REVIEW OF DAM SAFETY EDUCATION, EXTENSION AND OUTREACH MATERIALS IN NEW YORK

A small earthen dam in Cortland County, NY. *Photo by Roy Widrig, New York Sea Grant.*

Executive Summary

Thousands of small, low-head dams are present across the Great Lakes Basin. Despite federal and state inventories, many small dams on private property – referred to here as "ghost dams" – are absent from publicly-accessible inventories and remain unaccounted for in climate and weather-related planning efforts. This project, conducted in partnership between New York Sea Grant (NYSG) and the Water Resources Institute at Cornell University (WRI) and funded through the Cooperating Technical Partners (CTP) program through the Federal Emergency Management Administration (FEMA), was completed to evaluate the current extent of education and outreach material related to low-head dams, ghost dams, and their associated hazards.

Dam safety resources were compiled and analyzed by target audience, topic, and accessibility. Through this analysis, it was determined that outreach to dam owners and safety professionals was adequate, but deficiencies exist in delivering useful outreach material to residents both up- and down-stream from ghost dams, as well as to recreational enthusiasts using the small streams and rivers on which these dams are located.

Additionally, the project team selected a small drainage within the upper Black River Watershed in Lewis County, NY, to determine the extent of ghost dams within the region using a combination of machine learning, desktop verification, and field verification of unmapped dams. This analysis resulted in 391 unmapped dams within the Sugar River and Mill Creek sub-basins of the Black River.

Funding Acknowledgement

Introduction

Recent flooding events in the Northeast and Great Lakes Regions have placed a focus on the state of infrastructure, with emphasis on the stability, longevity, hazards, and usefulness of thousands of small dams across the region. With the increasing likelihood of severe storms within the region, residents, dam owners, municipalities, and recreationists stand to benefit from education and outreach programs regarding the potential hazards of these dams. Municipalities and residents would benefit from being aware of flooding and erosion hazards facing their communities. Dam owners would be informed on the hazards their dams may present as well as options for managing these dams to reduce hazards and improve aquatic connectivity. Additionally, water recreationists such as swimmers, kayakers, boaters, and fishermen can be made aware of potential drowning-related hazards associated with dams.

Narrative

There are currently 92,392 known dams in the United States, according to the United States Army Corps of Engineers' most recent inventory (Dams of the Nation). While 5% are regulated at the federal level, 18% of all dams are listed as High Hazard Potential Dams. There are 435 High Hazard Potential Dams inventoried by NYS Dam Safety (excluding federal regulated dams, 353 are regulated by the state). High Hazard Potential is based on downstream impacts should a dam fail as identified in 6NYCRR Part 673.5.

The goal of this project was to evaluate the state of dam safety outreach and education in New York State, with emphasis on the Great Lakes Basin. To do this, the team compiled resources from government programs, non-government organizations and not-for-profits, peer-reviewed publications, and mass media. Within these resources, our analyses focused on low-head dams. As a result, much of the consumable media around other types of dams and dam failures was not included in this report.

    I.   **Connectivity:** While the safety of low-head dams and the connectivity of the region's waterways are inextricably linked, connectivity has been heavily studied outside of this project and was not included in the scope at this time. The connectedness of waterways directly influences the hazards associated with dams. Within the scope of this report, dam removal will be considered only from a natural hazard focus.

    II. **Tailings Dams:** Tailings dams, which are earthen embankments designed to store materials from mining and extraction, may be present in New York State, but are not included in this report.

    III. **Funding Dam Projects:** With multiple governments involved and the inconsistency of federal, state, and local funding, this report will not focus on funding opportunities for dam studies, repairs, or removals. When applicable, funding sources for completed or in-progress projects will be mentioned as integral parts of dam projects.

Relevance

Recent events have caused dam safety to become a prominent topic in environmental hazards. After heavy rains in May of 2020, a dam on the Tittabawasee River in Edenville, Michigan, failed. This sent a pulse of floodwater downstream towards Edenville and eventually 10 miles further downstream to the Sanford Dam, which was overtopped. The incident triggered the evacuation of Midland, with around 10,000 residents being displaced. Subsequent forensic reports of the failure determined the cause as "foreseeable and preventable," resulting in significant national media coverage and bringing dam hazards and safety in the Great Lakes into a more prominent light.

Research has shown that intensified precipitation may contribute to the increasing failures of dams (Hwang and Lall, 2024). Although numerous efforts aim to improve the resiliency of America's infrastructure, concerns about dam safety often fade from public attention in the absence of recent disasters like the Edenville dam failure. The combination of increasingly extreme weather events and the under-engineered or poorly maintained condition of thousands of low-head dams poses a significant risk for river communities, including residents within the floodplain, municipal officials managing the floodplain, the dam owners themselves, and those recreating on the waterways.

Low-head or "ghost" dams, despite their often small size, may provide certain risks to communities, including:

I. **Flood Risk**
Unmapped low-head or "ghost" dams are generally unknown to the public and absent from government inventories. While these dams usually impound small amounts of water, their contribution as a population of additional water storage within an entire watershed should be a consideration in evaluating flood risk for a watershed or within specific catchments. Dams that fall out of government databases or regulation are left uninspected and may have significant impacts on flood risk, especially without proper maintenance.

II. **Infrastructure Risk**
Ghost dams rarely act as important infrastructure. In the event of flooding or failure, they can actually contribute to erosion and flooding risk around infrastructure such as culverts, bridges, and stream crossings. In some cases, ghost dams may have a secondary purpose in providing roadways along farm, landscape, and recreational ponds, potentially serving as necessary infrastructure for emergency fire or medical response.

III. **Recreation Risk**
Many ghost impoundments are found within the bounds of private properties, so their immediate risk to recreation is limited due to the lack of public access. During flooding events, however, ghost dams may overtop or fail. Consequences for downstream riverine communities may include debris, pollutants, and other hazards being released into recreational waterways.

IV. **Ecological Opportunities**
Many ghost dams fulfill minimal ecological purposes. Their presence is frequent in low-productivity lawns and agricultural fields, where they serve as water storage or recreational features with little to no contribution to the local ecology. For this study, ghost dams were recorded with an inflow and an outflow along the course of permanent streams. Their impoundments may be providing a negative influence on ecological connectivity of small streams and creeks, introducing complexities to hydrological processes. A significant exception to this would be the presence of beaver dams, which often provide excellent habitat and ecological productivity, but may be temporary in nature.

This report is intended to be an overview of the project, provided in compliance with the deliverables of COMS SOW No. 2022-NYSG-01. Completed in September 2024 as this first phase of this project, the report should be considered a snapshot of the work done up until this point, with future work on this project focused on creating outreach material deemed missing and on further explorations into modeling the amount of and functionality of low-head dams in New York State.

State of Dam Education and Outreach in New York

Literature Review

In order to adequately evaluate the state of outreach and educational programming in regard to dam safety, this report focuses on resources from multiple sources, including but not limited to government organizations, non-government organizations and not-for-profits, independent educational outreach, mass media, and forensic reports. Audiences for this outreach material ranged from residents and municipalities, ecosystem or environmental scientists, dam owners and operators, and in rarer cases, recreationists.

In addition to public-facing education and outreach, the report also includes peer-reviewed studies relevant to ongoing issues in dam safety, including the disciplines of civil and hydraulic engineering, environmental sciences, geology, and social sciences when available.

Below, we highlight the major contributors to public outreach. A fully detailed spreadsheet, with links to documents, videos, and articles, is available in the supplemental material for this report and posted on the New York Sea Grant websites.

I. **General Outreach.** This includes but is not limited to government or agency-produced outreach material. These materials exist generally as documents housed online or printed and distributed by federal and state agencies.

    i. **NYS Dam Safety**
The New York State Department of Environmental Conservation website hosts a significant amount of information for dam owners. The website hosts the Technical and Operational Guidance Series (TOGS) regulatory information, as well as manuals and guides on best practices related to dam ownership, with topics including design of dams, dam risks, and dam inspection and maintenance. Also included within the Dam Safety webpage are resources for municipalities and residents, including links to Association of State Dam Safety Officials (ASDSO) material such as "Living with Dams: Know Your Risks" and "Living with Dams: Extreme Rainfall Events," two important outreach documents for communicating dam safety to a variety of audiences.

    ii. **NYS DEC Dam Inventory**
Every dam in NYS is regulated by Environmental Conservation Law (ECL) 15-0507. The owner must operate and maintain their dam, and all appurtenant works, in a safe manner at all times. This is the case whether inventoried or not.

    This product is freely available to residents of New York through the NYSDEC website but requires a working internet connection to access. Navigation through the DECinfo Locator is simple, with the dam database being available as a clickable layer in the list of layers (Figure 1). Users are presented with the following information for each dam datapoint: Name, State ID, Last Condition Rating, Dam Height, Construction Type, and Hazard Description. The website serves as an adequate resource for residents to understand their physical relationship to known, managed dams in New York State.

    iii. **FEMA Guidance**
The Federal Emergency Management Agency (FEMA) is a significant source for dam safety information. FEMA administers the National Dam Safety Program, which as stated on the FEMA website "...is a partnership of states, federal agencies and other stakeholders to encourage and promote the establishment and maintenance of effective state and federal dam safety programs to reduce the risk to human life, property, and the environment from dam-related hazards."

iii. FEMA Guidance (continued)

FEMA develops guidelines for federal agency dam owners and regulators, provides grant opportunities to minimize dam safety risk, and leads advisory committees such as the Interagency Committee on Dam Safety (ICODS) and the National Dam Safety Review Board. Additionally, FEMA operates the Dam Safety Training Program and the National Inventory of Dams (NID).
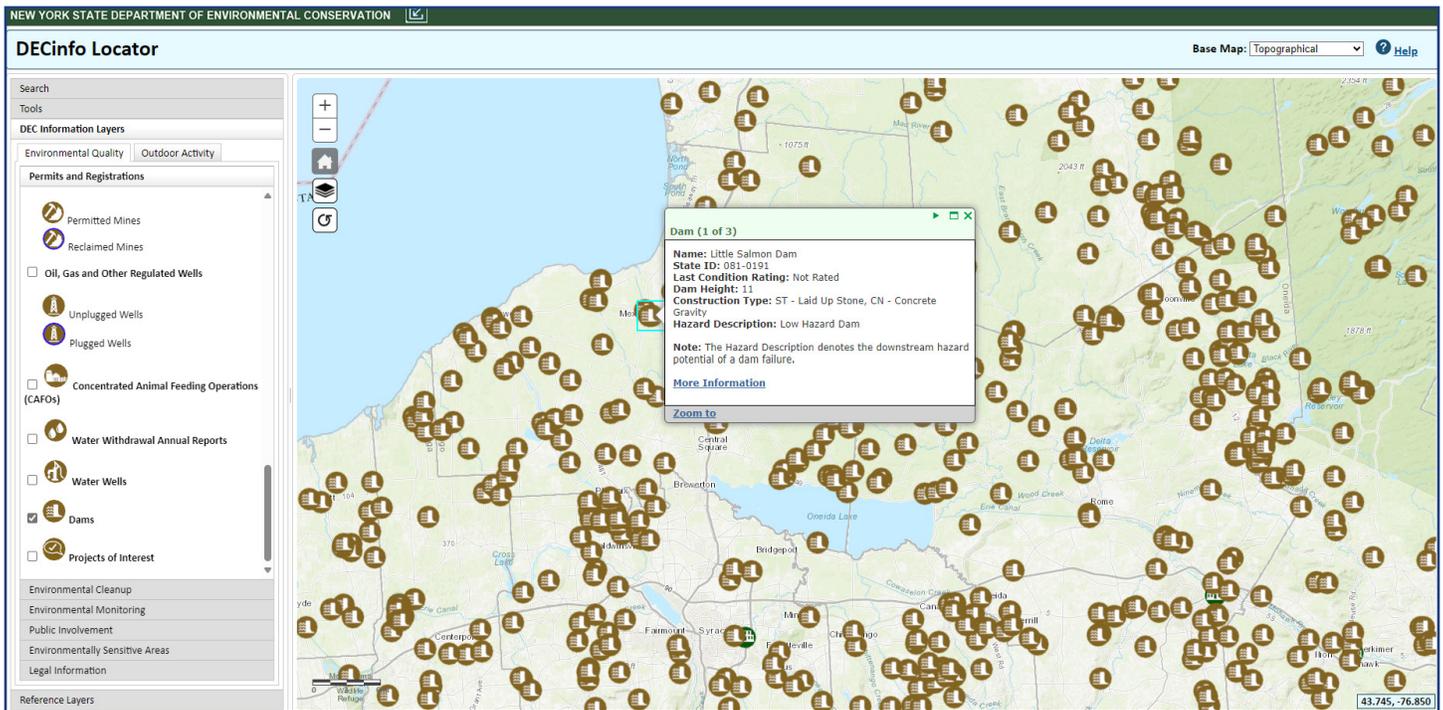
Figure 1. DECinfo Locator Map with the "Dams" layer enabled, set over Oswego County, NY, and highlighting the Little Salmon Dam in Mexico, NY.

Located within the FEMA website and provided by the National Dam Safety Program is a Publication Library with resources intended for states and the public. This project will highlight many of these publications within the expanded literature review (Supplemental Material), but we have chosen to highlight some here:

- Technical Manual: Overtopping Protection for Dams

- Rehabilitation of High Hazard Potential Dam Floodplain Management Plan Fact Sheet

- National Dam Safety Program Research Summit Report

- Model State Dam Safety Program Manual

- Human Consequences of Dam-Break Floods Fact Sheet

- Be Aware of Potential Dam Failures in Your Community Fact Sheet

In additional to these resources, FEMA also has a publication series regarding Technical Manuals, Guides and Reports, Technical Advisories, Safety Series Fact Sheets, Response & Recovery (R&R) Dam Response Operation Matrices, and Dam Safety & Risk MAP/Flood Mapping Studies Fact Sheets. Direct links to these publications can be found at the end of this document.

Figure 2. Low-head dam during high flow in Camillus, NY. *Photo by Roy Widrig, New York Sea Grant.*

II. **Media Outreach**

While not purely educational or designed as outreach material, the press is often the general public's only readily accessible source of information on dam-related safety messaging. Press material may be presented with bias and should be interpreted with that in mind.

    i. **Regional Media Coverage**

Media outlets in New York, ranging from local to state- or region-wide publications, have been at the forefront of reporting on dam hazards. Media outlets such as newspapers, websites, and magazines can provide significant information in short periods of time in the form of articles and social media posts, but often lack expertise from government officials and scientists in exchange for producing timely information for their readers.

Significant information has been provided by media outlets in the Hudson River Valley and Adirondack Mountains regarding low-head dams, yet other regions of the state have had significantly less material available to residents. This may be partially due to the steep terrain and potentially higher risks associated with dams in the Hudson and Adirondack regions, the amount of protected recreational lands in these regions, and the presence of non-governmental environmental organizations.

    ii. **Not-for-Profit Outreach**

Not-for-profits and non-governmental organizations have assumed partial responsibility for the creation and distribution of outreach of dam safety education. This includes academic institutions, academic extension and outreach organizations such as Cornell Cooperative Extension, and advocacy-driven organizations such as American Rivers, The Rewilding Institute, and Vermont Natural Resources Council. These organizations are integral in providing outreach material to a wide variety of communities.

iii. Media Coverage of Dam Removals, Failures and Incidents

This project utilized Google Alerts to track dam safety coverage across the United States in 2024. It was determined that the most robust source for information (by volume) regarding dam safety was traditional online media. The media proved to be a timely source for news regarding failures, incidents, removals, and planning for dam projects. Recent climate events such as those in Michigan in summer 2020, Adirondack Park in summer 2023, and both in Minnesota and on Long Island in August 2024, were heavily covered by both local and national media. This type of media — online and local short-form content such as past news articles, often with embedded social media videos — fits the playbook of the often fast-paced coverage of climatic or weather events. Slower processes, such as the planning, public outreach, engineering and design, and implementation of dam removal and restoration processes, was more fitting to slower media, including press releases, ESRI StoryMaps, compilations, and even books.

III. Scientific Literature

Peer-reviewed material is generally unavailable to the public but was collected here in terms of information available. It is the purpose and mission of some organizations, such as New York Sea Grant, to access this peer-reviewed research and develop this information into outreach and educational programs for the public. Development of this outreach material is considered an additional project to be explored after completion of Phase I of this project.

i. Dam Removal

Dam removal, especially within the Pacific Northwest, Great Lakes, and Hudson Valley regions, has been extensively studied across many disciplines. Studies have been completed in the fields of fisheries, biological connectivity, hydrology and hydrogeomorphic processes, and coastal processes, as well as extensively within the social sciences.

ii. Dam Safety – Recreation

Research regarding dam safety, especially with a focus on recreational usage, remains the largest gap in current studies. However, usage of research articles in regard to low-head dams can be used to aid in informing outreach material produced by government and agencies tasked with communicating risks to those recreating around low-head dams – especially on the topics of hydraulics, influences of changing climate on reservoir/dam dynamics, and social impacts of dam restoration and removal.

iii. Dam Safety – Hazard Mitigation

There exists plentiful research regarding hazardous currents associated with dams within scientific literature. Unfortunately, these studies are inaccessible to the public due to significant paywalls, and proved very difficult to access within the course of this study, even with significant academic library access. This adds to the issue of creating science-based outreach materials for dam safety, as some of the best research is often obscured from those who could turn it into useful outreach material.

It must be mentioned here that there is a designated academic journal focused on dam safety. This journal is available only to members of the Association of State Dam Safety Officials (ASDSO) and is published quarterly to 3,000 members.

Strengthening Dam Education and Outreach in New York

The goal of this project was to evaluate the existing educational and outreach material readily available to consumers in New York State. The evaluation was conducted to determine gaps that may exist within this suite of outreach material that could be filled by the project team or partner agencies, not-for-profits, or other organizations with similar goals of producing educational material for the residents of New York's Great Lakes Basin. The following communities and types of education, extension, and outreach materials were evaluated during the course of this project.

I. **Criteria for Evaluation**
    i. Material included within this report should be readily accessible, as in easy to find, through a known government resource webpage; through printed media, news, or videos posted online; or through television and radio. Times where paid accounts were needed to access the information have been noted. Additionally, heavily-biased articles or blatant propaganda were not included.

II. **End Users**
    i. As dam safety and hazard outreach is a topic of concern to many communities, the end users considered in this project are potentially unlimited. Outreach material audiences included floodplain residents, municipalities and elected officials, not-for-profits and education-based organizations, dam owners, and river-based recreational communities such as anglers and personal watercraft enthusiasts. No group of New York residents was purposefully excluded from this review.

III. **Types of Resources**
    i. **Resources for Dam Owners**
       Currently, the resources available to dam owners are adequate, with numerous resources on dam maintenance, engineering, removal, repair, and other management options that exist at multiple levels, especially from state and federal governments (New York State Dam Safety, FEMA, USACE), as well as through multiple not-for-profit or non-governmental organizations (Association of State Dam Safety Officials [ASDSO]).

       These resources fall short when it comes to the direct outreach of these materials. While training courses exist from groups like ASDSO, the courses are often behind a paywall and have no official requirement for attendance or renewal of certifications. While it is not necessarily the responsibility of these organizations to enforce commitment from dam owners to pursue these resources, this is an area in which dam outreach could be improved. Of course, this would require significant financial and staffing commitments from these organizations, as well as time and staffing commitments from the dam owners themselves.

    ii. **Resources for Municipalities**
       Direct outreach to municipalities is one area in which educational materials are lacking, though outreach to municipalities is complicated in both scope and application. Through this analysis, it was not determined a) who among municipal officials or under municipal employment would benefit from this information, b) in what ways this target audience would prefer to receive this information, and c) what information would be of most use to municipal officials and employees.

The existing resources for dam owners and dam safety officials could also be delivered to municipal officials. While it is impossible for a one-size-fits-all approach to this topic, there exist many best practices for design, maintenance, monitoring, and rehabilitation of dams, as well as for planning resources with a focus on adapting to weather changes. To deliver these resources to this audience would require additional implementation on the part of educators to make it happen. Workshops, planning and zoning board training, repackaged outreach material, and online tools and resources listed within a single repository would be integral in bringing this information to the municipalities in greatest need.

iii. Resources for Recreation

Of all end user communities evaluated, the largest gap in outreach material was determined to be recreational users. This community consists of anglers, personal watercraft enthusiasts, and anyone else recreating near dams. With the potential hazards associated with dams, including rapid changes in outflow, dangerous currents, and navigational obstructions, there remains a significant gap in available outreach material communicating these hazards to recreational audiences.

Through the analysis, it was identified that outreach material in the form of signage exists for dam owners or operators to place near dams with a potential for hazardous conditions. Regulations around standardization of these signs, however, were difficult to find and inconsistent between various levels of governing bodies.

Figure 3. A warning sign below a swimming area and dam in a New York State Park.
Photo by Roy Widrig, New York Sea Grant.

IV. Gaps in Outreach

While there is extensive material available to a range of audiences, gaps remain in outreach material regarding dam safety, both in type of material and in target audiences. The list that follows is not exhaustive but serves as a starting point to begin exploring the creation of outreach materials. The gaps are recognized below by potential audiences.

i. Recreation

While further research would be needed to determine how to address these gaps, we present several examples below that could be created and implemented to aid in communicating recreation hazards:

- Enhanced signage above and below dams with hydraulic jumps, also known as "drowning machines."

- Curriculum within boater safety courses focusing on the hazards of operating personal watercraft near dams.

- Pamphlets, rack cards, stickers, or other low-cost material for anglers detailing hazards associated with dams, including information on dangerous currents for wading fisherman.

ii. Downstream Communities

Communities downstream from high-hazard dams could benefit from targeted outreach from state and federal organizations, in partnership with not-for-profit non-advocacy agencies, to develop and present educational material. Potential outreach forms for this may include:

- Targeted outreach to residents downstream from dams when any planning and implementation is being considered – including removal and repair. Residents can be targeted based on potential changes to their FEMA flood map zones.

- Enhanced outreach to small communities and governments. Many communities located within New York State are rural, contain many mapped and unmapped ghost dams, and function with small government models. These small governments are important to reach through direct outreach, as local officials are often the decision makers regarding building projects within designated floodplain areas.

iii. Upstream Communities

Recent dam failures have received significant media attention focused on downstream communities. However, events such as the Midland and Sanford Dam failures have also focused on upstream residents affected by the loss of reservoirs. These communities could benefit from potential outreach foci, including:

- "Living on reservoirs" style documents or videos, discussing the varying water levels and potential hazards of dams in a changing climate.

- Recreational hazards of low-head dams, including information on hydraulic jumps and other dangerous currents.

iv. Local Governments

Government outreach materials, such as those developed by NYSDEC and FEMA, can be applied specifically to municipal decision-makers. Focusing this educational material in organized training would be an important step in making local governments more aware of and resilient to dam-related hazards. We speculate that topics of interest regarding dam safety within this community would be:

- Risks associated with dam failures and overtopping (upstream and downstream).

- Recreational risks associated with low-head dams.

- Controls on property value (loss of lake frontage and tax revenue after a dam failure, flood risks associated with failing dams, etc.)

- Water storage for emergencies (drought, fire, etc.)

v. Dam Owners

A comprehensive list of research, governmental, and outreach material will be hosted online as a result of this project. More information is located at the end of this document with links to the applicable sites that will be publicly available.

Low-Head and Ghost Dam Analysis

In addition to the literature review, compilation of case studies, and analysis of outreach material, this project also includes a low-head dam analysis within a small Great Lakes watershed. The analysis was included to evaluate the potential for ghost dams within the Great Lakes Basin, a previously unexplored topic within the Lake Ontario drainage basin. Previous efforts utilizing this analysis in New York State have focused on the Hudson River Valley, an area of steep terrain and narrow mountain streams. In contrast, the Great Lakes watershed in New York is significantly less steep, featuring regional uplands and plateaus, expansive plains shaped by repeated glaciations, extensive farmland, and large forested areas.

Definitions

i. Low-Head Dams

Low-head dams are structures spanning the width of a river designed to allow water to continually pass over their crests. Low-head dams are common throughout the United States, built with the intention to control water levels for multiple uses. These uses include water diversion, water storage, milling, creating drops for hydropower, and navigational purposes.

ii. Ghost Dams

Ghost dams are low-head dams, often abandoned and in poor condition, that are absent from state and federal dam inventories. These include earthen dams, concrete or rock spans across small streams, beaver dams, and weirs made of various materials.

Summary of Ghost Dam Analysis in the Black River Watershed

I. Introduction and Methods

This summary details our efforts to identify unmapped dams in the Mill Creek, Otter Creek, and Sugar River subbasins within the Black River Watershed in Northeastern New York (Figure 4), following the procedure outlined in Buchanan et al. (2022). First, we used high resolution geospatial datasets (LiDAR DEMS, multispectral imagery, National Wetlands Inventory, and the National Hydrography Dataset Plus) to engineer a set of variables representing physical stream characteristics useful for predicting the location of unmapped dams. Second, using the desktop validation procedure outlined in Buchanan et al. (2022), we created a training dataset of known dam locations in the 480 km^2 Otter Creek subbasin (Figure 5). Third, the Otter Creek training dataset was combined with training data from two smaller subbasins in the Hudson River Valley (drainage areas < 60 km^2) and used to train a binary random forest classification algorithm (Breiman 2001) to predict dam locations. Fourth, we quantified model performance across the Black River and Hudson Valley subbasins via Monte Carlo cross validation. Finally, we predicted unmapped dam locations in the Mill Creek and Sugar River subbasins (Figure 6).
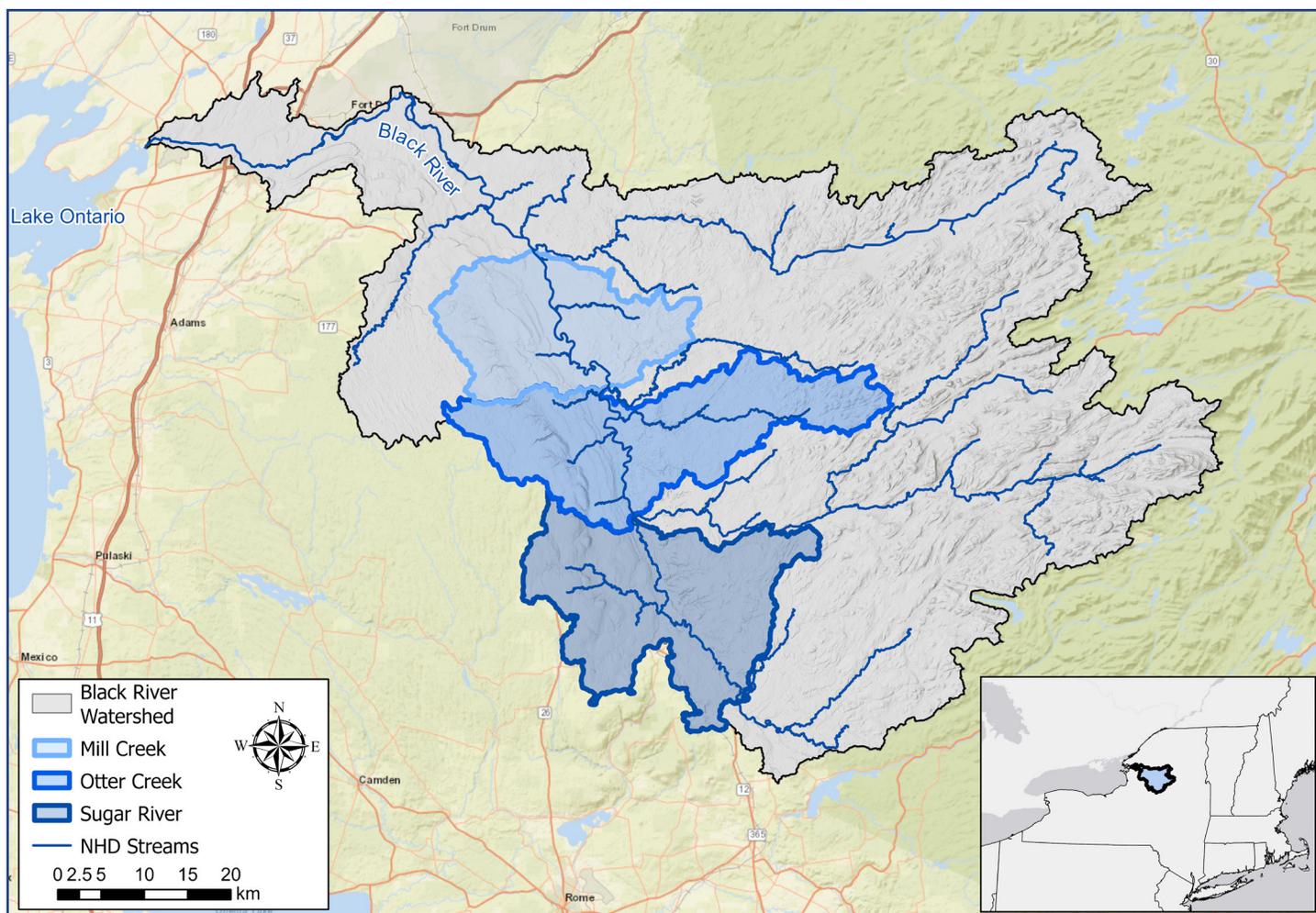

Figure 4. Location of the Mill Creek, Otter Creek, and Sugar River subbasins in the Black River Watershed.

II. Preliminary Results

i. Desktop Dam Identification

In the process of creating a training dataset of known dam locations within the Black River Watershed, we identified numerous beaver dams, as well as natural cascades and ponds that may confound the random forest algorithm (i.e., their physical attributes overlap with those of the unmapped dams; refer to Figure 5 and Table 1).
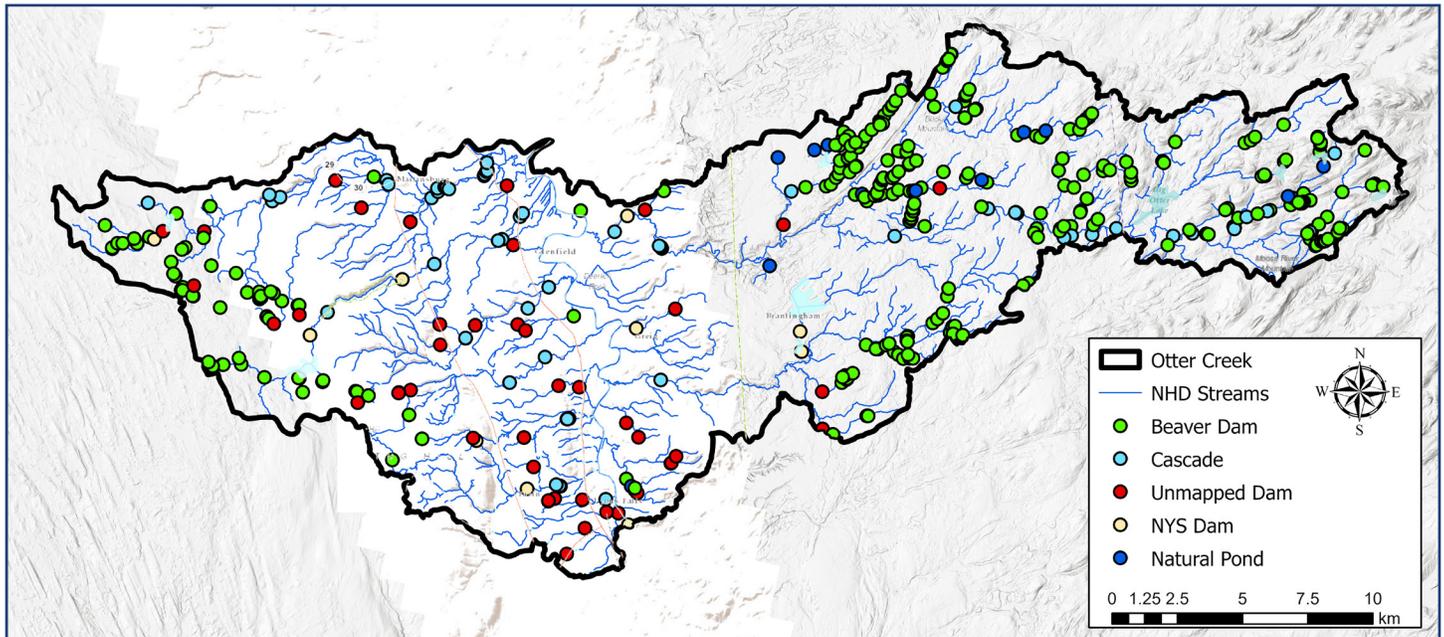
Figure 5. Training dataset of known barrier locations in the Otter Creek subbasin created via desktop analysis.

While outside the scope of this exercise, the ability to identify beaver dams and other natural barriers may be of significant interest from an aquatic connectivity and conservation biology perspective. Furthermore, identifying beaver dams may also be relevant for flood hazard assessments, as they commonly fail during storm events and lead to localized flood damage. In addition to the fact that the Hudson River training datasets were considerably smaller (e.g., 75,000 vs. 6,100 sampling points in Otter Creek and Foundry Brook, respectively), the Hudson River subbasins also possessed zero beaver dams and natural ponds. This is likely attributable to the substantially different geologic, topographic, and, especially, land use characteristics between the Hudson River valley and the Black River watersheds (Table 1).

Table 1. Summary of barrier classification results for the three training datasets in the Black River (BR) and Hudson River Estuary (HR) watersheds.

Basin	No Dam	NYS Dam	Unmapped Dam	Beaver Dam	Cascade	Natural Pond
BR - Otter Crk	78,284	10	35	229	63	12
HR - Foundry Brook	6,088	11	56	0	20	0
HR - Lattintown Crk	5,265	4	65	0	8	0

The approximate height of all identified barriers in the Otter Creek subbasin was estimated during the desktop analysis. A similar procedure to estimate barrier heights was not carried out in the Hudson River subbasins. As indicated by Table 2, the mean height of beaver dams was typically < 0.7m, whereas unmapped dams and inventoried dams (NYS dams) averaged ~1.7 and 5.3m, respectively. Using dam height as a simple flood hazard metric, it is evident that inventoried dams may pose the greatest risk. However, many of the unmapped dams are greater than 2m in height, lack inspections, and do not have spillways designed to accommodate anywhere near a 100-year flood. Given that the likelihood of a 100-year flood occurring during the lifespan of a dam designed to last for 50 years is ~40%, the risk of small dam failure is orders of magnitude greater than that of large dams (National Research Council 2012). Because small dams fail much more frequently than larger ones, they tend to be responsible for most of the annual cost of dam failures (Swan and Griffin 2020).

Table 2. Approximate barrier heights extracted from the desktop barrier identification procedure.

Classification	Approximate Height (m)	
	Mean	Max
Beaver Dam	0.67	1.68
Unmapped Dam	1.69	4.57
NYS Dam	5.30	15.85
Natural Pond	1.15	3.05
Cascade	3.97	32.62

ii. **Model Performance**

The random forest model demonstrated high predictive skill with a mean true positive rate >90% and false positive rate of only 1.2% across 10 Monte Carlo cross validation iterations (mean balanced accuracy = 95%) using a dam presence probability threshold of 5% (i.e. accept a site as a dam if the predicted probability of the "dam present" category is ≥ 5%; refer to Table 3 & 4). Low standard deviations of performance metrics across Monte Carlo iterations also suggests high model stability across unseen data (Table 4). When using lower dam presence probability thresholds, the classifier's predictive performance for identifying dam presence improved, albeit with an increased false positive rate. For example, at a probability of dam presence acceptance threshold of 2.5%, an average of 97% of validation dams were correctly predicted, although false positive rates increased to ~3% (data not shown).

Table 3. Summary of cross-validated performance metrics using a probability threshold of 5%.

CV Iteration	True Positive Rate	False Positive Rate	Balanced Accuracy	F-beta
1	87.8	1.1	93.3	0.40
2	89.6	1.0	94.3	0.47
3	95.9	1.4	97.3	0.39
4	87.8	1.3	93.2	0.34
5	86.3	1.2	92.5	0.38
6	90.0	1.1	94.5	0.40
7	92.2	1.3	95.4	0.38
8	91.8	1.0	95.4	0.44
9	93.9	1.5	96.2	0.39
10	91.5	1.1	95.2	0.40
Mean	**90.7**	**1.2**	**94.7**	**0.40**
St. Dev.	**2.8**	**0.2**	**1.4**	**0.033**

**Table 4.** Confusion matrices for all 10 Monte Carlo cross-validation iterations at a 5% probability threshold.

Performance Metric	CV Iteration									
	1	2	3	4	5	6	7	8	9	10
False Negative	6	5	2	6	7	5	4	4	3	4
False Positive	295	221	359	386	338	317	370	271	348	309
True Positive	43	43	47	43	44	45	47	45	46	43
True Negative	26,488	22,068	26,020	28,734	27,731	29,130	27,568	27,356	22,906	27,902

iii. Model Predictions Over Mill Creek and Sugar River

The model predicted a total of 140 unmapped dams in Mill Creek and another 251 unmapped dams in the Sugar River subbasin at the 5% probability threshold (Table 5 and Figure 6). Using such a low probability threshold ensures the model has a low false negative rate (misses the fewest number of true dams) but comes at the cost of a higher false positive rate. Assuming the density of unmapped dams in Otter Creek (i.e. 0.07 dams/km²) is somewhat similar in the two test subbasins, we can reasonably expect the true number of unmapped dams in the Mill Creek and Sugar River subbasins to be 25–40 in each basin, which is more than double the number of inventoried dams.

Table 5. Number of known dams in the New York State (NYS) dam inventory vs. the number of unmapped dams predicted by the machine learning model for the two test subbasins at a 5% probability threshold.

Catchment	NYS Dams	Predicted Unmapped Dams
Mill Creek	10	140
Sugar River	37	251
Total	**47**	**391**
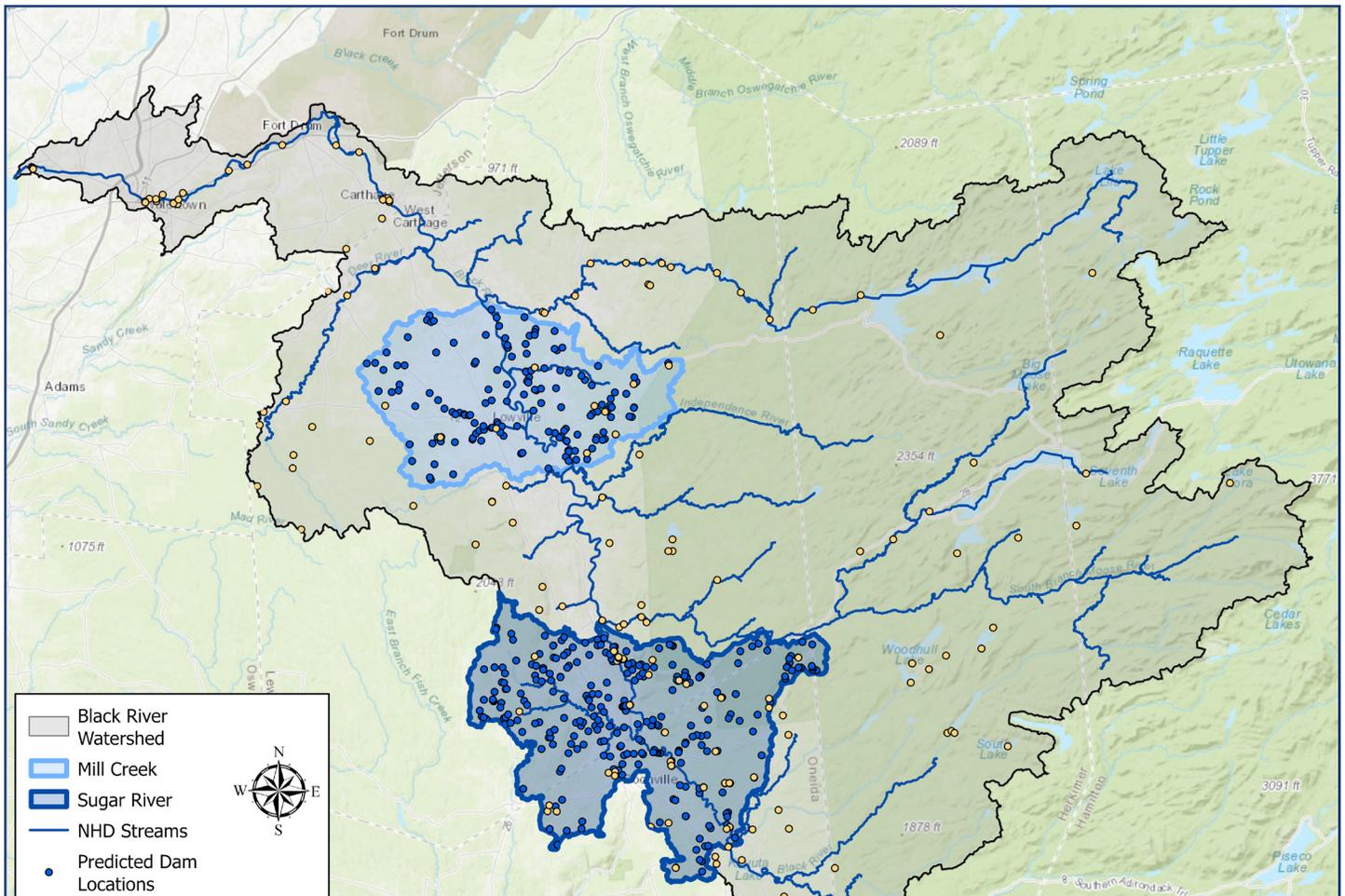
Figure 6. New York State inventory dams and predicted dam locations in the Mill Creek and Sugar River subbasins in the Black River Watershed.

III. Conclusions

Our machine learning algorithm achieved high accuracy in predicting dam locations (true positive rate > 90%, false positive 1.2%). Unmapped dams averaged ~ 1.7m in height and were prevalent throughout the Otter Creek subbasin, where the training dataset was created using desktop analyses. In fact, existing dam inventories in Otter Creek underestimated the true number of dams by ~80%. In the two additional test subbasins, model predictions suggest there may be as many as 391 unmapped dams in addition to the 47 known dams in the NYS inventory. As the model was run with a 5% probability threshold for dam presence, however, a certain number of these putative dam locations will likely prove erroneous (i.e., false positive). Thus, predicted dam locations should be validated via desktop analysis and/or field survey.

Moving forward, we recommend that i) the model be expanded in geographic scope, ii) model predictions be validated to verify model results and to build a larger training dataset, and iii) the model be refined to a multi-class classification that can uniquely identify unmapped dams, beaver dams, and natural cascades and ponds.

Field Survey of Ghost Dam Inventory

1. **Process**

    A field survey of the ghost dam inventory took place over one day on November 20th, 2023, within the Sugar Creek watershed. A dashboard inventory was completed of locations selected due to their proximity to local roads and public property, as no access to private property was guaranteed.

Figure 7. A Ghost Dam located near Lowville, NY, acting as a farm pond and access road. *Photo by Roy Widrig, New York Sea Grant*.

2. **Limitations**

    The Black River Watershed in New York flows through a wide range of physical landscapes, with the headwaters originating deep within the protected forests of the Tug Hill Plateau before descending into the Black River Valley. The uplands of Tug Hill are sparsely populated, with small parcels located along logging roads built throughout the country allowing for minimal observation of dams not visible from these small, forested roads. The ghost dam inventory for the uplands was dominated by beaver dams and small cascades or quick, rocky drops in stream elevation.

    The valley of the Black River and its tributaries, Mill Creek and Sugar River, are characterized by small towns and large dairy farms, and allow for greater viewsheds of geographic features such as rivers, streams, and dams. Within the valley, the frequency of man-made dams increased, with minimal beaver dams. Most of the dams within the valley belonged to farm ponds (Figure 7), with the exception of a few cascades and waterfalls.

Figure 8. Field photo of FID 44, misclassified as a Cascade. It appears this beaver dam sustained some degree of storm event failure, only to be rebuilt by beavers and read by the machine learning algorithm to be the stepped elevation points in-stream that would flag this site as a Cascade. *Photo by Roy Widrig, New York Sea Grant*.

3. **Results**

a. **Properly Classed Examples**
   Of the 22 selected sites, the majority of observable dams were classified correctly, with at least two sites being unobservable. Results from ground-truthing can be seen in Table 6 below.

b. **Misclassed Example**
   Twenty-two sites were selected and compared to modeled results of the following: GhostDam, BeaverDam, Cascade, and NYSDam (Figure 1). Of the 22 sites, only one was misclassified (FID 42), a beaver dam classified as a Cascade (Figure 8).

Table 6. Field observations of dam sites compared with algorithm-based classification.

FID	ID	Verified	Field	Notes	Class
9	11			Confirmed	Ghost Dam
10	12	Desktop	Photo	A bit far but very likely	Beaver Dam
42	44		Photo	MISCLASSED (Beaver Dam)	Cascade
51	49	Desktop	Observed		Cascade
52	50	Desktop	Photo		Ghost Dam
71	69	Desktop	Observed		Cascade
77	75	Desktop	Photo	Weir	NYS Dam
84	82	Desktop	Unobserved	Heavily wooded, private	Cascade
85	83	Desktop	Photo	Heavily posted, but observable	Cascade
89	87				Ghost Dam
93	91			Confirmed	Beaver Dam
97	95	Desktop	Observed	Confirmed, very shallow, piled rocks	Ghost Dam
110	109	Desktop	Photo		Cascade
111	108	Desktop	Photo		Cascade
112	110	Desktop	Photo		Cascade
119	117	Desktop	Observed		Ghost Dam
121	119	Desktop	Observed		Ghost Dam
127	125	Desktop	Observed but obscured by forest	Unknown	Ghost Dam
128	126	Desktop	Observed	Elevation check	NYS Dam

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Selected Terminology

Term: Beaver Dam
Definition: Beaver-built impoundment providing protection from predators and food storage, usually with a small pond upstream with significant resultant changes to the landscape

Term: Cascade
Definition: Small waterfall, often with several stages of elevation change

Term: Ghost Dam
Definition: Small dam, often only known by the owner, and not within published inventories and potentially exempt from regulations

Term: Hydraulic Jump
Definition: Rapid or sudden increase in the height of a liquid (such as water) occurring as high-velocity liquid flows into low-velocity liquid (example: water flowing over a low-head dam)

Term: Low-head Dam
Definition: A small structure built across the width of a river or stream channel, designed to allow continuous water flow over the crest across the channel

Term: NYS Dam
Definition: Dam listed within the New York State Dam Inventory and subject to regulation

Term: Weir
Definition: Small barriers built across streams or rivers, used primarily to control water levels

Supplemental Material

1. **Case Study Compilation:**
   This project is accompanied by a StoryMap created through ArcGIS online and viewable at https://arcg.is/9OPzi0. The "Dam Safety in the Northeast & Great Lakes" StoryMap was launched in September of 2024, and will be continuously updated through the life of this project with current events and resources available to end users. This interactive mapping tool allows the public to quickly and simply access content related to the following topics, linked with local case studies from across New York State and the Great Lakes Basin:

   a. Dam Failures
      i. Edenville (Edenville, Sanford and Midland, MI)
      ii. Echo Lake (Arden and Tuxedo, NY)
      iii. Long Lake Dam (Long Lake, NY)
      iv. Blydenburgh Dam (Long Island, NY)

   e. Dam Repairs, Studies, Alternatives Analyses
      i. Hawkinsville Dam (Booneville, NY)
      ii. Indian Lake Stone Dam (Indian Lake, NY)
      iii. Loon Lake Dam Repair (Chestertown, NY)
      iv. iv. Glen D. Palmer Dam Constructed Bypass (Yorkville, Michigan)

   c. Dam Removals
      i. Peninsular Paper Dam (Ypsilanti, MI)
      ii. Hamilton Dam (Flint, MI)
      iii. Smith Mills (Smith Mills, NY)
      iv. Kinneytown Dam Removal (Kinneytown, CT)
      v. Yarmouth Dam Removals (Yarmouth, ME)

   d. Ongoing Dam Incidents
      i. Nashville City Reservoir (Nashville, IL)
      ii. Glenwood Park Dam (New Albany, IN)
      iii. Rapidan Dam (Blue Earth County, MN)

2. **Outreach and Case Studies Matrix**
   Case studies, literature review, and the compilation of outreach and educational materials was collected for this project. The Outreach and Case Studies Matrix was completed in an Excel spreadsheet before being integrated into the ArcGIS StoryMap and within the New York Sea Grant Dam Safety website. Resources reviewed include:

   i. Government Resources

   ii. Non-government and Mass Media

   iii. Research Publications

   iv. Books

   v. Non-technical Resources

   vi. Dam Failure Reports

   vii. Modeling Resources

The outreach and case studies matrix will be hosted online through the New York Sea Grant Website (www.nyseagrant.org). Additionally, many of these resources will be located on the "Dam Safety in the Northeast & Great Lakes" ArcGIS StoryMap, located at https://arcg.is/9OPzi0.