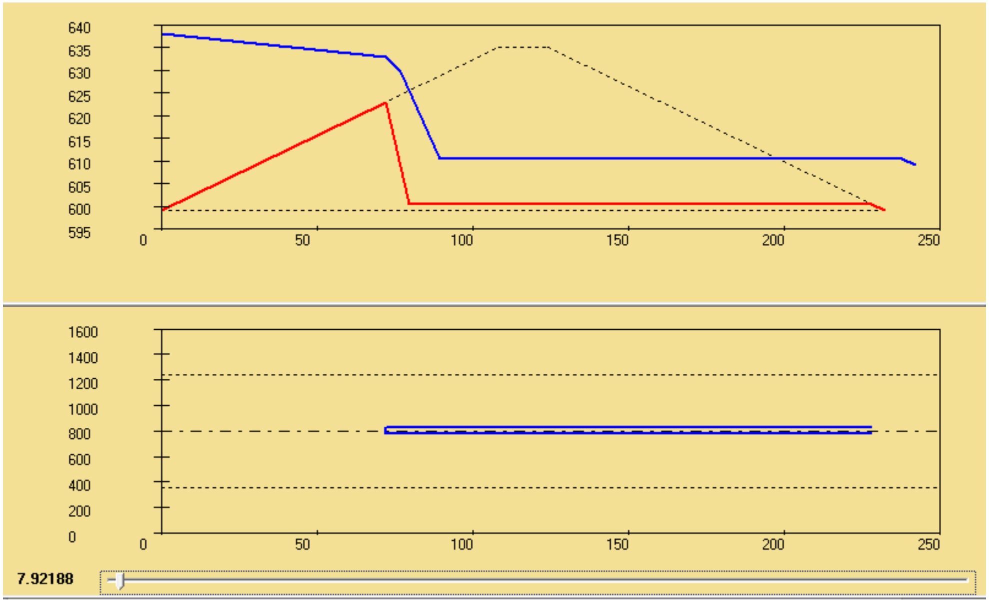
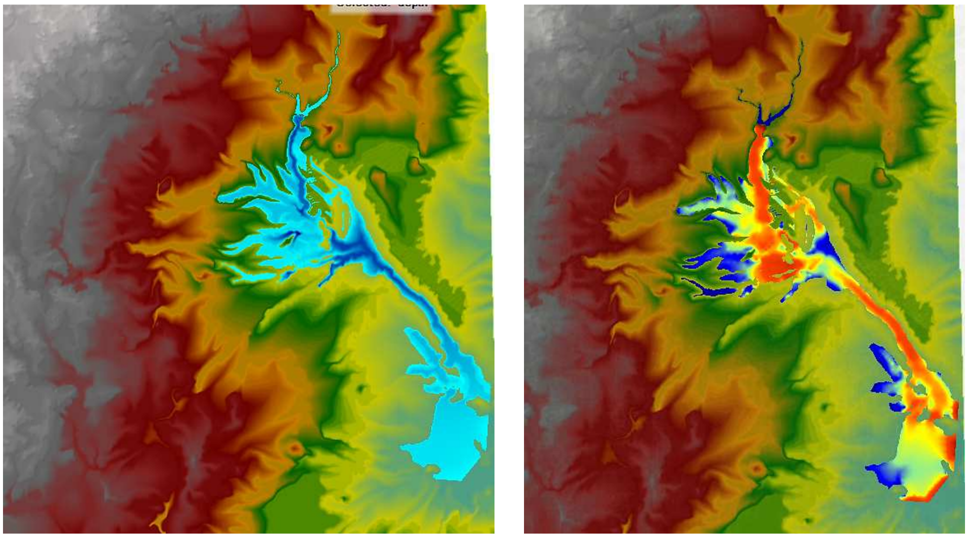


Fig. 13: WinDAM simulation for overtopping analysis for Sanford Dam with 2020 inflow.

6.2 HEC-RAS simulation results

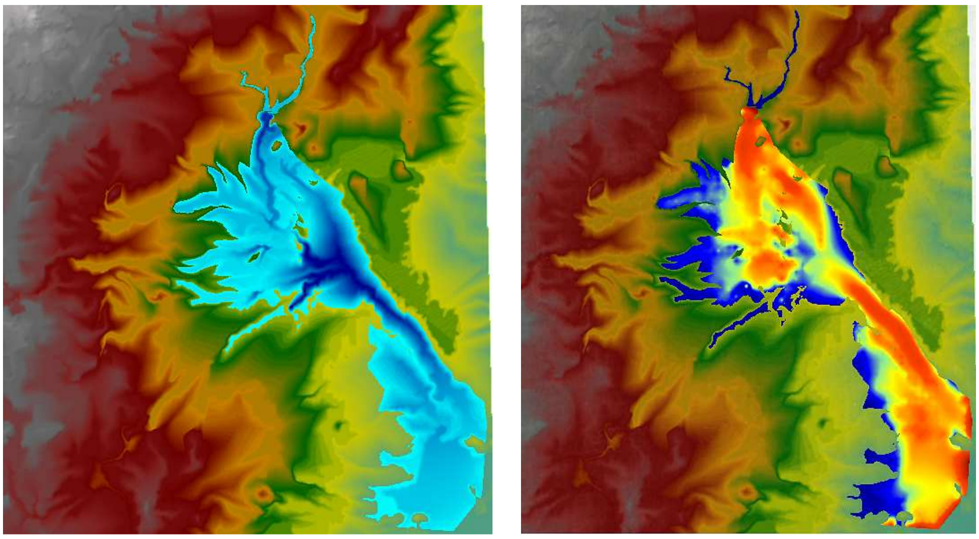
The HEC-RAS simulation is conducted by applying a 2D unsteady flow analysis for the inflow for the years 1994 and 2020. If the Edenville dam had to breach during the 1994 peak discharge, the floodwater would have traveled overtopping Sanford Dam downstream, as shown in Fig. 14. The following figures illustrate the depth and velocity details of flood flowing in the downstream area with the 1994 discharge in May. The light blue to dark blue color in the floodwater in Fig. 14 a) shows the increasing depth of water, and the bright yellow to bright orange color in Fig. 14 b) shows the increasing velocity of the water. The maximum depth of water observed in the downstream area was 2.71 m, and the maximum velocity was observed to be 0.94 m/s.



a) b)

Fig. 14: a) Depth of flood propagation and b) Velocity of flood propagation, after HEC-RAS simulation, using May 1994 discharge data. The storage area for both analyses is upstream of Edenville Dam.

Similarly, a post-failure analysis of Edenville Dam after its failure in May 2020 is conducted in HEC-RAS to compare the results from 1994 versus 2020. After the Edenville dam breach during the 2020 peak discharge, the flood water traveled downstream, overtopping the Sanford dam downstream, as shown in Fig. 15. The following Fig. 15 a) and 15 b) show the depth and velocity details of flood flowing in the downstream area with the May 2020 discharge. The light to dark blue color in the floodwater in Fig. 15 a) shows the increasing depth of water, and the bright yellow to bright orange color in Fig. 15 b) shows the increasing velocity of the water. The maximum depth of water observed in the downstream area was 4.6 m, and the maximum velocity was observed to be 2.07 m/s, which are significantly higher than that of 1994.



a) b)

Fig. 15: a) Depth of flood propagation and b) Velocity of flood propagation, after HEC-RAS simulation using May 2020 discharge data. The storage area for both analyses is upstream of Edenville Dam.

6.3 Limitations and future research

This paper utilizes three key research techniques to evaluate two earthen dams that failed in series in Michigan, USA, in May 2020. Firstly, the main objective was to study if climate change had any role in the failure. While the rising temperature and precipitation are associated with the failure, we cannot establish a causal relationship. Indeed, the major cause of failure was later identified as static liquefaction and slope instability. Secondly, in the absence of on-site data, this paper only focuses on the examination of other potential non-risk drivers of dam failure such as internal erosion and overtopping. So, we performed WinDAM analysis adopting the technique by Ghimire and Schulenberg [17] to observe these failure mechanisms. Lastly, we conducted HEC-RAS simulation to observe the dam breach and downstream flood using secondary data. While these techniques were useful to examine potential factors of failure, they do not catch static liquefaction – the true cause of failure. A comprehensive analysis to cover the static liquefaction would involve in depth case study and relevant on-site data. Future research should be geared towards investigating in the problems like static liquefaction.

7 Conclusion

From the above analyses, it can be concluded that climate change has impacted the water flow patterns in the river channels, their watershed areas, and the reservoirs where the dams are located. Based on the data availability, this paper analyzes the data from the years 1994 and 2020 to observe the temperature, precipitation, and water levels in two dams in Midland County in Michigan, USA. The overall results show that the temperature and precipitation rates have been increasing, thus prompting extreme storms and flooding. Such phenomena became more evident when the earthen dams like Edenville and Sanford failed in series. There are a lot of similar dams across the US that are made of earthen materials, which may not be up to the current design standards as these dams are aging. So, careful precautions should be undertaken before any catastrophic events may occur. The analysis presented here can be useful for the dam agencies to reconsider their guidelines and policies in future updates. The methodology is also helpful for researchers who want to analyze potential dam failure using secondary data in the absence of primary, on-site, data.

Acknowledgements

This research was supported with funding from the WIU Foundation and the Office of Sponsored Projects at Western Illinois University. Authors are grateful for the support.

References

[1] ROHDE, R. - MULLER, R. A. - JACOBSEN, R. - MULLER, E. - PERLMUTTER, S. - ROSENFELD, A. - WURTELE, J. - GROOM, D. - WICKHAM, C.: A New Estimate of the Average Earth Surface Land Temperature Spanning 1753 to 2011. Geoinfor Geostat: An Overview, Vol. 1, Iss. 1, 2013, pp. 1-7.
[2] MONTZKA, S. A. - DLUGOKENCKY, E. J. - BUTLER, J. H.: Non-CO_2 greenhouse gases and climate change. Nature, Vol. 476, Iss. 7358, 2011, pp. 43–50.
[3] REDDY, K. R. - CAMESELLE, C. - ADAMS, J. A.: Sustainable engineering: Drivers, metrics, tools, and applications. John Wiley & Sons, 2019, 544 p.
[4] GOBIET, A. - KOTLARSKI, S. - BENISTON, M. - HEINRICH, G. - RAJCZAK, J. - STOFFEL, M.: 21st century climate change in the European Alps - A review. Science of the Total Environment, Vol. 493, 2014, pp. 1138–1151.
[5] BARNETT, T. P. - ADAM, J. C. - LETTENMAIER, D. P.: Potential impacts of a warming climate on water availability in snow-dominated regions. Nature, Vol. 438, Iss. 7066, 2005, pp. 303–309.
[6] NOAA: National Centers for Environmental Information (Climate at a Glance: National Time Series). Retrieved September 29, 2020, https://www.ncdc.noaa.gov/cag/.
[7] GHIMIRE, S. N. - SCHULENBERG, J. W. - NEILSEN, M. L.: Sensitivity Analysis of the Auxiliary Spillway Erosion Based on the Material and Structural Properties. Geo-Extreme, 2021, pp. 111-126.
[8] KOTRASOVÁ, K. – LOUKILI, M.: The seismic response of fluid filling in rectangular reservoir at Nador city Morocco. Civil and Environmental Engineering, Vol. 16, Iss. 2, 2020, pp. 267-75.
[9] HARABINOVÁ, S – KOTRASOVÁ, K. – KORMANÍKOVÁ, E. – HEGEDÜSOVÁ, I.: Analysis of Slope Stability. Civil and Environmental Engineering. Vol. 17, Iss. 1, 2021, pp.192-199.
[10] NGUYEN, G.: Determination of Stress in Spread Foundation Subsoil by Various Approaches. Civil and Environmental Engineering. Vol. 11, Iss. 1, 2015, pp. 29-37.
[11] BAHLS, V. - HOLMAN, K.: Climate Change in Hydrologic Hazard Analyses: Friant Dam Pilot Study-Part I: Hydrometeorological Model Inputs. Tech. rep., US Department of the Interior, Bureau of Reclamation, 2014.

[12] FLUIXÁ, S. J. – ALTAREJOS, G. L. – MORALES, T. A. – ESCUDER, B. I.: Climate change impacts on dam safety. Natural Hazards and Earth System Sciences, Vol. 18, Iss. 9, 2018, pp. 2471–2488.
[13] USACE: US Army Corps of Engineers. Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects, United States Army Corps of Engineers, EBC 2016-25, 2016. Retrieved September 4, 2020, https://bit.ly/3MI0ma1.
[14] CHERNET, H. H. - ALFREDSEN, K. - MIDTTØMME, G. H.: Safety of hydropower dams in a changing climate. Journal of Hydrologic Engineering, Vol. 19, Iss. 3, 2014, pp. 569–582.
[15] SUTTON, A. R.: Evaluating design criteria for high hazard dams in a changing climate, 2019.
[16] AZIMI SARDARI, M. R. – BAZRAFSHAN, O. – PANAGOPOULOS, T. – SARDOOI, E. R. Modeling the impact of climate change and land use change scenarios on soil erosion at the Minab Dam Watershed. Sustainability, Vol. 11, Iss. 12, 2019, 21 p.
[17] GHIMIRE, S. N. - SCHULENBERG, J. W.: An Automated Screening Technique to Identify At-Risk Auxiliary Spillways: Modified Approach in WinDAM. Journal of Hydraulic Engineering, Vol. 147, Iss. 8, 2021.
[18] FRANCE, J. - ALVI, I. - MILLER, A. - WILLIAMS, J. - HIGINBOTHAM, S.: Final Report: Investigation of Failures of Edenville and Sanford Dams. Independent Forensic Team, 2022, https://bit.ly/ 3MPyBMu.
[19] AYRES ASSOCIATES: Probable maximum flood determination (Tittabawassee River Hydroelectric Project). Retrieved October 4, 2020, https://bit.ly/3b0hhaD.
[20] FOUNTAIN, H.: Expect More: Climate Change Raises Risk of Dam Failures. The New York Times, Retrieved June 2, 2020, https://nyti.ms/3dNFUmq.