

Evaluating Minnesota's **HISTORIC DAMS** A Framework for Management

Prepared by Principal Investigators:
Sigrid Arnott, Douglas A. Birk, and David Maki

with contributions by Geoffrey Jones

DECEMBER, 2013



This project was funded by the Arts and Cultural Heritage Fund of the Minnesota Clean Water, Land, and Legacy Amendment as part of the Statewide Survey of Historical and Archaeological Sites

**ARCHAEO-
PHYSICS**

SHALLOW
SUBSURFACE
GEOPHYSICAL
SURVEY

Report of Investigation Number 198
Archaeo-Physics, LLC
4150 Dight Avenue South #110
Minneapolis, MN 55406
(612) 379-0094 info@archaeophysics.com

This volume is dedicated to the memory of Minnesota archaeologist

Douglas C. George

(1948-2013)

MANAGEMENT SUMMARY

In 2013 the Minnesota Historical Society (as authorized by the Oversight Board of the Statewide Survey of Historical and Archaeological Sites) contracted Archaeo-Physics LLC to investigate historic dams within the area of Minnesota. The goals of the “Documenting Minnesota’s Historic Dams” project are to *create an inventory* of known historic dams, to *develop a contextual framework* for evaluating and interpreting the historical significance of these properties, and to *suggest strategies* for their documentation. The findings of this study are intended to facilitate cultural resource management activities and to promote heritage tourism and education in Minnesota.

The major tasks completed were: review of existing databases held by various state and federal agencies and individuals, literature review and aerial LiDAR (Light Detection and Ranging) searches, field survey and documentation, context development, and ground-based laser scanning of selected dams and dam sites. The project deliverables include:

(1) An inventory of historic dams and dam sites in database form of known historic dam properties within the State of Minnesota. The geo-referenced database includes earlier recorded historic dams, and many previously unrecorded dams or dam sites that were identified, or verified by the Archaeo-Physics team through the innovative use of aerial LiDAR imagery.

(2) Ten Site Forms that document a sample of field-surveyed historic dam property types.

(3) This narrative report that: (A) discusses the terminology and history of Minnesota’s historic dams, (B) *defines* historic dam property types within selected historic contexts, and (C) provides strategies for the future survey, interpretation, and evaluation of Minnesota’s historic dam properties.

A primary purpose of this survey is to understand the siting, condition, and general characteristics of historic dams, including those already evaluated. Overall, the team field checked a total of 31 sites in 12 Minnesota counties: 12 historic milldam sites in Rice, Goodhue, Mower, Fillmore, and Hennepin Counties, nine Works Progress Administration (WPA) dams in Cass, Crow Wing, Morrison, Stearns, and Wright Counties, nine logging dams in Pine and Cass Counties, and one irrigation dam in St. Louis County.

All of the logging and WPA dams were previously unrecorded as historic properties. The WPA dams were inventoried in the National Inventory of Dams (NID) but had not been recorded as historic dams (the bridge component of two had been identified). Most mill dam sites were either recorded as mills or dams in the Minnesota State Historic Preservation Office (SHPO) database but most had not been resurveyed for over 20 years. A total of eight dams not in the Office of the State Archaeologist (OSA) or SHPO files were documented, and updated site forms were made for two milling dams.

The historic dams database contains a total of 1691 records. This is a relational database summarizing records from six different source tables. Original information for each record can be found in the source tables, which are included in the database. The database source tables are summarized as follows:

- 1) The National Inventory of Dams (NID) table contains a total of 949 records.
- 2) A query of the SHPO archaeology database for the keyword “dams” returned 110 records.
- 3) A query of the SHPO structures database for the keyword “dams” returned 126 records.
- 4) A query of the SHPO archaeology database for the keyword “mill” returned 14 records.
- 5) A query of the SHPO structures database for the keyword “mill”, edited to remove non-water-powered sites returned 91 records.
- 6) A logging dam table created during this project. This table contains 399 records, and was compiled using a combination of historic documentation and analysis of aerial LiDAR data. The logging dam table focused on logging dams and contains 354 records with logging listed as the function. The table also includes 17 milling dams (both grist and sawmills) and a limited number of hydroelectric, WPA, Army Corps, miscellaneous, unknown function dams. A significant number of dams in the logging table were obtained from a list of dams provided by Superior National Forest staff.

At present, 515 of the NID dams are greater than or equal to 50 years old (that is, the date of completion is less than or equal to 1963). Forty NID dams are classified as hydroelectric and 268 are classified as WPA dams. 105 properties that likely had mill dams are recorded in the database. These represent returns from a query of both the SHPO archaeology and structures databases for mills. Mills that ran on other than water power were eliminated from our database by cross checking against information provided by Bob Frame (Frame 2013).

A total of 400 logging dams are recorded in the database. This includes 44 records from the SHPO archaeology table, two records from the SHPO structures table, and 354 records from the logging dam table. 219 of the logging dams in the logging table were identified in LiDAR data and their UTM coordinates were digitized and recorded. Of these, a total of fourteen dams were visited and field verified. The field verification success rate was one hundred percent. In other words, all dams identified as possible logging dams in aerial LiDAR imagery were subsequently confirmed as logging dams during field visits. A limited number of watersheds were searched in great detail for logging dams using LiDAR imagery. These included the Kettle, Snake, and Upper St. Croix River watersheds of the St. Croix drainage basin, and the Pine River watershed of the Upper Mississippi drainage basin. It is expected that similarly detailed searches of additional Minnesota watersheds would identify additional logging dams.

The database may be searched using a number of different methods. Three custom queries allow users to search for dams within specific geographic areas of interest. These include searches by: county; by township, range and section; and by UTM coordinates defining a rectangular search area. The database may be searched using an unlimited number of custom queries.

TABLE OF CONTENTS

MANAGEMENT SUMMARY	2
TABLE OF CONTENTS	iii
List of Figures	iv
INTRODUCTION.....	1
Terminology.....	1
Human-made Dams: Some Considerations and Issues.....	4
HISTORICAL BACKGROUND OF DAM BUILDING IN MINNESOTA.....	7
HISTORICAL CONTEXTS	17
Introduction.....	17
Logging Dam Systems in Minnesota: 1840-1920.....	19
Historic Milling Dams in Minnesota: 1823-1910	27
Federal Relief Dams in Minnesota: 1933-1941	37
Illustrated Historic Dam Construction Techniques.....	51
Brush Dams with logs and gravel	52
Loose Rock Dams	53
Timber and Timber Crib Dams and support structures.....	54
Timber Crib Dam Elements	56
Earthen Dams.....	58
Example of Earthen Log-Driving Dam.....	59
Earthen Milling Dam	62
Plank Dams	64
Masonry Dams	65
Plank Additions and Flashboards.....	69
WPA Minnesota Type “C” dams	71
Identification, Survey, and Documentation Strategies.....	76
Light Detection and Ranging (LiDAR) Methods	76
Ground Penetrating Radar Investigation.....	93
Three dimensional Laser Scanning	96
PROPERTY TYPES AND EVALUATION GUIDELINES.....	105
Resource Categories and Property Types	105
Guidelines for Evaluation for Eligibility to the NRHP.....	107
Integrity Considerations for Dams.....	108

Overview of Criteria for Dam Property Evaluation.....	109
Registration Requirements: Logging Dams 1850-1930.....	110
Registration Requirements: Mill Dam Properties.....	113
Registration Requirements: Federal Relief/WPA Dams.....	115
Recommendations.....	118
Sources.....	121

List of Figures

Figure 1: A map of Minnesota’s watersheds	2
Figure 2: A map showing Minnesota’s major pre-settlement plant communities or biomes	11
Figure 3: Part of the Original Land Survey plat for T135N-R34W, Wadena County, Minnesota	13
Figure 4: A 1991 aerial photo of a dam on the Lower Tamarack River	25
Figure 5: Overshot Wheel illustrated in Evans 1848	30
Figure 6: Illustration of a wooden penstock and wheel or discharge pit for a Leffel Turbine.....	31
Figure 7: Standard Minnesota Type “C” Dam.....	43
Figure 8: Plan for a typical Type DB, or Dam/Bridge.....	44
Figure 9: Construction of a Type “C” dam at Island Lake in Crow Wing County, ca. 1940	45
Figure 10: CCC/WPA dam bridge built at Elk Lake in Itasca State Park.....	46
Figure 11: Cast concrete and masonry sign at Mayo Lake from 1936	47
Figure 12: Modified Mayo Lake Type “C” dam.....	49
Figure 13: Brush and stone dam with fish traps in Mendota 1895 and under repair 13 years later....	52
Figure 14: Modern loose rock dam built to raise lake levels near Cross Lake, Minnesota	53
Figure 15: Basic Timber Rafter construction method from Brown (1936)	55
Figure 16: Redwood Falls Rafter style Timber dam from circa 1869	55
Figure 17: Side plan of a rock filled crib dam, with upstream plank covering.....	56
Figure 18: 1912 River Driving Dam at Clam Falls on the Clam River, Minnesota	57
Figure 19: Earthen Logging Dam on Sand Creek, a small tributary to the Snake River	58
Figure 20: Cribwork timber with peg holes affixed on the Lower Tamarack River.....	60
Figure 21: Tamarack Logging Dam (21PN 096) ruins facing south	60
Figure 22: Farthest downstream remains of a the log apron at the Tamarack Logging Dam.....	61
Figure 23: Lake Louise Dam at the former site of the LeRoy Mills facing west.	62
Figure 24: Lake Louise Dam at the former site of the LeRoy Mills facing north	63
Figure 25: Milldam with timber crib abutments and a plank dam ca 1920	64
Figure 26: Section view of masonry dam built for the Housatonic Dam.....	65
Figure 27: Ruins of the Ard Godfrey Milldam on Minnehaha Creek (21HE386).....	66
Figure 28: Dam ruins at Zumbrota showing two stages of masonry construction (June 2013).....	68
Figure 29: Godfrey Mill Dam from 1890s, with the plank addition built by Franklin Steele.	69
Figure 30: Schech’s Mill Dam on Beaver Creek showing flashboards on top of concrete dam.	70
Figure 31: 1937 Blueprint for Typical Lake Control Dam Type “C” 6’-0” Head.....	71
Figure 32: WPA “Type C” Ossawinnamakee Dam	72
Figure 33: 1937 Blueprint for Typical Lake Control Dam Type “C” 6’-0” Head.....	72
Figure 34: This view of the Skunk Creek Dam in Pierz Minnesota shows the ten-foot bays	73
Figure 35: Dam embankment and foot bridge approaches at the Skunk River Dam in Pierz	73
Figure 36: All WPA dams originally had a dated WPA plaque.	74

Figure 37: Emily Dam/Bridge in Crow Wing County, Minnesota.....	75
Figure 39: Hillshade image of a logging dam with borrow pits	80
Figure 40: A double borrow pit logging dam on Sand Creek in Pine County.....	81
Figure 41: A single borrow pit logging dam located on Chelsey Brook in Aitkin County.....	82
Figure 42: Example of a single borrow pit logging dam on the Ann River in Kanebec County.....	82
Figure 43: Example of a double borrow pit logging dam on the Ann River in Kanabec County.....	83
Figure 44: This example depicts Bean Logging dam on the Snake River in Kanabec County.....	84
Figure 45: Hillshade map image of a logging dam, borrow pits, and associated dike.....	85
Figure 46: Elevations profiles associated with dam and dike presented in Figure 45 above.....	86
Figure 47: LiDAR map of Schech’s Mill, located on Beaver Creek in Houston County.....	87
Figure 48: Hillshade LiDAR image of Godfrey Mill on Minnehaha Creek, Hennepin County.....	88
Figure 49: 3-D surface map depicting the environmental context of the Godfrey Mill dam ruins.....	89
Figure 50: Constrained shading color LiDAR image of Ramsey Mill ruins, Washington County.....	90
Figure 51: LiDAR color image map 1868 Lanesboro dam on the Root River, Fillmore County.....	91
Figure 52: Color LiDAR image of hydroelectric dam on the Red Lake River, Pennington County.....	92
Figure 53: Location of the GPR subsurface profile at Lizzie Creek Dam 2 in Cass County.....	94
Figure 54: GPR survey in progress.....	94
Figure 55: Results of the Lizzie Creek Dam 2 GPR investigation	95
Figure 56: Laser scanning at the Tamarack Creek dam site in Pine County.....	99
Figure 57: Intensity 3D view of the Pierz Dam, plan view.....	99
Figure 58: Intensity 3D view of the Pierz Dam, looking north.....	100
Figure 59: Intensity 3D view of the Pierz Dam, looking northwest.....	100
Figure 60: Color quick view of the Godfrey Dam, looking southeast.....	101
Figure 61: Color 3D view of the Godfrey Dam, looking southeast.....	101
Figure 62: Color quick view of the Tamarack Creek Dam, looking east.....	102
Figure 63: Intensity quick view of the Tamarack Creek Dam sluiceway, looking east.....	102
Figure 64: Intensity 3d cutaway view of the Lizzie Creek dam looking southeast.....	103
Figure 65: Aerial LiDAR hillshade map of the Glensheen Mansion dam on Tischer Creek.....	104
Figure 66: 3D intensity view of the Glensheen Dam, looking southwest.....	104

ACKNOWLEDGMENTS

Many people gave their time and expertise to make this project successful. Most importantly, we thank Scott Anfinson (Minnesota State Archaeologist) and Patricia Emerson (Head, Minnesota Historical Society Archaeology Department) who conceived, directed, and encouraged the “Documenting Minnesota’s Historic Dams” project.

We are pleased to acknowledge the many agencies and organizations that cooperated in this undertaking, including the Chippewa and Superior National Forests, the St. Paul District of the United States Army Corps of Engineers, Voyageur's National Park, the Minnesota Department of Natural Resources (MnDNR), the Minnesota State Historic Preservation Office (MnSHPO), the Northeast Minnesota Historical Center, the Minnesota Historical Society (MHS) Forest History Center, and the Cass, Koochiching, and Morrison County Historical Societies.

For their shared materials, comments, and assistance we give special thanks to:

Jason Boyle (Department of Natural Resources)
Mary Budak (Chief of Resources, Voyageurs National Park)
Christy A. Hohman-Caine (Soils Consulting)
Tom Cinadr (Minnesota SHPO office)
Skip Drake (MHS Forest History Center, retired)
Brett Ewald (Heritage Resources Program, Superior National Forest)
Robert M. Frame III (St. Paul, Minnesota)
Lori Gamache (Cass County Historical Society)
Rene Geving (Cass County Historical Society)
Grant E. Goltz (Soils Consulting)
Kelly Gragg-Johnson (Minnesota SHPO office)
Dan Hartman (Director, Glensheen Mansion Historic Estate)
Becky Jennings (Site Supervisor, MHS Forest History Center)
Lee Johnson (Heritage Resources Program, Superior National Forest)
Edward Krugmire (Schech’s Mill)
Timothy N. Loesch (IT Business Services Manager, Minnesota Department of Natural Resources)
David Mather (Minnesota SHPO office)
Patricia Maus (Curator, Northeast Minnesota Historical Center)
Edgar Oerichbauer (Director, Koochiching Museums)
Elizabeth C. Reetz (Heritage Resources Program, Superior National Forest)
Susan Roth (Minnesota SHPO office, retired)
Collin Swift (Baxter, Minnesota)
Jan Warner (Director, Morrison County Historical Society)
Christopher Welter (Archivist, Minnesota Discovery Center)
Bruce M. White (Turnstone Historical Research)
Mark Zaczkowski (Pine River, Minnesota)
Bill Yourd (Heritage Resources Program Manager, Chippewa National Forest)

Sigrid Arnott
Douglas A. Birk
David Maki
28 December 2013

INTRODUCTION

For at least 200 years people with various motives, interests, and capabilities have sought to capture and control Minnesota's surface waters by building dams. Early on, such barriers were most used to power mills and transport logs. The most prolific era of dam building occurred over a roughly 90-year period between 1849 (when Minnesota became a territory) and 1940, the end of Civilian Conservation Corps/Works Progress Administration (CCC/WPA) construction projects.

Dams are functional, variably engineered, and often visually pleasing features of built landscapes. "Down by the old mill stream" is more than a song. Rivers, dams, and reservoirs are also celebrated places that have influenced every aspect of the American experience from settlement and industry to poetic reflection. While many Minnesotans like dams for what they are and what they do, others question the viability and safety of dams and express concern about ecological impacts.

The treatment of historical dams and dam sites will increasingly be an issue as more Minnesota streams are returned to more natural hydrological configurations. This study is a first step in the process of creating a framework for evaluating some of the common types of historic dams found in Minnesota.

Terminology

Historically, water has been considered a plentiful resource in Minnesota. The state has a vast network of streams and wetlands, and thousands of natural freshwater lakes. These surface waters are replenished by precipitation or, during drought conditions, by springs and seeping groundwater. The flow of Minnesota's rivers, whether continuous or intermittent, is fueled by available runoff. The pulse of all river systems is ever changing. During winters, lakes and wetlands typically ice over, slowing or stalling flowage. Accumulated snows on frozen landscapes create great reservoirs of stored water and energy primed for release with the spring melt (e.g., Waters 1977:17; Carlson 2007:9).

Minnesota's many distinct surface water drainage systems or *watersheds* are separated by elevated ridges or "heights-of-land." In the early 1970s the United States Geological Survey and other federal agencies developed a national watershed mapping and classification system. This hierarchical or nested system defines watersheds by size, so as to divide and subdivide the United States into successively smaller hydrologic units. In this comprehensive scheme Minnesota is overlapped by four *regional watersheds*: Great Lakes, Missouri, Souris-Red-Rainy, and Upper Mississippi (<http://www.dnr.state.mn.us/watersheds/index.html>).

In 1979 the Minnesota Department of Natural Resources (MnDNR) adopted this national system to standardize the identification, delineation, and mapping of watersheds within Minnesota. The MnDNR project defines eight *major drainage basins* within the state that are further partitioned by 81 *major surface water watersheds* (Fig. 1). For instance, the Great Lakes Basin area of Minnesota is subdivided into five major watersheds: (1) Lake Superior North, (2) Lake Superior South, (3) St. Louis River, (4) Cloquet River, and (5) Nemadji River. The state has also defined about 5600 minor watersheds. These include all Minnesota lakes with a surface area of at least 100 acres.

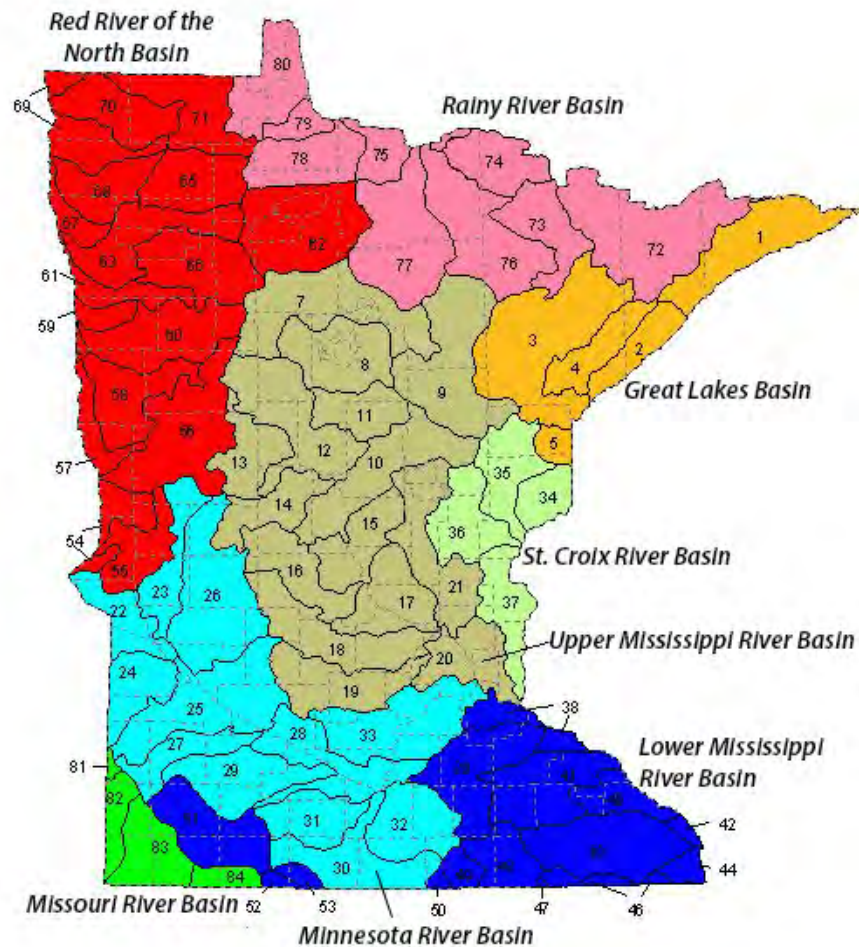


Figure 1: A map of Minnesota's watersheds, showing the eight major basins and 81 major surface water watersheds (Adapted from: <http://www.dnr.state.mn.us/watersheds/map.html>). Minnesota surface waters drain north to Hudson Bay, east to the Atlantic Ocean, and south (via the Missouri and Mississippi Rivers) to the Gulf of Mexico.

MnDNR's watershed mapping project enables ongoing evaluation of water resources in geographical contexts. By monitoring water resources within watersheds, the state can better understand how human or natural modifications, like dams, can impact the quantity and quality of our waters within and between watersheds.

For this study, a *dam site* is defined as a place with sufficient water catchment and storage capacity, flow potential, and integrity for construction of a dam. A workable site for a logging dam, a logging historian once said, is any place where a river or creek "ran through a valley between two hills with a large flat area upstream that would hold considerable water" (Ryan 1976:55). In reality, dam sites can have a wide range of differing characteristics—like a natural bottom of sand, quicksand, soft mud, clay, gravel, or rock—or purposes that might dictate the type of dam best suited to the location (e.g., Leffel 1881). Other concerns in selecting dam sites might be the availability of local building materials and of the presence of adjacent terrain suited for other improvements (like camps, mills, or dam-tender structures). Many recognized dam sites in Minnesota are now occupied by working dams. Many others were used and abandoned or were proposed but never used at all. Numerous dam sites contain two or more generations of dams (or modified dam structures) built at the same location.

Dams are defined as human-made barriers built across a river or other drainageway to obstruct or redirect the flow of water.¹ Minnesota dams have been built in myriad shapes and sizes. All were made for specific purposes using designs, materials, and methods particular to a time and place. Most have features or mechanisms like bays, gates, spillways, or aprons that allow and direct the controlled release of water. Some have associated locks, canals, auxiliary dikes, log sluices, and fish ladders. *Historic dams* are defined in the Resource Categories and Property Types section on pages 105 to 107 of this report.

Dams have been built for purposes like transportation and navigation, power generation, stream diversion, irrigation, wildlife and habitat management, and recreation; to provide municipal, agricultural, and industrial water supplies; and for flood, flow, or erosion control. Where required, dams of sufficient size might also be used as bridges to accommodate vehicular, train, and pedestrian traffic.

Dam height is expressed in terms of head. The *head* of a dam is the difference in elevation between the surface of its reservoir and the surface of the river downstream (i.e., the *tailwater*). The greater the head the greater the water pressure behind the dam, and the more energy released by the water's discharge or fall. Increased energy from head reduces the volume of water needed to produce power. It can also allow the use of smaller, cheaper, and more efficient equipment to operate the system. The discharge capacity of a dam is usually measured in cubic feet per second, or in mill-powers; one mill-power being equal to say, 75 horsepower (Hunter 1979:210-211).

Dams built to store water are usually high head dams. In Minnesota, a *high head dam* is typically one with a height of over 10 feet. The reservoirs of such dams can help compensate for variations in the natural flow of water. They also help offset temporal shifts in the demand for water or waterpower.

Low head dams, usually from one to 10 feet high, are frequently sited at a notable elevation change in a river. Such dams are built to detain water or to divert the flowage from the river's natural course into a canal, flume, raceway, sluice, tunnel, or even to another natural waterway. Some low head dams, like logging dams, have gates or other water-control mechanisms. Others are designed so that, with sufficient runoff, water flows constantly over their crest. Many of Minnesota's low head dams were built to control lake levels and to provide water for grain mills or early hydroelectric generators (Elverum and Smalley 2012).

Dams placed at the outlets of lake basins raise lake levels and convert natural impoundments into larger and deeper *reservoir lakes*. In some cases the elevated waters might flood connecting channels between lake basins to form sprawling *chain-of-lakes reservoirs*. Noted Minnesota logging historian, J.C. "Buzz" Ryan, has suggested that logging dams built at lake outlets were often of better and more robust construction than those built along rivers and creeks (Ryan 1976:55). Dams that raised water levels on rivers might also inundate shoals, reefs, rapids, and other obstacles that previously necessitated portaging. In some cases, portage trails themselves might be submerged or drastically reduced in length.

Dams built in narrow river valleys with limited storage capacity typically have *run-of-river reservoirs*. The volume of water held in such reservoirs is usually designed to meet the basic

¹ Although not common, some Minnesota dams have been designed and used to capture or contain industrial waste, such as taconite tailings (e.g., .GISL 2012:61-62, Fig.23) or animal waste such as pig or cattle manure.

requirements for generating power or for creating desired pondage above the dam. “Run-of-river” means the quantity of water allowed to flow from the dam’s reservoir is about equal to the amount that flows in (minus any seepage, evaporation, or other extractive use). In other words, during normal operation, such reservoirs do not materially alter the volume of river flowage.

Many of Minnesota’s early dams were isolated structures built for independent operation (like a stock pond dam or one that is part of a privately owned flour mill catering to local farmers). Some dams, like those at St. Anthony Falls in Minneapolis or Little Falls in Morrison County, provided water and waterpower to clustered groups of industrial mills and manufactories.

Many dams were built in series to create broad-based *water-management systems*. For instance, many rivers in east central and northern Minnesota once had dams built at intervals along their course to facilitate the transport of buoyant pine logs from harvesting cells to mills and consumer markets downstream. One of the largest and most noted water-management systems within Minnesota is the network of Mississippi Headwater Reservoir Dams built by the Corps of Engineers at Leech, Winnibigoshish, Gull, Cross, and Gull lakes and Pokegama Falls between 1881 and 1912 for the purpose of promoting navigation and industry (e.g., Merritt 1979; Carroll 1990; USACE 2012).

Human-made Dams: Some Considerations and Issues

Dams are controversial. Once constructed, they become parts of both natural as well as engineered systems. The human manipulation of water and waterways has had many beneficial economic and recreational effects, but is also a source of ecological and safety concerns. By interrupting natural levels and flow of water, dams can impact critical habitats, fish and bird migrations, water temperature and oxygen content, the flow of nutrients, and aquatic plant growth.² Flooded areas can produce greenhouse gases by increasing the rate of vegetal decomposition and emissions of methane and carbon dioxide. Dams and reservoirs might also promote streambed and shoreline erosion, changes in stream carrying capacity, and sedimentation rates. Dam operations can create rapid water level fluctuations above or below a dam, also leading to fish kills, decreased wild rice production, and poor waterfowl nesting success. While they can obviously improve river navigation, dams without locks block boat traffic. Many low head dams create dangerous “drowning machines.”

Dams are artificial constructs subject to aging, deterioration, and failure. They require regular monitoring and maintenance to assure their integrity. Dams might fail because of their siting within areas of geological instability, or through deficiencies in design, materials, construction, or maintenance.³ Dams can be overwhelmed by runoff that surpasses their physical capacity, and that overtop, flank, or undermine their core structures. Excessive water pressure can cause a dam to

² Of course dams might also slow or stop the upstream migration of undesirable species such as Asian silver carp, which can by themselves adversely impact aquatic environments while depriving native fish, larvae and mussels of plankton and detritus.

³ For instance, in the 1870s an entrepreneur attempted to develop a cranberry marsh on a 40 acre wetland he owned south of Mora, Minnesota. He constructed dams and a drainage ditch to reroute the overflow. When he found that water seeped beneath his dams and the water level refused to rise he abandoned the enterprise (Ziegler 1977:113).

blowout, or even slide downstream.⁴ Wooden dams or the exposed wooden elements of dams might be damaged or destroyed by fire, flowing ice, or rot.⁵ Earthen dams are often given to seepage, internal failure, and erosion. Whatever the cause, catastrophic dam failures might lead to flash flooding, human injury or loss of human life, property and environmental damage, pollution, disruption of emergency services, and loss of transportation routes and utility lines.

Dams, dam sites, and reservoirs can become obsolete. Reservoirs can fill with sediments limiting their storage or energy-producing capacity. Water-powered mills lacking sufficient water supply or to sustain or increase output go out of business. In Minnesota, hundreds of logging dams were abandoned after the available pine was depleted. Some derelict dams were later removed to restore “natural” flowage. On occasion, the reservoirs of more recent dams have immersed older dams upstream, or they have so elevated the tailwater at the upstream dams that it rendered them useless as sources of waterpower.⁶

Dams have been long been targets of opposition. In the past, some groups in Minnesota have tried to stop the construction or operation of dams, have opened dams without authorization, or have tried to remove dams—through lawsuits, force, and even the use of dynamite.⁷ Among early adversarial concerns was flood damage to hay fields, wild rice crops, or riparian lands, the illegal taking of timber and other materials for dam construction and operations, the transport of stolen timber, and what was deemed to be unfair compensation for such losses.

For instance, in 1901, Ojibwe at White Earth forced the closure of a dam when it was learned that loggers had illegally cut timber on reservation lands and were driving it down the Otter Tail River (Vanderluis 1974:299; Birk 1997d:7). There are also instances in Minnesota where law enforcement agents forced the opening of controversial dams.⁸

⁴ One logger likened a poorly built dam to a car with bad tires, as “you never know when you’ll have a blowout” (Nelligan 1929:136). The washout or “blowing” of dams was not uncommon, and the effects might be disastrous. When a logging dam blew out on Bradbury Brook (a branch of Rum River) in June 1895, the direct property loss was placed at \$2,000. However, the premature release of water also left 35,000,000 feet of pine logs lying along the river, temporarily closing a few saw mills and putting dozens of men out of work (Anonymous 1895).

⁵ In September 1894, during a period of extreme drought, massive wild fires (including the “Hinckley Fire”) swept through cutover areas of central Minnesota claiming hundreds of lives. Losses in the Rum River Valley also included timber, hay, livestock, homes, logging camps, and two logging dams. The upper dam on the main stem of the river at Milaca was burned, and the dam at Tibbetts Brook was “completely burned out” (Anonymous 1894).

⁶ For example, the reservoir of Lock and Dam 1 (Ford Dam) on the Mississippi River floods the razed remains of an earlier lock and dam at Meeker Island near what is now the Lake Street Bridge that links Minneapolis and St. Paul (Anfinson et al. 2003:83-93). Likewise, the Little Falls Hydro Dam on the Mississippi River floods the site of an older mill dam at the mouth of the Little Elk River, the Sylvan Hydro Dam on the Crow Wing River backs water up the Gull River inundating two former mill dams there, and the reservoir of a former hydro dam on the Pine River at Pine River, Minnesota, submerges the remains of an earlier logging dam at the outlet of Norway Lake. A provision of a Minnesota mill dam law passed in May 1857 anticipated such occurrences by declaring that “No mill dam shall be erected or maintained...to the injury of any water power previously improved” (State of Minnesota 1859:849).

⁷ For example, a logging dam at Chengwatana on the Snake River was dynamited at least twice (Merritt 1979:286; Johnson 2009:16).

⁸ For example, in 1903, a lumber company had a logging dam near the source of the Mississippi River that backed high levels of water into Lake Itasca. The acting commissioner of Itasca State Park (a woman named Mary Gibbs)

All dams and reservoirs should be thought of as having useful lifespans. The life expectancy for temporary logging dams and under-engineered mill dams is quite short, from one to seven years. In contrast, well-designed, well-built, well-maintained, and little-stressed dams will typically last much longer, perhaps minimally 50 years. Lack of proper maintenance almost invariably shortens the lifespan. The core structural elements of a dam (e.g., the abutments, wings, or embankments) will commonly outlast the exposed and mechanical parts of a dam (e.g., the gates, sluices, turbines, etc.). In practical terms, the useful life of a dam has expired when it is no longer safe. Likewise, no dam should unquestionably be considered safe beyond its anticipated lifespan.⁹

Dams that outlive their original intended purpose may still be important for other reasons. Mill ponds and other municipal-based reservoirs often become essential for local recreational pursuits like fishing, swimming, boating, camping, and ice skating (although silting in may limit their lifespan). Dams might sit at the center of historic milling districts, communities, and parks and add to the sense of history and drama they instill in the built environment. Impounded waters may also create shorelines that play an important part in defining and shaping cultural landscapes, riparian boundaries, economic values, and natural spaces. In addition to maintenance costs and ecological concerns, all such considerations should be studied when contemplating the future of Minnesota's historic dams and reservoirs.

and the sheriff arrested the gun-wielding loggers who refused to open the dam. The lumbermen quickly got a court injunction that allowed continued closure of the dam and unabated riparian damage at the lake (Anonymous 1903).

⁹ See, for example: <http://www.waterpowermagazine.com/features/featurelife-span-of-storage-dams>

HISTORICAL BACKGROUND OF DAM BUILDING IN MINNESOTA

Water, water rights, water management, and marine navigation are enduring critical issues in American history. Within the area of present-day Minnesota, people have freely traveled by water and on frozen pathways of winter ice for generations. The construction (and in some cases, the deconstruction) of dams to control the flow of water likely begun before the time of Native-European contact and has continued into the modern period. This brief review of dam building and use in the Minnesota area emphasizes the significance of such structures. It also provides historical and chronological perspectives for understanding the importance of any surviving dams, dam elements, dam sites, or associated dam properties like mills and milling machinery (e.g., Frame 1977:8).

Natural and Human Built Dams

In Minnesota, natural water barriers vastly outnumber those built by humans. For humans, however, the origins of dams are often less important than the water they hold. Among common “natural” barriers or obstructions on Minnesota’s waterways are ice jams, floating bog islands, and beaver dams. Also common are rafts of forest debris (like limbs and uprooted trees) that accumulate in dense concentrations along streams. The latter, known to French travelers as *embarras*, might extend partly or fully across stream channels creating areas of calm water interspersed with violent currents (e.g., McDermott 1941:72). The many driftwood piles on the Zumbro River in southern Minnesota early led the French to call it the *River des Embarras* (“River of Difficulties”). The same is true in St. Louis County in northern Minnesota, where two rivers that often jammed with rafts of driftwood are now known as the Embarrass and Floodwood rivers (Upham 1969:11, 482). When the first lumbermen ascended the Rum River in 1847, they were forced to carry their canoe “for miles” over jams of uprooted trees and other debris that “filled the river” (Stanchfield 1901:330).

The early distinction between natural and human-made dams is somewhat blurred in the western Great Lakes Region, particularly with regard to canoe travel. In the spring of 1680 when the French explorer, Daniel Duluth, ascended the Brule River from Lake Superior to reach the headwaters of the St. Croix River he found it necessary to break through “about one hundred beaver dams” (Kellogg 1953:331). Although Duluth did not say so, the water released by breaching or deconstructing parts of the dams undoubtedly helped him in moving his heavily laden birch bark canoes upstream.

Flash forward to 1794 when a trade expedition led by John Hay and others attempted to descend the Prairie River (north of Cromwell, Minnesota) on their way to Sandy Lake. Low water forced them to build small dams on the Prairie River to coax their canoes downstream (Quaife 1916:205). Similar activity was later documented for canoe travel on the West Savanna River northeast of Sandy Lake. An early visitor there described his dam-building endeavors as “simple, but somewhat tedious.” It involved collecting water behind a series of hastily constructed little dams, and then “successively” opening the dams to create lift and current (Oliphant 1855:188-189).

Albeit very temporary, these little dams essentially served as systems of locks. In that sense, they were not unlike a canoe lock and canal completed by the North West Company in 1798 to move fur trade canoes past St. Mary’s rapids at the outlet of Lake Superior. When that lock was later abandoned, the canal was reused as a millrace (Capp 1904:117-121; Carstens and Sanford 2011:10).

In 1832 the missionary, William Boutwell, told of men building a series of improvised dykes (small dams) along a portage path in the marsh at the east end of the Savanna Portage, so that canoes with

light loads could be pulled through that low, muddy thoroughfare (Hart 1927:125-126).¹⁰ Such simple means of capturing or releasing water for canoe navigation might have easily originated with native peoples who also developed technologies for making birchen canoes. The Dakota had traditional names for dams or “anything that stops” the flow of water (e.g., Williamson 1992:44; Riggs 1992:100), and the Ojibwe did too. The latter used the phrase, “I make a dam,” implying that they knew how to make small dams and had procedures for doing so (Baraga 1966:66).

Some nineteenth century observers documented what they took to be early Native American dams on rivers in northern Minnesota. One, the archaeologist Jacob Brower, told of seeing two old stone dams on the Mississippi River below Lake Bemidji. According to Brower, the dams were rude attempts to throw the current of the river “to a central channel by arranging rows of boulders from either shore toward the deepest water at rapids, intended to facilitate the passage of canoes” (Winchell 1911:363). Similar features on the Thief River in northwestern Minnesota were early described as stone fish traps, each made in the shape of a V, with the point downstream. All of the latter were thought to have been “used for a time by the Indians and then abandoned” (e.g., Washburn 1886).

The early Minnesota land surveyor, George Stuntz, reported numerous stone and boulder dam constructs on northern rivers that he attributed, at least in part, to the work of ancient peoples. He recognized at least three types: (1) slight dams built to flood rapids or shoals, (2) wing dams or jetties built to direct water from bank to bank so as to secure sufficient depth to float watercraft, and (3) substantial dams built to create artificial lakes. Some large boulders in the latter features were said to weigh several tons apiece. Equating the accumulation of peat deposits in various basins with the passage of time, Stuntz suggested that some of the lake-forming dams might be as much as 7,200 years of age (Stuntz 1884, 1885). The described rock features undoubtedly helped facilitate canoe transportation, but the broad claims of human involvement in their construction or modification, as well as the claims for the great antiquity of that involvement, are suspect.

When it comes to creating or appropriating reservoirs, people are opportunists. For example, in the 1890s, loggers built a series of dams on the South Fork Pine River in central Cass County Minnesota, to regulate the river’s flow for their spring log drives. At the head of the highest branch of the river, water trapped behind a narrow morainic ridge—a natural dam—formed a small lake with limited catchment and no reputable outlet. The loggers wanted the water in the lake to assist their log drives. They cut through the ridge, essentially “opening the dam,” and allowing a great volume of water to drain from the lake into the river. Their treatment of the ridge as a cutaway dam gave the lake its present name of “Cut Lake” (Birk 1997a:71-74).

Similar activities are documented in many parts of the state where capturing water for log drives was a priority. One intriguing act of dam construction and deconstruction involved the diversion of water from the headwaters of the Boy River into the adjacent headwaters of the Willow River. The Willow River has its source in Pug Hole (Little Thunder) and Big Rice Lakes near the town of Remer in

¹⁰ Loggers also created ad hoc dams to facilitate log transportation. For example, loggers conducted log drives on the North Turtle River in northern Minnesota despite having no formal dams there. One logger said that the stream was so narrow he could touch the banks on each side with the oars of a rowboat. To back up water and float his logs downstream, he and his crew made temporary water-control structures from the logs themselves. In the end, after the drive was completed, no logs and no trace of the improvised barriers were left behind (Vanderluis 1974:286). Similar temporary dams made of timbers are described by Ryan (1976:56).

northeastern Cass County, Minnesota. Thunder Lake, lying just south of these lakes, is naturally tributary to the Boy River. In the 1890s, loggers built a dam at the outlet of Thunder Lake. Then, by cutting a short ditch through a morainic ridge, they created an entirely new outlet that drained Thunder Lake into Pug Hole and Big Rice Lakes. The extra water increased the flowage needed for log drives on the Willow River (Upham 1899:58).

Minnesota loggers routinely increased the storage capacity of natural morainic dams and beach ridges by blocking existing drainageways in those features with dams of their own. A well-known example of this is at Lake Onamia, one of the lakes at the outlet of Mille Lacs Lake in east-central Minnesota. Mille Lacs Lake is hemmed in by a glacial end moraine; a great natural barrier that limits drainage from this iconic fishing destination (Schwartz and Thiel 1963:265-266). By building dams on the outlet stream (the Rum River) near the lake, early loggers were able to store great volumes of water needed for downstream log drives (McClurkin et al. 2000).

Introduction of Industrial Dam Construction in Minnesota Waters

Industrial dam construction began in Minnesota shortly after the land-ceding Ojibwe and Dakota Treaties of 1837. It gathered some momentum when Minnesota became a United States territory in 1849, and reached a crescendo of sorts in 1857 just before the over-extended national economy stymied investment in potential town and mill sites. Dam building gained traction again after Minnesota's rise to statehood in 1858 and the subsequent Civil and Indian wars. Many of the first dams were built by lumbermen and millers who had prior dam-building experience in Maine and elsewhere (e.g., Stanchfield 1901:334; Dunn 1966:49-51; Frame 1977).

Ojibwe peoples, who occupied most of the lake-forest country of Minnesota before the advent of land-ceding treaties in 1837, were particularly annoyed by early dam builders. Wild rice and fish are important food resources for the Ojibwe and central to traditional gathering activities. According to Indian agency records, as early as 1843 some Ojibwe destroyed logging dams on the Snake and Rum rivers that threatened their rice crops. Construction of a logging dam near the source of the Rum River in 1849 was similarly opposed when rice beds flooded there. In the latter case, a confrontation between the Ojibwe and the lumbermen resulted in men on either side being killed (McClurkin 2000:76). Ojibwe also strongly objected when dams disrupted their traditional activities at Leech Lake, Lake Winnibigoshish, and Pokegama in the late 1800s (e.g., Nelligan 1929:145-146; Merritt 1979:108-114; Carroll 1990).

Minnesota's first commercial dams were built in the St. Croix River Basin. As early as 1838 entrepreneurs began developing a sawmill complex at a rapids above The Dalles—a rocky gorge at Taylor Falls. To the north of The Dalles the St. Croix River (and its western tributaries the Snake and Kettle rivers) drained an area heavily timbered with white pine. South of The Dalles the river was wider, more tranquil, and flanked with picturesque hills and ravines (Dunn 1966:5-9). Since 1849, the St. Croix River has formed part of the dividing line between Minnesota and Wisconsin.

The saw mill by Taylor Falls had a mill race blasted out of bedrock, a log boom, and a wing dam (Folsom 1888:358). The entire complex was in a rugged setting on a remote frontier, and the developers suffered from inexperience and lack of revenue. The development, now remembered as a “melancholy failure,” was abandoned in 1844, after a flood tore out the log boom and the mill's entire stock of logs (Folsom 1888:304-305; 1901:294; Durant 1905:648-649; Dunn 1966:80-81).

Many early Minnesota saw mills were powered by steam. Because they could use mill waste for fuel, such mills were typically more efficient and dependable than those reliant on water-power. Steam-

power saw mills had no need for dams except to create millponds for holding and moving logs. In the 1880s on the Grindstone River, for example, a Hinckley firm had a steam saw mill with a ten-foot dam that was “used for floating logs to the mill but not for water-power” (Upham 1888b:645).

In areas of steep or rugged terrain water-power mills could gain head through the use of remote dams, and flumes. In the 1880s, for example, the Franconia Mill in Chisago County had a ten-foot dam fed by some springs on Lawrence Creek. Water from the dam was delivered to the mill by a flume, one-quarter mile long. The flume, with a descent of only two feet over its extended length, provided a head of 30-feet where it discharged onto an overshot wheel at the mill. Despite the lavish investment in infra-structure the wheel produced only seven horsepower and was eventually supplemented with steam power (Upham 1888a:421).¹¹

The use of flumes or millraces could also decrease the need for large or high head dams at water-powered mills. Bolles flour mill built in the early 1840s on Bolles Creek near Afton in Washington County had a nine-foot waterwheel powered by water channeled through a millrace, but no appreciable dam.¹² The mill is said by some to be the first commercial flour mill in the Mississippi Valley above Prairie du Chien (Folsom 1888:357; Frame 1977:16).¹³

The Upper Mississippi River Basin, with its extensive forests and natural waterways, offered many of the same industrial and settlement opportunities as the St. Croix Valley. Upstream from St. Anthony Falls (at Minneapolis) at the time of initial white settlement was a vast reservoir of valuable pine timber that joined seamlessly with coniferous forests in the upper St. Croix Valley and throughout northeast Minnesota (Fig. 2). Log drives in that northeast sector occurred on streams within the Great Lakes and Rainy River Basins, and eastern margins of the Red River Basin (Fig. 1).

St. Anthony Falls is the greatest natural source of waterpower in southeastern Minnesota and the practical head of navigation for large boats on the Mississippi River (Lass 1977:4). Troops from Fort Snelling were the first to erect mills at the falls in the early 1820s. Lacking a dam, the government saw and grist mills were powered by water conducted from the brink of the falls to the mills by a wooden flume or race (Kane 1987:9-10; Folsom 1888:505, 512; Frear 1963:3-4).

The first artificial dam at St. Anthony Falls was an industrial structure built in 1847-48 for the dual purpose of creating a millpond and powering a saw mill. It was erected on a side-channel above the falls, between Hennepin and Nicollet Islands and the east bank of the river. At about 700 feet long,

¹¹ Among other examples is a mid-1840s saw mill at Arcola south of Marine that also had an overshot wheel propelled by spring water (Folsom 1888:43, 377-378). A flour mill opened at Marine in 1857 had turbines powered by a 60-foot fall of water brought a distance of 1,000 feet by an elevated race (Folsom 1888:375; Winchell 1888:376). Plans were later developed (but not implemented) for similar operations on rugged landscapes along the Pigeon River and the North Shore of Lake Superior using canals (or races) and pipe lines. For example, the greatest fall of the Poplar River near Lutsen Minnesota is within three miles of the lake. It was determined that the 610-foot fall over that distance could be used for waterpower by installing a race or pipe about 12,100 feet long (Minnesota State Drainage Board 1912:536).

¹² <http://www.belwin.org/news/2010/08/18/valley-creek/>

¹³ Others assert that the first commercial grist mill in what is now the Minnesota area was the Gervais Mill at Little Canada (http://www.waymarking.com/waymarks/WM3H10_Gervais_Grist_Mill_Little_Canada_MN). Later mills on Bolles Creek included one with a 26-foot overshot wheel and another with a 32-foot overshot wheel (Winchell 1888:376). Water-powered sawmills built on St. Croix River tributaries at Marine in 1838-39 and Stillwater in 1844 also apparently had no substantial dams (Folsom 1888:375; 1901:298, 301; Durant 1905:649-650).

16 feet high, 12 feet wide at the crown, and 40 feet wide at the base, it was the largest dam constructed to that time in Minnesota. The dam was built of hardwood timbers cut on the adjacent island, and from slabs and planks cut at the government mill and the St. Croix River (Stanchfield 1901:334-335; Frear 1963:4; Kane 1987:18; Folsom 1888:500-501).

No water-powered mill development could succeed financially without a dependable flow of water, a ready supply of raw materials, viable markets, dependable transportation, and capital (e.g., Kane 1987:15). In 1848 when the first private sawmill at St. Anthony Falls began operations, lumber (even though all “green”) was sold as fast as it could be produced (e.g., Kane 1987:15, 18). Much of the lumber was purchased by immigrant families and businessmen in St. Anthony and St. Paul (Stanchfield 1901:339-341).



Figure 2: A map showing Minnesota’s major pre-settlement plant communities or biomes.

Legal Framework for Dam Construction

In March 1849 Minnesota became a territory of the United States. As in Michigan and Wisconsin, the pre-statehood Minnesota legal system determined that “a stream which could float a saw log was a ‘public highway’ and that saw logs had just as much right to be on the rivers as rafts, barges, and steam-boats” (Rector 1949). Essentially, laws and regulations divided Minnesota’s waters into two basic categories: *navigable and non-navigable*. If a stream can be used for the purposes of trade and commerce in any mode, even by a canoe or for floating logs, the stream was considered navigable.

Navigable waters could not be blocked by structures except by legislated charter, even dams built to navigate logs. As an example of pre-statehood logging dam authorization, when the first Minnesota territorial legislature convened in September, 1849, the St. Croix lumberman, Elam Greely, petitioned to build a logging dam at the outlet of Cross Lake on the Snake River in Pine County (Folsom 1888:648). On October 20 the legislature granted Greely the right to build and maintain the dam for a period of twelve years. Remarkably, for its time and place, Greely’s dam was also to have “a chute, with such an inclination, that fish may pass freely up and down the river” (Minnesota Territorial Legislature 1849). Greely’s dam was the first full-channel industrial dam built

by government charter within the Minnesota Territory (Minnesota Territorial Legislature 1849).¹⁴ Later known as the “Chengwatana” dam, it was to be operable by April 1, 1850 (Birk 1988).

Dam legislation, like that authorizing Greely’s construction, often included other rights and restrictions as well. Greely’s charter required that his dam have a head of 5.5 feet with gates, sluices, and “all the other appurtenances necessary for sluicing logs.” Greely was legally entitled to collect a toll for every thousand feet of lumber in the logs that passed through the dam. The fee was not to exceed the sum of ten cents the first year, and six and one-fourth cents per thousand thereafter (Minnesota Territorial Legislature 1849). To put that in perspective, some very large logs might individually contain a thousand board feet (Rector 1949:240; Bacig and Thompson 1982:76).

When Minnesota gained statehood new laws were created to manage dam building. Rather than requiring a legislative charter, the state followed the example of Michigan and created a system of licensing that gave county commissioners the right to authorize toll logging dams. This streamlined the process and favored logging interests (Rector 1949: 240). By 1859, any request for dam construction and operation in Minnesota was to be brought to public attention by publishing notice of such request in a duly recognized local newspaper for three successive weeks. Court-appointed commissioners were then to meet at the place specified in the notice to examine properties above and below the dam for purposes of assessing potential damages to other parties (State of Minnesota 1859:846-850; Ralph 1910: 50). Counties were to establish the stage of water levels for lakes and allow construction of dams to maintain them, but the law also stated that: “Logging dams and stage of water needed for sluicing are exempt” (Ralph 1910: 50). Thus, the logging industry was able to set water levels and regulate water flow on most log transport streams to their own advantage.

Over the years other state statutes were passed from time to time with regard to the siting, construction, and operation of mill and logging dams; and for defining dam owners’ rights. The legislation was often inspired by similar actions in Michigan and Wisconsin and by the powerful self-interests of lumberman-politicians. As before, considerable authority over dam building was passed down to counties.

Information regarding stream navigability is further derived from Minnesota’s original township plats.¹⁵ In general, a stream is considered navigable if it was meandered during the Original Land Survey. That is, if the land survey lines stop at the water’s edge on the original plats, the body of water or stream is considered meandered and the adjacent parcels (fractional sections) are assigned government lot numbers (Fig. 3). If the land survey lines continue across a river or stream

¹⁴ Prior to the present research, Greely’s Chengwatana Dam was also erroneously considered to be the first dam built on the Snake River watershed and the first full-channel industrial dam in the Minnesota Territory. Once completed, the dam had a nine-foot head and backed water 16-miles upstream. Like many Minnesota dams it later underwent various changes, including use as a bridge and as a waterpower for a sawmill (Upham 1888b:645; Birk 1988). Greely’s dam occupied a strategic location well suited for its purposes. Above the dam the area drained by the Snake River is a mix of marshy and rolling terrain with a few lakes, but “no considerable valley.” Below the dam the Snake River charges through a deep valley flanked by hills and ridges--some from 50 to 100 feet high. Water released at the dam carried pine logs from the tranquil setting of Cross Lake through a nine mile stretch of rocky rapids where the river drops with an average of 14-feet per mile en route to the St. Croix (Upham 1888d:630, 645).

¹⁵ Minnesota’s original Public Land Survey plats were created during the first government land survey of the state conducted by the U.S. Surveyor General’s Office during the period 1848-1907. See: <http://www.mngeo.state.mn.us/chouse/GLO/>

uninterruptedly, the waters are not meandered and might be considered non-navigable (Minnesota State Drainage Board 1912:537-538).

An example of this is seen in the accompanying map from Wadena County, Minnesota (Fig. 3). In 1863 the surveyor, George B. Wright, made a meandered survey of the Leaf River from its mouth up to where the river crosses the line between Sections 27 and 28 in Township 135 North-Range 34 West (about 7.75-miles north-northeast of Verdale, Minnesota). Noting that the Leaf River received the flow of the Wing River in Section 28, Wright concluded that above that juncture the Leaf River was no longer of sufficient size to be meandered. In contrast to the sharply angled bends he depicts in the meandered downstream portion of the river, the course of the Leaf and Wing rivers farther west are shown in rounded curvilinear outline.

Loggers understood or accepted that dams or dikes could be erected on streams not subjected to meandered surveys. According to the timber cruiser, Charles Wight, the Clearwater River (south of Red Lake) was not navigable, was not meandered during the Original Land Survey, and was never divided into government lots. As a result, in 1875, without permission, the lumberman Sumner Bagley built a logging dam on the river about 11 miles northeasterly of what later became Bagley Minnesota (Vandersluis 1974:202, 204).

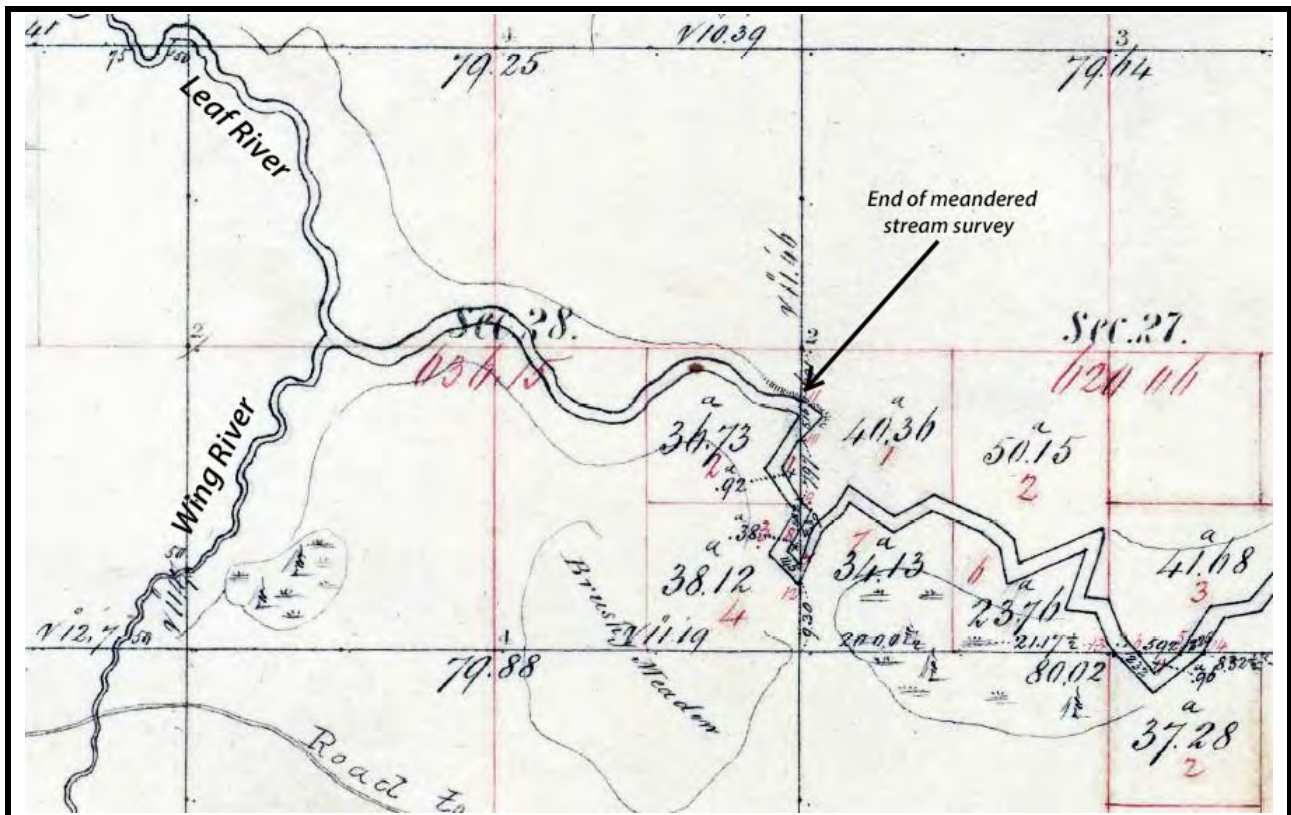


Figure 3: Part of the Original Land Survey plat for T135N-R34W, Wadena County, Minnesota, comparing meandered and un-meandered segments of the stream survey of 1863. Note government lots up to 50.15-acres numbered in red (Map courtesy the Minnesota Historical Society).

In fact, the Federal Government claims jurisdiction over interstate commerce on navigable streams, and it has authority to prevent any bridge, dam, dike, or other obstruction to navigation from being placed in or across any recognized navigable stream. This authority has not always been exercised, however. Like Bagley's Dam, most of Minnesota's logging dams were built without permission, interference, or complaint of the Federal Government (Minnesota State Drainage Board 1912:538, 544; Merritt 1979:291). The regulation and oversight of such industrial dams on navigable waters in Minnesota has mostly been controlled by other units of government, including the state legislature.

Expansion of Dam Building

Logging and lumbering interests dominated the St. Croix River for a period of 75 years (1839-1914) (Merritt 1979:270). Viable water-power sites were widely available on its tributary streams, and in the 1880s, observers assumed that with a greater number of immigrant settlers, many such sites would "doubtless be utilized for manufacture of lumber, furniture and wooden wares, and for flouring mills" (Upham 1888d:645). The same was essentially said of potential water power sites in other forested areas of Minnesota. That included Cass and Crow Wing counties, where many sites occupied by logging dams in the 1880s and 1890s were felt destined in the future to become flouring mills or New England-style woolen and cotton factories (Upham 1899:79-80).

Of course, not everyone thought so highly of logging dams. Some saw dams as symbols of the transient lumbering business whose main purpose was to exploit timber resources in one area and then leave for another (Merritt 1979:281). Cutover areas were variably seen as promising agricultural lands or as wastelands that invited wild fires, erosion, and polluted streams.

Through 1889 the flow of the St. Croix River was largely unencumbered. In that year construction began on Nevers Dam, the largest pile-driven dam in the world,¹⁶ about eleven miles above Taylor Falls. Nevers Dam was built to control the river's flow, to regulate the transport of logs to mills, and to alleviate need for a large, channel-choking log boom at Stillwater. In reality, as with most logging dams, the irregular release of water and sluicing of logs at Nevers Dam brought unwanted change to the river downstream. Even repeated dredging and the removal of deadheads from the river could not provide a navigable boat channel downstream between Stillwater and St. Croix Falls. For that and other reasons operation of the dam was widely controversial, particularly for those who considered the river to be a public thoroughfare open to all. The last log went over Nevers Dam in 1912, marking the end of major log drives in the St. Croix Basin. The dam later served as a control point and reservoir for a hydroelectric dam downstream before being washed out and razed in 1954-1955 (Folsom 1901:316-317; Holmquist and Brookins 1972:48-49; Merritt 1979:274-86).

The State of Wisconsin authorized construction of 331 logging dams (including Nevers Dam) in the last half of the nineteenth century (Merritt 1979:270, 277). An equal or greater number of dams were likely built in Minnesota during the same period. Indeed, during the logging era, Minnesota's pine districts were heavily populated with logging camps and dams. It is estimated that in the late 1800s and early 1900s, up to 100 logging dams were built on the St. Louis River watershed alone (Waters 1977:37). Northern and east-central Minnesota counties like Aitkin, Becker, Beltrami, Cass, Clearwater, Hubbard, Itasca, Kanabec, Lake, Mille Lacs, Morrison, and Pine collectively had hundreds more. So many old logging dams are located in and around Superior National Forest that to management of those resources is a major challenge (Elizabeth C. Reetz, personal communication).

¹⁶ http://files.dnr.state.mn.us/destinations/state_parks/wild_river/nevers_dam.pdf

Based on his firsthand knowledge of logging operations, historian Buzz Ryan concluded that “wherever logs could be moved by water, there were dams” (Ryan 1976:57). He was convinced that “practically every stream in northern Minnesota had from one to a dozen” logging dams (Ryan 1976:56).

Because the dams were constructed with considerable variety and purpose on diverse landscapes, probably no two were exactly alike. For instance, loggers might built wing dams to channel currents and seal off backwater sloughs, freshet dams to create pocket reservoirs and artificial surges, full-channel reservoir and river dams to capture and regulate the flow of large volumes of water, and ancillary dams or dikes needed to block alternate outlets (Dickmann and Leefers 2003:138; Ryan 1976:55). Some of the most dramatic logging dams (with flumes) were built in rugged lower valley of the Pigeon River in northeast Minnesota at places like the Cascades and High Falls canyons.

Most logging dams were temporary constructs of little repute. For many, their names, builders, ownership, modes and materials of construction, dates of origin and operation, and circumstances of abandonment were never recorded and are now lost. Too often, the very existence of many logging dams went unrecorded as well. Indeed, some logging dams were such improvised and ephemeral structures that, after use, little or nothing was left behind to mark their former locations. Buzz Ryan asserts:

Just how many dams were used by the logging industry will never be known, as some of them were used but one season and dismantled, burned out by forest fires or in some cases moved to a better site (Ryan 1976:56).

Probably an even greater number of logging dams washed out or wasted away. For example, several logging dams on Skunk Brook in Morrison County were carried away in a spring flood in 1896. Just a year earlier the water was so low on that stream that even with these dams, the spring drive was difficult.¹⁷ None of these Skunk Brook dam sites are revealed on aerial photographic or LiDAR imagery and their exact locations have yet to be determined.

The practice of razing dams often obscured all signs of their former presence. For example, the last log drive on the Otter Tail River in Becker County occurred in the spring of 1919. Some years later, CCC-workers and Tamarac National Wildlife Refuge personnel removed all evidence of eleven former logging dams on that river above the big mill at Frazee (Stearns 2003:27, 40).

With the rapid cutting of pine forests in Minnesota, the pine-logging frontiers crept ever northward or upvalley. The industry began dramatic change in the 1890s with increased need for investment funds and the costly use of logging railroads to access and transport pine timber. Huge mills also competed to sell wood products through widely distributed outlets (e.g., Forester 2004:60-61).

Most Minnesota pine lands were cut over by 1920. The last major log drives in Minnesota occurred in the 1930s (e.g., Bigfork Commercial Club et al. 1956:19) coincidental with the Great Depression. By then, the use of logging dams in the state was a thing of the past and so was the era of the initial pine harvest. Even the operations of Edward Backus, one of the last big-time lumber barons, working

¹⁷ These details are gleaned from articles in the *Little Falls Daily Transcript* for April 13 and 15, 1896, and for April 30 and May 2, 1895.

at International Falls and along the northern border, were brought down by the depression and by the dogged resistance of early preservationists who fought proposed new dams and water level changes (e.g., Rajala 1998:25).

There are many differences and similarities among Minnesota's logging and mill dams.¹⁸ For starters, grist and saw mill dams were generally constructed to be more permanent and reliable than those built for driving logs. Dams built to power mills were typically sited on streams where there was an expectation for uninterrupted flow. Logging dams were erected on a wide range of waterways including small streams that in some years might have little more than intermittent flow. Logging dams were often built and operated in series along a stream or some combination of streams and waterways. Feed and flour mills were typically individual or clustered facilities built aside or near singular dams.

Sawmill and logging dams were typically built downstream from accessible reserves of buoyant pine timber. Sawmills were also located with consideration for selling or shipping wood products to consumer markets. Logging dams were placed wherever needed, often in remote and unsettled areas far from markets and supply centers.

Gristmills and dams were mostly built in populated agricultural regions, where corn and grain crop reserves were available. Professional engineering skills might be required to design, assemble, operate, and maintain all of the mill and mill dam equipment and components. Logging dams were typically less complex and precise, custom-built by skilled laborers with primitive tools, and operated by anyone who could follow orders.

Sawmill and logging dams were nodes on linear transportation lanes like rivers and railroads, and they relied on log drives or trains to channel resources to their location. Feed and flour mills were more often loci or destinations that attracted raw product from within a radial resource base. Corn and grain resources for grist mills were replenished on an annual basis. After forests were cut and the logs carried off, logging and sawmill dams became obsolete. Reforestation could take years.

Logging dams were often little known structures that drew no lasting attention. Grist and sawmill dams, as parts of permanently situated, named, and advertised businesses, were often highly visible and celebrated features within viable communities.

Once abandoned, any dam might quickly deteriorate or be repurposed for other use. Many old logging dam sites were re-outfitted as WPA dam embankments. Regardless of when or where they were built, each dam (or the remains of each) can be studied and evaluated as a separate cultural expression or as a fixed and definable part of a past production system, or in the case of logging dams part of a past transportation system (Birk 1997b:56, 73). Historic dams have been seen as hazards and liabilities by some and as structures of unique historical and architectural interest by others (e.g., Halsey et al. 1997).

¹⁸ Minnesota mill historians Robert M Frame III and Willard Larson have completed studies of the state's early flour and saw mills (Frame 1977; Larson 2011). Some of the best-known sawmill dams, used to enable the local movement, storage, and milling of logs (for lumber or for paper), were at St. Anthony Falls, Anoka, St. Cloud, Sauk Rapids, Little Falls, Gull River, Brainerd, Grand Rapids, Cloquet, International Falls, and Frazee. In each case, the mill dams were probably less well known than the mills and companies they served.

HISTORICAL CONTEXTS

Introduction

For this study, historic dams and dam sites are dam properties built or used before 1941 that have extant structures or remains with historic or archaeological significance. The “Property Types and Evaluation” section below has a more in-depth treatment of historic properties as defined by the National Register of Historic Places. The contexts in this document focus on the human manipulation of water for purposes of stream-based log transportation, milling, and conservation. The contexts are *Logging Dam Systems in Minnesota (1840-1920)*, *Historic Milling Dams in Minnesota (1823-1915)*, and *Federal Relief Conservation Dams in Minnesota (1933-1941)*.

Although Minnesota’s historic dams were built individually, they were often designed, created, and operated as part of larger strategies. The interrelationships might include a dam’s role in transporting saw logs, milling of wood or agriculture products, and creating reservoir containments for waterpower, water conservation, recreation, or other purposes. Historic dams are often associated with other industrial and water control structures such as mills, locks, millraces, flumes, fish-ladders, dikes, and even land-based transportation features or systems like bridges, roads and railroads.

Documenting dams without knowing their relationship to larger systems or associations can lead to fragmentation of the cultural resources management process. A mature understanding of a property’s historical significance within an historical context is a necessary prelude for effective site evaluation and interpretation. A goal of the present research has been to create thematic contexts and associations to assist in the identification, definition, and evaluation of historic technological systems centering on dams.

Logging dams are among the most numerous industrial logging structures built in Minnesota. The dams facilitated the transportation of pine logs (and occasionally pulpwood) from forests to mills, but they were just one aspect of much larger extraction, economic, and ecological systems. By knowing the nature, purpose, and patterned distribution of logging dams one can better understand the spatial organization and interrelationship of all logging-related transportation properties.

An existing Multiple Property Documentation Form (MPDF) on *Commercial Logging in Minnesota (1837-1930s)* treats these larger historical patterns and associations (Birk 1997b). Some other informed and readily available sources of Minnesota’s logging history include Agnes Larson’s *History of the White Pine Industry in Minnesota* (1949), *Mainly Logging* edited by Charles Vandersluis (1974), the published works of William H. C. Folsom (1888, 1901), Daniel Stanchfield (1901), William G. Rector (1949, 1953), and Alton Stearns (2003), the writings of Warren Upham, J.C. Ryan, and Benhart Rajala, and Douglas Birk’s “Outta the Woods and Onto the Mills: Shifting Timber-Harvest Strategies on Minnesota's Early Lumbering Frontier” (1997a).

Minnesota's milldams, like Minnesota's mills, are products of both technological change as well as innovative response to locational settings and environment. Milldams store water that, when released, generates waterpower to drive machinery such as used to mill flour or saw wood. These activities are parts of larger systems like agriculture and lumbering. Related statewide contexts are: *Indian Communities and Reservations (1837-1934)*, *Early Agriculture and River Settlement (1840-1870)*, and *Urban Centers (1870-1940)*.

Robert Frame's survey of statewide resources *Millers to the World: Minnesota's Water Power Flour Mills* (1976) and his doctoral thesis, *The Progressive Millers* (1980) are definitive works on the context of Minnesota Milling. These will soon be joined by another book by Frame that promises to even further assist the researcher of Minnesota mills. Another important study entitled, *Early Sawmills of Minnesota*, has been issued by Minnesota historian Willard Larson (2011).

Conservation dams, built with WPA assistance and either local or CCC labor, are part of a program of federally assisted construction in the depression-era economy. The MPDF, *Federal Relief Construction in Minnesota (1933-1941)*, provides an excellent background on this context and is a good starting point for research on the larger historical movement (Anderson 1993). A related statewide Minnesota State Historic Preservation Office (MnSHPO) Context is: *Minnesota Tourism and Recreation in the Lake Regions (1870-1945)*.

Among historic contexts and property types not addressed in this report are Mississippi River navigation and headwaters dams, hydroelectric dams, agricultural-related reservoirs, check dams, and soil-saving dams (e.g., Granger and Kelly 2005, I:6-131, 132). Also not considered are temporary coffer dams, and diversionary structures such as dikes and wing dams that might not cross an entire channel. Although beyond the limits of this study, some extant resources for the evaluation of such constructs include the MPDFs for *Hydroelectric Power in Minnesota (1880-1940)* and *the Upper Mississippi River 9-foot Navigation Project (1931-1948)*. Both these documents are on file at the MnSHPO office in St. Paul. *The Upper Mississippi River Headwaters Reservoirs Damsites: Cultural Resources Investigation* looks at the six headwaters dams (Zellie 1988). Indeed, these studies cover most dams that will be found on the Mississippi River.

The contexts in this report are designed to fill major gaps in existing evaluation frameworks or studies. Between previous studies and this document, most historic dams in Minnesota should fall within a developed context with defined property types and evaluation guidelines.

Logging Dam Systems in Minnesota: 1840-1920

From the moment a living tree is felled and cut into logs, the fundamental challenge of logging is that of transportation. To stay profitable, logging companies needed inexpensive means of moving large, bulky, heavy tree trunks to wood processors. The buoyancy of pine logs and the often close relationship between pine forests and streams has made moving (or “driving”) the logs down rivers the cheapest and most efficient means of log transport. In many situations log drives depended on logging dams (Brown 1936:7, Rector 1953). The methods of river driving in North America were developed in the eastern forests and brought westward, and persisted relatively unchanged prior to the introduction of mechanized transport (Brown 1936:231).

In Minnesota, several related ecological factors favored the use of water to transport logs, including an appropriate climate, the buoyancy of pine logs, and gentle topography incised with low-gradient streams. The climate with generous annual precipitation supported the growth of vast forests of floatable tree species that were easily milled and desired for building.¹⁹ Cold winters facilitated log skidding and also stored water in the form of snow and ice that was released during spring melts to push harvested logs downstream. To capitalize on all these natural advantages, the lumbering process early depended on human manipulation and use of water.

In the years of Minnesota logging prior to the Civil War, most timber was cut from the margins of rivers with ample flow, such as the St. Croix and Mississippi, so few dams were needed to float logs to downstream mills (Rector 1953:103). Logs were first skidded or hauled on snow to rivers and lakes where they were stored on either the ice or frozen banks until the weather warmed. At the optimum time the logs were started on the spring drive. The basic natural requirements for a good driving stream were: a good water supply and current, adequate depth and width with no sharp turns, and high banks to channel the logs and keep them from being stranded in marshes (Vogel 1983).

Minnesota’s rivers funneled logs and water from vast watersheds into a few industrial milling zones that were connected to greater transportation networks. River drives began in Minnesota in the 1840s and continued into the second quarter of the twentieth century. Pine timber from the St. Croix Triangle (of east central Minnesota) was initially floated all the way to mills in St. Louis, but milling operations soon emerged in Marine, Stillwater, and Winona much closer to the source of the harvests (Larson 2007). The Upper Mississippi River Basin early carried logs to water-powered lumber-mills in the developing industrial center at St. Anthony Falls. The St. Louis River watershed pushed logs to milling centers in Cloquet and Duluth where lumber could be shipped south and east, while tributaries of the Red River sent logs to Grand Forks, Fargo/Moorhead providing lumber for developing farms and settlements in the Red River Valley and northern plains. The lumbering industry depended on human manipulation of natural systems, such as damming lakes and rivers.

¹⁹ White Pine is one of the trees most desirable and easiest to float. The hardwoods of Minnesota’s Big Woods were less important in the initial phase lumber industry partly due to their difficulty to transport, and partly because they grew on what was considered prime farmland and were quickly disposed of to create agricultural fields (Larson 1949:7-8).

Watersheds and Logging Dams

Watersheds can be thought of as trees with a dendritic pattern of collection that captures water in small branches and carries it down progressively larger limbs to the trunks. Lumber companies started cutting along the trunk and moved farther and farther into the areas of the smallest twigs. As logging operations moved upstream to smaller and “even imaginary” creeks, floating timber—particularly large quantities of timber—became increasingly difficult (Rector 1953:103, Kane 2006:172). Smaller rivers and streams were typically “improved” for driving logs by removing rafted driftwood, cutting through sharp turns and oxbows, cutting overhanging branches and clearing alder swamps typically in fall and early winter (Rector 1953:98). Where banks were insubstantial, revetments like log cribbing or earthen dikes might be added to shore them up.

A major and common alteration for loggers was the construction of dams to raise water levels for log drives, especially on smaller feeder creeks (Sedell et al. 1991, Brown 1936:230-249). Even the smallest trickles were eventually used to float logs or impound water to assist drives (Ryan 1976:8).

Between 1881 and 1895 the rate of cutting peaked, with over 7 billion board feet of logs cut each year in the Lake States (Rector 1953). The frenzy of exploitation coincided with a period of intermittent drought, complicating the task of getting logs from the forests to the mills (Rector 1953, Minnesota Department of Conservation 1934:40). The solution was to build even greater systems of dams and “river improvements” some improvised, some engineered, to raise water levels adequately to float logs down shallower waterways with less water volume (Rector 1953:103-110).

In the early years of lumbering, loggers were in the habit of building dams at will wherever they chose. Some of the dams were of a permanent character and erected at great cost, while others were temporary improvised structures suited only for one-time use. Logging dams were often built in series to assist the process of lowering logs step-by-step (reservoir-by-reservoir) down selected waterways. At one point there were 148 dams on the Chippewa River in Wisconsin, nearly 100 on the St. Louis River in the northeastern Minnesota; and close to 70 in the St. Croix Valley, many that worked in coordination with one another (Vogel 1983, Rector 1953). Even smaller rivers had numerous dams. For example, there were eleven dams on the Ottertail River above Frazee in 1911 (Stearns 2003), nine on the Platte River in the 1880s (Rector 1953:104), and at least seven on the South Fork Pine River in Cass County in the 1890s (Birk 1997a).

Rarely did the rectilinear system of land ownership coincide with networks of meandering rivers, so a logging company might drive logs down two or more different streams often comingling their logs with those of other firms (Rector 1953:110). Although each group was internally coordinated, the overall process of river driving was not. One company’s dam might block another’s logs or render their dam useless. The random release of torrents of water within watersheds might lead to huge floods of water and logs, especially during periods of natural high water such as spring runoff. To coordinate the passage of water and logs, boom companies operated some logging dams charging individual logging companies a sluicing fee for each log they handled. In some areas, single large logging concerns controlled both the logging and the river drives (Stearns 2003, Bell 1999).

Logging Dam Construction

Logging dam technology changed little through time and was only slightly influenced by advances in engineering. Instead, generations of lumbermen accrued the folk knowledge and expertise to cheaply and quickly construct timber-and-earth structures (Brown 1936:235, Vogel 1983:191). An 1881 newspaper described the methods of Billy “the Beaver” England a folk technologist who specialized in designing and overseeing the construction of logging dams:

To realize the work it is necessary to understand that Mr. England the builder, has no pile drivers or coffer dams or dump carts, or sawed timbers at his command. The axe and the wheelbarrow are his only resources. The trees are felled in the woods surrounding, squared or hewn into plank, and drawn to place with a yoke of cattle. The gravel, thousands of cubic yards, is carted on wheelbarrows (Vogel 1983:180).

Unlike mill dams that only needed to impound enough water to power a waterwheel or turbine at one location for a day of milling, logging dam systems had to store months’ worth of water to flush a winter’s worth of harvest—millions of board feet—down a river. Dams were often sited at the outlets of lakes or swamps to exploit the natural water-retaining capabilities of such basins. River dams typically had less capacity unless downstream from large marshlands, pocket marshes, low-gradient side streams, or wide floodplains.

The *Annual Report Chief of Engineers to the Secretary of War for the Year 1879* briefly describes the three main types of dams used in Minnesota log transport systems: gated driving dams, “roll” driving dams, and temporary “cutaway” dams.

The lumbermen (loggers, properly speaking) have been in the habit, for years, of building dams at will upon the tributaries and the main streams as well, many of the dams of a permanent character and erected at great cost, while others are temporary structures or "cut-away" dams. These dams pond up the water until a sufficient quantity is collected so that the logs may be floated down to the dam, when they are driven or flashed through, or over, according to the construction of the dam, depending upon the head of water, into the reach below, the process to be repeated at the next lower dam. The term "cut-away" is applied to a cheap temporary dam, without gates or sluices, erected to collect the water above it; sufficient water being collected, an opening is made in the dam, the logs run through, and the dam abandoned (Frizzel and Allen 1879:1196).

During spring log drives, lumbermen and millers closely watched water levels. An April 26, 1878 article in the *Mississippi Lumberman and Manufacturer* reported on the spring drive as if it were a sporting event:

Alex Johnson commenced on Mud Creek today, with a full head on dam. He will come along with 2,000,000. John Dudley is below on Sand Creek, with 1,500,000. . . The Groundhouse drive is all in the flowage of the big dam, and they will sluice tomorrow and reach this point next Sunday. . . Isaac Staples crew on Ann hoisted their gates today and sluiced what few they had above the dam and commenced driving. They have everything in order with plenty of men and water and expect to reach Snake in eight days (Kane 2006:190).

River driving and manipulation of water levels

Modern dams are built with the objective of maintaining water levels and controlling high water. However, many logging dams were built to maximize water reserves in a stream and then suddenly release it to float logs impounded above and below the barrier.

Properly sited dams could backup huge volumes of water. Lakes were often created or used as headwaters reservoirs with gated or cutaway dams near the outlets (Birk 1997a, Larson 207:185). As late as 1910, dams on the outlets of Wild Rice Lake and Twin Lake on the Wild Rice Rivers held back water all through winter and spring for spring drives (Ralph 1909:234). The water was usually collected throughout the winter and early spring (the log harvest season), and then released over a relatively short period of time during and after spring breakup (the log driving season).

Loggers had to study individual waterways and learn how to use impounded waters to their best advantage. Driving dams, particularly when built in series, could supply sufficient water to float logs down even some of the smallest non-navigable streams. Timing was essential to manage the limited water resources: it could take weeks to months to fill a dam basin, but it might be emptied in as little as 4 hours (Brown 1936). A dam on the St. Croix watershed took eleven months to raise a six feet head all of which was released in 20 days through a stepped series of downstream dams (Rector 1953:105, 110).

Driving Dams

To flush logs downstream loggers usually timed the release of water from dams to coincide with spring high water. When a full head of water was raised in a reservoir, gates were opened and logs were flashed down to the next dam. “It was like walking the logs down a stairs. The walking bosses knew just how long it took the logs to go from one dam to another, so they could open and close the gates to best advantage” (Stearns 2003:29). The rate at which a plank floated downstream would be used to calculate the time it would take logs to travel from one dam to another. By the 1890s battery-operated telephone systems were used in some places to time the opening of dams along streams (Bell 1899:25).

A logger describing drives on the Ottertail River noted, “After so many logs had been let through the dam, the gate would be closed to allow the water level to be built up again, which would be accomplished in a short time. Then they would let another bunch go. The water travelled in bursts” (Stearns 2003:29). The “flashing” of logs and water through dams caused wild daily fluctuations. On the Cloquet River the opening and closing of gated logging dams in 1909-1910 caused the gauge height to rise and fall several feet during the day (Ralph 1909:268).

In spring the surges on major rivers were dangerous and could lead to gigantic jams. Even after water levels receded and jams were broken up, some logs might be stranded for months or even years. Thus driving dams on larger streams were sited and operated to keep water levels consistently high without creating excessive floods. Dams were even built in tiny drainages and swamps that were too small and level to float cut timber. The carefully controlled release of water impounded in these smallest

branches could be combined to maximize the quantities of logs floated out of a watershed and reduce the number of logs left “high and dry” (Kane 2006:185). Timing was crucial in this procedure and skilled river bosses were known for their fabled ability to “float logs on heavy dew.”

Gated driving dams (also known as splash or sluice dams) are the best-documented type of logging dam. They were widely used to control water levels and run logs (e.g., Brown 1936:235-242; Ryan 1976:55-57; Bacig and Thompson 1982:101; Stearns 2003). Although built in several forms, all were designed to be closed and opened as often as needed. Other than flushing surplus water, the dams were most often opened and closed during the spring log driving season. Gated driving dams that held water adequate for a week of log driving might cost between \$500 and \$2,000 to build. In 1869, a substantial dam 12 feet high with 326 piles in the 400 foot long structures on the Namekagon River in Wisconsin cost little more than \$5,000 (Rector 1953:106).

Roll dams were essentially large, ungated weirs built to control water levels for log drives. There were no sluices. With sufficient runoff, water and floating logs would simply overtop a roll dam. Alone or in series, roll dams could flood rapids, reefs, sand bars, boulders and other obstructions (e.g., Upham 1888b:608). By helping to maintain water levels and flowage for a longer time, these dams could extend the period of log drives by several weeks, sometimes right through June (Vogel 1983:176; Stearns 2003:14, 29).²⁰

Alton Stearns tells how roll dams were used on a swift stretch of the Otter Tail River where the river drops 34-feet in 15 miles. The loggers would periodically open a gated driving dam at the head of that stretch, releasing bursts of water and logs. Before roll dams were installed downstream, the steep gradient of the river allowed the water to run away often stranding logs behind (Stearns 2003:29).

Driving logs down small streams during flash flood events was dangerous work. As the water receded, logs were easily left stranded in adjacent swamps. To reduce the losses and amount of time spent sacking logs left “high and dry,” lumbermen also built dams or dikes on small streams and swamps in the headwaters or cut through ridges high in the valley to capture water above the log drives (Brown 1936:232, 248, Vogel 1983).

Cutaway Dams

Cutaway dams were temporary dams without gates or sluices. Like gated dams, cutaway dams were built to store and release water. But, unlike gated dams, cutaway dams were operated by what might be considered as a timed, coordinated, and human-assisted failure (Frizzel and Allen 1879:1196). Once sufficient water was collected in the reservoirs behind these dams, an opening was made in the dam (perhaps with the use of dynamite), the logs and water were flushed through. The dam, having served its intended purpose, was then abandoned.

²⁰ In 1881, loggers had a system of dams on Hillman Brook and its branches east of Pierz in Morrison County, Minnesota. Most were gated, but some were low-head roll dams without gates, “built to make the water a few feet deeper where boulders obstruct the channel” (Upham 1888b:608).

Dam building on smaller streams was largely unregulated (Frizzel and Allen 1879:1196) and these waterways would now likely fall within the DNR Watershed and Sub-watershed levels 5 or 6. Logging activities on upper reaches of small streams are among the most poorly documented, but archaeological evidence suggests that such areas are where many cutaway dams were built. For example, Sand Creek, a slight thread of water within an area of magnificent forest, is said to have produced a greater number of logs than any similar sized stream tributary to the St. Croix (Durant 1905:648). LiDAR and field surveys conducted during the present study identified cutaway logging dams on this creek, and even its tiny tributaries that made logging the area feasible.

Because the smaller creeks drained much smaller areas of timber, the cutaway dams were only opened during spring freshets and often stranded logs on stream margins (Moon and Brown 1915:177). Rather than build a permanent dam and engineer a gate system, the single-use dams were simply constructed from earth. The advantage of water transport was great enough that these disposable dams were economically viable even if only used for one or possibly two seasons.

In cutaway dam systems, the dams in the uppermost reaches of the drainage were opened first. River drivers armed with peavey poles waited next to the waterways ready to roll timber into the oncoming flood or coax impounded logs downstream. As the water levels in downstream dams began to rise in response, the lower dams were blown out in sequence creating a series of tides that flushed the logs down through the waterway. Dams on feeder streams could be opened simultaneously to increase the flow (Coy 1992). The surging pulses of the streams carried logs to larger waterways where they could be easily driven by conventional driving dams.

Logging Dam Failure

Cutaway dams functioned through planned failure. Unplanned “blowouts” were common for all types of logging dams, however, and in fact almost all failed to some extent long before they were removed (Stearns 2003). When the earthen structures developed leaks or were overtopped by floods the passage of water could quickly carve holes. Once started, water pressure and velocity could accelerate the process of dam failure. The increased pressure of high water could also slide timber framing structures downstream, or lift and overturn the structures carrying away logs and much or all of the dams themselves. The bond between wooden gates and earthen or earth and brush dam structures was typically a weak link, and leaks at this area might compromise a dam. To encourage better dam assembly, limit dam failures, and resolve possible litigation, by 1905, the construction of a dam required a bond of at least \$1,000 to “insure the proper construction and maintenance” (Ralph 1910:50).

Consequences of Logging Dams and River Driving

Any human affront to the natural flow or ponding of water might have unintended consequences. Past studies of the environmental impacts of historic dams has yielded mixed results. The sudden release of water, through either gated or cutaway dams, created temporary flash floods, which might easily equal a 100-year flood event (Sedell et. al. 1991:328). Paradoxically, repeated floods caused by logging dams made some streams less navigable for the running of loose logs. Human-exaggerated floods of water and logs scoured streams beds and sometimes contributed to huge log

jams, especially on larger rivers. A 1870s report to the Army Chief of Engineers noted that, “This irregular, unsystematic interference with the flow of water, while serving the interests of the loggers, is very injurious to the low-water navigation for steamers and rafts, in the navigable reaches of the Saint Croix and Chippewa Rivers especially” (Frizzel and Allen 1879:1196).

Early government examination also found that artificial flooding from dam releases and scouring from logs widened riverbeds requiring more water to maintain their depths (Rector 1953:103). Logging increased erosion in cutover areas carrying sediments into lakes and streams. The demolition of cutaway dams added tons more soil into rivers. While many “improved” rivers gained miles of log navigation, others lost miles or became impassible. For example, between 1849 and 1869 the Tamarack River was improved so that 15 miles became open for log driving. At the same time Rush River in Chisago County lost all 25 miles of navigation (Rector 1953:100). In slack or slow-moving water, river sediments were often trapped or dropped at snags or log jams making large sand bars that further impeded navigation and flow. These effects were largely ignored until the 1930s when conservation projects removed the remains of many old dams and dug channels through sediment deposits to improve river flow (Stearns 2003:27, Department of Conservation 1936).

River channels were often deeply eroded below the aprons of dam sluices by the repeated release or “flashing” of water and logs. At the same time, upstream reservoirs might become clogged with silt (McMahon 2009:96). These effects are often evident at logging dam sites over a hundred years after their abandonment. For example, 1991 aerial photographs of an old logging dam on the Lower Tamarack River in northern Pine County show how sediments collected above the dam and how a large, deep cavity was carved out below the dam (Fig.4).

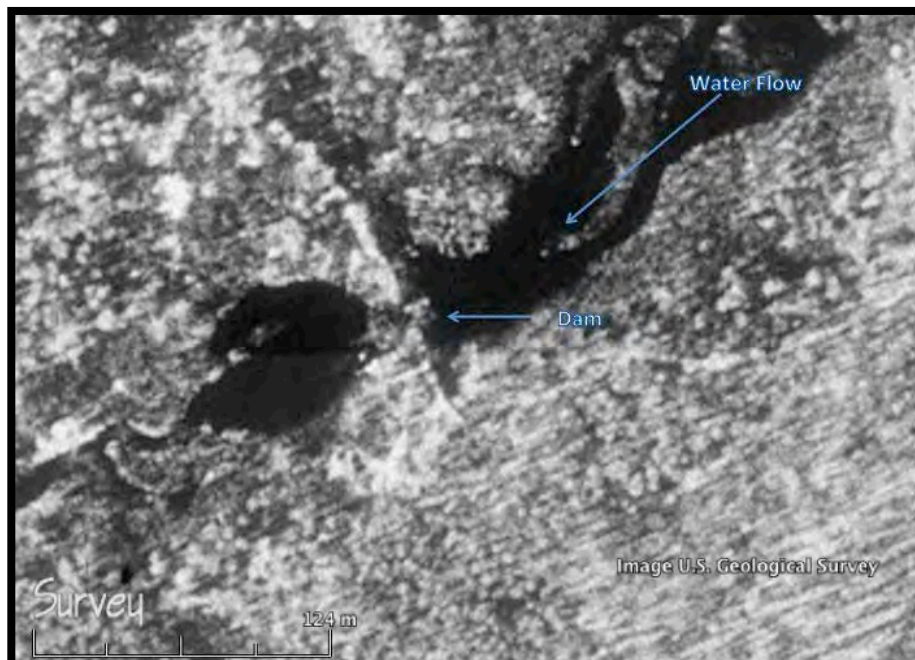


Figure 4: A 1991 aerial photo of a dam on the Lower Tamarack River (from Google Earth, accessed October 24, 2013)

One multi-disciplinary study of the effects of early logging on fluvial geomorphology and fish habitat was conducted for the Hiawatha National Forest in the 1990s. The study, done on the sandy-bottomed Indian River in the Upper Peninsula of Michigan, explored the complexity of reconstructing the position of the river and the nature of riverine environments before and after use of the river for dam-assisted log drives. Archaeologists involved in the study found the remains of ten logging dams on the main stem of the 80 km (50-mile) long river. They determined that:

...logging did have an effect on the river, but it was only temporary. Dam construction introduced sand into the river and created new pools and flats. The river channel was cleared of deadfalls and large woody debris [by loggers] so the logs would not hang up on these obstructions. River drives broke down the river banks, and one catastrophic flood scoured portions of the bed. But for the most part, the river has recovered and is flowing just as it did before logging (Benchley 1997:170).

They concluded that logging did greatly reduce the physical and biological diversity of many parts of the river, and they suggested ways to fix that through various maintenance activities. With regard to logging dam remains along the river they recommended that the remnants be “left in place, as they mark an important part of the river’s history, and they also create pools and riffles which are good trout habitat” (Benchley 1997:170).

Conclusion

Logging dams and dam systems were built by a lumbering industry that had the capital to finance the great expenditure of human and animal labor needed to build these massive structures. Vernacular logging dam construction was efficient, inexpensive and effective for moving logs, but logging dams—like the industry itself—were only intended to last as long as the timber. As the last pines were extracted from Minnesota’s once vast pineries, logging companies moved on leaving the infrastructure, waste, and effects of river driving behind. At remote sites throughout the north woods the remnants of logging dams remain as monuments to a former time; a frontier industry that casts historical, ecological, and economic shadows to this day.

Historic Milling Dams in Minnesota: 1823-1910

“Under the intelligent control of man, the power of water is one of the chief instrumentalities in promoting human comfort and spreading the blessings of civilization. The uses to which it may be turned are so various, and the products for the manufacture of which it is a serviceable agent are of such manifold forms and minister to so many wants of our nature, that the country which is possessed of abundant water power is looked upon as especially favored by Providence”²¹

These were common sentiments in the nineteenth century when moving water provided most of the power not derived from the labor of humans or animals. Mills greatly improved the quality of life. Food and shelter—two of life’s basic needs—could be much more expediently provided for by milling lumber to build homes and grinding corn and grains for meal and flour. When industry was extolled in the Ante Bellum West, it was not great factories that were being praised, but the small enterprises that reduced the discomforts of frontier life.

Milling and Industrial Development in Minnesota

The industrial development of Minnesota was closely tied to waterpower, both in the small towns that proliferated in rural farming areas and at large milling complexes like St. Anthony Falls in Minneapolis. Although the steam engine had been invented, purchasing one required capital, transporting one required railways or good river navigation, and operation required a steady source of fuel (Hunter 1975). All these factors made the use of steam power less practical than falling water in most parts of the United States prior to the Civil War (Hunter 1975:170).

The first mills in Minnesota were able to harness the power of moving water without building dams. Between 1821 and 1823, the military built mills for both flour and wood at the Falls of St. Anthony. Colonel Snelling wrote, “Both of these mills are supplied with water from the falls; it is taken out at the table rock and conducted to the Mills by a race placed on the right bank of the river” (Kane 1987:10). In other words, these first mills were powered by water that was simply channeled into a flume above the falls and then carried to the mill where it dropped on a water wheel.

Similar sites with ample falling water were found at other places in Minnesota. In 1867, the *St. Cloud Journal* boosted the industrial possibilities of waterpower in nearby Sauk Rapids where two flourmills running a total of six run of stone were in operation although a dam had not yet been constructed.²² But these sites were the exception, in general waterpower relied on dams to maintain water levels and divert its flow into mills.

²¹Leffel J. 1874:7

²² *St. Cloud Journal*, Oct.3, 1867, p1. Accessed 10/1/31 at Chronicling America, “Historic American Newspapers” <http://chroniclingamerica.loc.gov/lccn/sn85033526/1867-10-31/ed-1/seq-1/>

In general, saw mills were built before flourmills, simply because early Minnesota settlers had excess wood and needed lumber to build homes. Often a sawmill would be built in a frontier town and then converted into a grist mill once the need for wood declined and a supply of wheat increased following clearing and cultivation. For example, a young miller from Maine, Ard Godfrey, and his partner John Jameson built the first gristmill outside of the St. Croix Triangle in 1851 by reusing a saw mill dam built in Elk River the year before (Frame 1976). Simple sawmills were somewhat easier to engineer because reciprocating saws could be powered more directly from a turning axle and the logs could be taken straight from the water sources. Many sawmills were converted to steam using sawdust and waste wood as a fuel source.

Hydrology and Mill Seats

Gristmills provided a community's long-term need for both flour and animal feed. Whenever land was opened to frontier settlement, promoters identified "mill seats," on any convenient rapids that could be dammed for waterpower. Town site boosters bragged about waterpower opportunities and settlers were tempted with the prospects of great possibilities for milling development (Frame 1980:6-8). In nearby Wisconsin, prospective town sites in some counties were platted near good mill sites (Hunter 1975:78). Presumably, the same process was often at work in Minnesota.

A mill seat was basically a good dam site with space to build an accessible mill. A good dam site had ample water, a well-bounded stream with an elevation drop of the stream bed—usually identified by a rapids. A stream with well-defined banks allowed for a solid dam to be built and a flowage reserved within its bounds. The elevation drop of the streambed largely determined the hydraulic head and thus what kind of wheel could be built. With a greater fall, a more powerful wheel could be used, but high volume flow could also be harnessed by the right kind of machinery.

One complicating factor in harnessing waterpower is the Hydrostatic Paradox: when liquids are contained, the upward pressure of water is equal to the downward pressure regardless of quantity (Evans 1848:79). For any type of wheel or turbine to work efficiently, the water has to be able to quickly escape the wheel so that it will not be constrained by this backpressure. Thus an important element in designing a mill was the need to have unconstrained tailraces where the water could speedily exit after passing over, under, or through a wheel. Thus, the best mill sites also had an elevation drop below the wheel to carry the water away from the power source, especially during high water.

The need for local mills powered by small dams was easily balanced by the available waterpower on the numerous tributaries that branch across the state. As in New England, "The brooks and creeks constituting the smallest class of millstreams were not only the most numerous by far, but the most widely distributed and the most readily brought under power development" (Hunter 1975:80). Prior to the concentration of milling into industrial centers, most mills were built to capture the energy of smaller rivers and serve local economies throughout the state. In Southeastern Minnesota's Driftless Area, the deeply incised valleys that cut through rich wheat-growing farmland provided ideal conditions for milling. There was a surge of claims made and mills built after the Dakota signed the

Treaty of Traverse Des Sioux in 1851 opening millions of acres of land for white settlement in the southern half of Minnesota. As mills sprung up across Minnesota, dam builders had to adapt to a variety of situations. Dams sat at the intersection of hydrology and technology and the mode of hydropower generation affected how water had to be managed. Most mills did not have the luxury of plentiful hydraulic head found at falls such as St. Anthony and Marine. Instead, milling entrepreneurs had to build dams to provide the specific hydropower needs of their enterprises.

Harnessing the energy of impounded water

Most dams impounded an energy bank of water for the mill that could be refilled on a daily basis to power a variety of wheels and turbines.²³ All water-powered mills depended on the force of water moving from a higher to a lower elevation. This basic concept is referred to as hydraulic head or more commonly head. Head is expressed as a linear measurement because it represents the pressure derived from a liquid's elevation. This pressure varies only with the elevation within the fluid and is not dependent upon the volume of water impounded (Roberson and Crowe 1993:36). With a greater elevation drop in a stream bed (increase of head) the pressure and thus energy increases. A milling dam impounding water at a higher elevation stored this hydraulic energy so that it could be transferred to milling equipment as it descended to the lower elevation.

Dam and mill builders recognized another type of head as well: velocity head. The movement of mass—in this case water—creates velocity head. This kinetic energy is the product of the volume of water multiplied by its speed and as it is derived more from natural stream conditions (elevation change and flow volume) and can be more difficult to store. Yet, certain types of dams could divert velocity head to water wheels to power milling equipment.

Water wheels

The most basic type of wheel was the *tub wheel*, a horizontally placed wheel sitting in a basin or channel that rotated by the impulse (kinetic energy) of water against radiating vanes. The advantage of this power source was the ease of construction and the fact that shafts could be directed straight to millstones or reciprocating saw blades without gearing. Another advantage of the tub wheel, in Minnesota, was that it was not exposed to extremes in weather, particularly freezing. The disadvantage was the low efficiency of the wheel, which typically had only the capacity to power one small run of stone and thus was only used in the most primitive flour mills in frontier situations.

The second flour mill built in Minnesota in 1843, north of Afton on Valley Creek, was powered by a tub wheel (Frame 1976:16). Although this style was only used on the earliest mills, it was still powering the Valley Creek mill in 1860 (Frame 1976:27).

Vertical water wheels powered the first real generation of mills in Minnesota. There were three basic kinds: undershot, overshot, and breast wheels. These vertically-mounted water wheels are much more

²³ Mill dams might impounded dramatically less than that that was held by most logging dams as they typically only needed to store enough water to power machinery for a day. Keeping the mill idle overnight gave the reservoir time to refill.

difficult to engineer and build because the shafts had to be geared and translated from the horizontal wheel shaft to the vertical millstone power drive.

Like the tub wheel, *undershot wheels* were rotated solely by the impulse of water pushing against floats on the wheel within an enclosed channel. These wheels were best adapted to situations of good velocity head with high volume and strong current. Only about half of the velocity of the water could be captured and thus the undershot required a much greater volume of water (Evans 1848). The advantage was that it was often much easier to engineer technology for high volume but low head (Howell 1975:128). Substantial dams were not needed to raise the elevation of the water. Instead a simple, low dam could divert the flow down a channel to a turning wheel.

Overshot wheels, on the other hand, created power from the gravitational acceleration of the falling weight of water captured in buckets on a wheel. These were the most efficient water wheels—a well-made overshot wheel could capture 60 percent of the water's falling energy (Frame 1977:29). Overshot technology greatly favored larger wheels because they leveraged torque by multiplying the force of the falling water by the radius of the wheel. Thus, a larger radius could extract much more power from a water source and the percentage of efficiency increased with hydraulic head and dam height. Overshot wheels required the greatest drop (usually more than 10 feet), and the water falling on the wheel also had to be of a great enough volume and velocity to fill the buckets and turn steadily (Evans 1848:66).

To operate an overshot wheel, water had to be dammed at one elevation and then diverted to the top of the wheel in a flume or channel with sufficient size and drop to allow enough water velocity and volume to fill the buckets. Thus overshot wheels required dams that could raise enough water volume

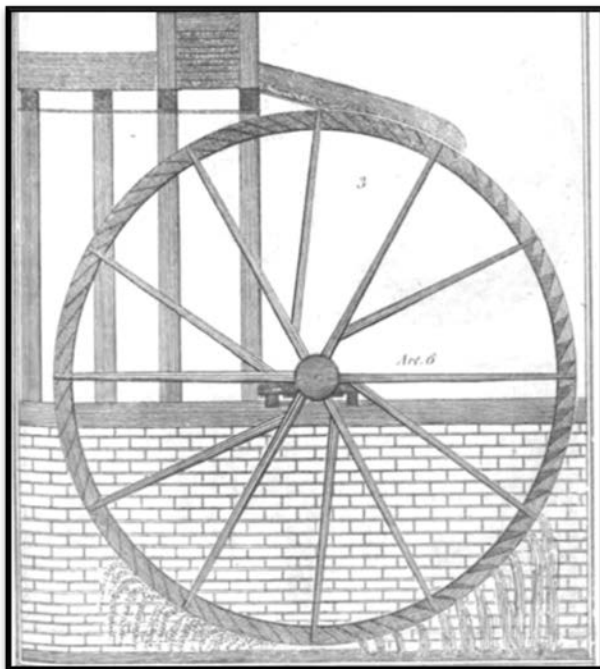


Figure 5: Overshot Wheel illustrated in Evans 1848, note the high flume and the distance from the bottom of the wheel from top of water in the tailrace.

to a higher head and were almost always used in tandem with a flume that diverted water to a water wheel that was installed at a lower elevation. In other situations, a low dam at a high elevation could divert water through a flume, pipe, or even a tunnel to a wheel positioned at a lower natural elevation, sometimes in the basement of the mill. In either configuration, the system was always sensitive to both the hydraulic head and water volume.

Breast waterworks were a type of compromise between these two types of wheels. Water was dropped on the middle of the wheel and they operated in much the same way as the overshot wheel. Lacking the head required by an overshot wheel they relied on a greater flow of water.

Turbines and Dams

Throughout the nineteenth century engineers worked to design more efficient means of extracting energy from water without building ever higher dams and larger wheels. Engineers began developing turbines roughly based on the old tub style wheels with some important innovations in the early nineteenth century. By the 1870s turbines were being mass-produced in multiple sizes and styles and began to outnumber waterwheels (e.g., Leffel 1874, Frame 1980). Reaction turbines provided a major breakthrough in efficiency by converting the potential energy of impounded water (hydraulic head) to kinetic energy with more than 90% efficiency. Reaction turbines produce power by spinning an impeller that is completely submerged and under hydraulic pressure. Wicket gates on the outside of the submerged turbine were manually opened to allow water to be sucked into the turbine, pass through the impeller and flow out the bottom. As the height of impounded water is raised, water pressure and thus water power increased. But, unlike wheels, turbines use all of the water that passes through and have the same percentage of efficiency no matter what the head, so they could be used in hydrological situations with both lower volume and head.

In the illustration below water enters the open wicket gates as shown by the upper arrows, flows through the turbine's hidden impeller, and out the bottom into the stone-lined wheel pit. The base of the turbine must be above the outflow or backpressure will impede power generation. The depth of water above the base of the turbine ("D") determines hydraulic head and power.

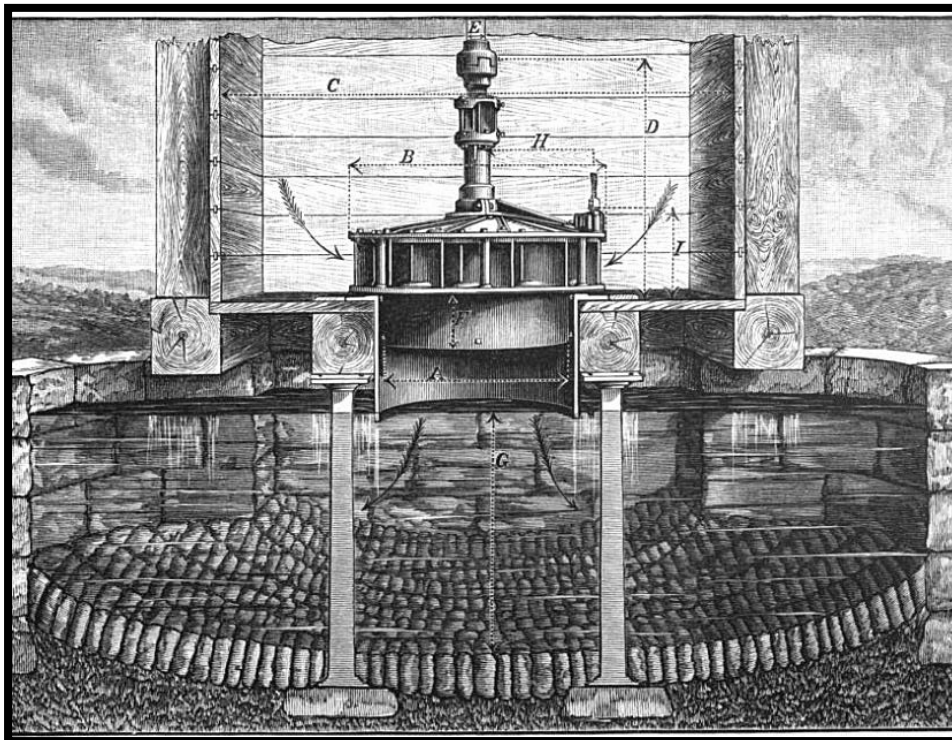


Figure 6: Illustration of a wooden penstock and wheel or discharge pit for a Leffel Turbine. (From Poole and Hunt 1883:45)

The power produced by the impeller is variable and depends on the direction and velocity of flow through the impeller vanes. Both of these variables could be adjusted by opening and closing wicket gates located on the outside of the turbine runner. In this manner the power production of the turbine could be adjusted to account for seasonal changes in available hydraulic head. Even if the water levels behind a dam lowered, the turbine would still function, and by manipulating the wicket gates the power output could be matched to the milling needs.

Not only were reaction turbines more efficient, the design also relied exclusively on hydraulic head and required no flow other than that required to replace water loss through the turbine. In other words velocity and volume was only required to refill the penstock, not to create kinetic energy. This often allowed turbines to be placed at considerable distances from the dams that supplied their hydraulic head. The superiority of turbines was quickly promoted in the milling literature. As early as 1862, Hughes noted the adaptability of the turbines with adjustable outer gates that could control the:

flow of water to the wheel, thus adapting the lines of this turbine to the head of water and amount of work to be done, however varying these may be. The water is taken in at the bottom of the wheel, and every inch of head is made available. In some situations, at different times of the year, the head and quantity of water vary greatly; this wheel is specially adapted for such places (Hughes 1862:61).

The increased efficiency of turbines transformed every mill—and mill dam—in Minnesota. By the time the 1880 manufacturing census was made the number of waterwheels in the state was negligible and by the turn of the century, every waterwheel had been replaced with a turbine (Frame 1979:29-34).

In addition to transforming existing mills, the availability of turbines meant that many more limited mill sites with low head and low volume could be brought under power while sites with ample waterpower could be developed into industrial centers. At the same time that turbines became widely available, the 1870s brought other innovations to milling that created better products but required the capital to make upgrades. Thus a trend in hydro-powered milling was both a proliferation of dam building and a concentration of milling in modernized centers (Frame 1976:23, Fossum 1930). At least 300 mills were built in the 1870s, more than any other decade of Minnesota's history and as a result development of water power in the state doubled (Frame 2013, U.S. Census Office 1880:12).

When turbines were added to mill sites developed under waterwheel technology, the hydrological system had to be modified. Channels that had directed water to wheels could be expanded to serve as forebays that both channeled and stored water prior to being directed to the turbine shafts or penstocks. Wheel pits could be converted to penstocks of either masonry or solid plank construction and the relation of the dam to the power source was also altered. The most obvious change took place at the industrial center at St. Anthony Falls. No longer did mills sit perched on the edge of the dam to catch whatever flow passed over its crest with water wheels. Now water was brought in canals to the

mills built at some distance to the river and then dropped onto turbines located at the bottom of deep shafts up to 50 feet below mills.

Dams at the intersection of hydrology and industry

Although millwrights were not physicists, they intuitively tended to create dams and dam systems that best captured the energy of the water at their particular sites. In addition, some milling guides of the day did discuss these principles and the formulas that could be used to estimate power output (e.g. Evans 1848). After all, the power that millers could capture determined the types of equipment that they would need to build or purchase.

Dam builders had to operate with very limited information regarding the hydrology of the streams they were damming. Around 1909, the State Drainage Commission began to set up gauging stations on streams and collect information of water flow and rainfall throughout the year and make recommendations for the coordinated development of dam sites (State Drainage Commission 1910, Ralph 1912). Before that time dam builders had to guess the mean and high water flow of rivers and hope the dams they built were sufficiently strong to withstand floods.

Dam builders had to consider more than the physical setting and materials at hand. The goal at every site was the same: extracting the most energy possible from the water source. Every mechanism that translated water to energy was useful in unique hydrological situations and a good millwright could match the available waterpower to the best wheel. To power more milling apparatus there was a temptation to raise head with additional dam height. But as dam height increases so does water pressure on the dam raising the costs of dam construction and the stakes of potential failure. Impounded water was stored energy that had to be safely transferred to historic milling equipment beginning with wheels and then turbines. Capturing more power from less water drove the process of innovations in hydropower, leading to improvement in water wheels and turbines.

There is little information regarding the construction of Minnesota's first milldams, but they were likely simple affairs made to impound only enough water to power 1-2 run of stone for a day. There was also an element of impermanence to many of them. Mills were frequently documented, but most dams are only mentioned in regard to destruction by floods or their need to be rebuilt. Millwright experts were brought in to advise the construction of some dams and larger mills, but scores of dams were built using vernacular methods and lay advice. The manual *Construction of Mill Dams, Comprising also the Building of Race and Reservoir Embankments and Head Gates, the Measurements of Streams, Gauging of Water Supply &C.* was published in 1874 by milling trade publisher James Leffel Company and went through many printings. The book contained a collection of illustrated examples of typical milldams—most designed by millwrights and not engineers—that could be replicated in different settings. Both the book and the journal it was derived from diffused folk building styles used by dam builders.

Decline of rural mills

As noted above, the initial industrial development of Minnesota milling was dispersed across the state on rivers and tributaries of all sizes. Sites with huge sources of waterpower with both volume and head, such as the Falls of St. Anthony, were difficult, dangerous, and extremely costly to dam and were only suited to huge industrial complexes with the capital and expertise to be exploited (Kane 1987).

The first dam built at St. Anthony Falls in 1848 was a massive timber crib structure (Kane 1987: 18). Planks covered the upstream face and flumes allowed navigable logs to pass through. In 1858 the rock-filled timber crib dam was enlarged to 2,206 feet long with sections up to 60 feet wide at the base, that were anchored to the limestone river bed with oak bolts (Kane 1987: 43). Because the dam was only 16 feet high from stream base to crest, it did not impound water so much as redirect it, first to sawmills built into a section of the dam above the falls and later to canals that allowed much more hydraulic head to be used. Although the technology was the same as that used on smaller logging and milling dams this massive structure built to redirect the Mighty Mississippi far exceeded them in scale, cost and complexity of construction and incorporated sawmills into the structure.

The quantity of water at St. Anthony and the available head for mills (up to 50 feet) allowed Minneapolis to dominate the milling scene in Minnesota drawing the railroads, a steady supply of wheat, and markets for flour (Anfinson 1989). Profits funded the construction and maintenance of dams, aprons, canals and mills that used the latest technologies in flour milling (Frame 1980). Meanwhile, peripheral mills increasingly suffered from lack of transportation networks, steady supplies of grain, reliable water and large national markets for their flour (Meyer 1956).

Even large outstate concentrations such as the combined Cannon River mills in Faribault, Dundas, Northfield and Cannon Falls had only 8% of the horsepower of Minneapolis (Ralph 1910). Although the Drainage Commission encouraged the development of more waterpower sites, it was no longer profitable to build small mills powered by low head dams. As milling in Minnesota was increasingly a large-scale industry, smaller mills converted to feed mills or even local electricity providers.

Although close to a thousand small water-powered mills, were built during the nineteenth century in Minnesota, only 72 water-powered mills remained scattered throughout Minnesota outside of the industrial center at Minneapolis by 1910 (Frame 2012, Ralph 1910). That means close to 900 rural mills were abandoned and almost as many dams decayed or washed away within a roughly 60 year period. Of the mills with dams that remained, 75% were small affairs. Fifty-five had less than 100 developed horsepower and operated using small dams with only 8 to 15 feet of working head (Ralph 1910). In 1910, all the dams powering the remaining mills had been constructed using traditional, expedient methods of the earlier century (Ralph 1910) and were likely failing unless they were seriously upgraded. By the end of the 1920s, only a handful of solid nineteenth century constructions such as the masonry dam in Lanesboro were still standing as built (NID database).

Interestingly, many of the dams in Leffel's manual were not designed to be permanent. Instead, the goal seems to have been to expediently build first generation dams on small streams that could be easily be rebuilt when they washed out. Another popular book for millers, *The American Miller, and Millwright's Assistant* by William Carter Hughes, which went through at least eleven printings and became a standard reference (Frame 1980:17), noted the variety of simple dams. "There are as many opinions on the proper way to build them as there are milldams in use. Some prefer stone, some clay, and others brush, logs, and every conceivable material of such nature" (Hughes 1862:117).

The section of this report that describes historic dam construction describes many of these dam types. We now expect dams to be solid construction that resist disintegrations or failure, so it is surprising how habituated nineteenth century citizens were to the regular destruction of dams by natural forces. Even milling experts only expected most dams to last less than 15 years. For example the great milling engineer Hughes was proud of his plank dam that, "gives the greatest satisfaction . . . my dam has been built about seven years, and has not given way once in that time (1855:120).

Newspaper articles often reported on the destruction of dams and mills with a sanguine tone. For example, a few months after a local newspaper praised two new mills in Sauk Center the author was already optimistically writing of their rebuilding:

It was here that the freshlet of July swept away two mills that were located with water power, and carried them several miles down the river. This disaster, together with minor misfortunes has been quickly recovered from and in less than sixty days afterward we see a new grist mill and saw mill in operation. The Sauk Centre grist mill has now been grinding some thirty days, and it is worthy of mention that Messrs. Moore & McClure have exhibited no ordinary enterprise in setting in operation these adjuncts of prosperity and thrift so necessary to a newly settled country.²⁴

In 1867, the mill owners optimistically rebuilt. But later, as the milling business became more competitive and less profitable, the loss of a dam often led to the abandonment of a mill, or even the whole town. For example, near Minnesota's southern border, the LeRoy Roller Mill was abandoned after the dam failed sometime after 1911. Millers had used the mill seat on the Little Iowa River since the construction of a saw mill in 1856. The entire business district moved away from the original location next to the mill when the nearby train line bypassed the site, but the mill remained in operation and even upgraded for the twentieth century (Curtiss-Wedge 1911:396). Then, sometime after 1911, the western half of the massive earthen dam washed out taking the business prospects of the milling company with it.

²⁴ Thursday, Nov. 14 1867. *St Cloud Journal*, p.1

The LeRoy Commercial Club raised money to rebuild a new concrete dam at the site in 1925 solely to retain the town's water rights.²⁵ The old millpond filled up once again, but the water no longer powered milling equipment. Instead it became one of Minnesota's purely recreational reservoirs named Lake Louise and the milling site was transformed into a park.²⁶

Rivers give but they also take away. Water energized the initial industrial development of Minnesota by giving power to mills. But the same streams could also destroy the dams that transformed rivers for industry:

This invaluable servant, once it bursts over the bounds which have been set for its action, becomes a destructive scourge, laying waste the very fields whose tillage it had made profitable and bringing to poverty, in an hour as it were, a whole community, whom until then it had sustained in prosperous industry (Leffel 1874:7).

²⁵ <http://www.visitleroy.com/organizations.html#history>

²⁶ http://www.dnr.state.mn.us/state_parks/lake_louise/narrative.html

Federal Relief Dams in Minnesota: 1933-1941

The Great Depression was a period of national financial insecurity, drought conditions, and low water levels. Yet it stimulated an explosion of federally funded dam construction in Minnesota. Even as local economies struggled they managed, by capturing federal-relief dollars for unemployed citizens, to sponsor the construction of more than 300 water conserving dams throughout the state on waterways of every size (Anderson 1991:67).

Although the most intense period of conservation dam construction began in 1936, the movement originated earlier in 1931, with the creation of the Minnesota Department of Conservation. Without this state framework and engineers capable of designing innovative water-control structures, it is unlikely that federal-relief money could have been so efficiently channeled into the hundreds of dams that were built statewide between 1935 and 1941.

The Department of Conservation and Water in Minnesota

Following the environmental impacts that industrial-scale timber extraction had on Minnesota's forests, rivers, and lakes, there was a need for a unified conservation strategy but no government agency to oversee it. Prior to the 1930s, the state's conservation programming was limited to the elimination of forest-fire hazards, wildlife poaching, and standing water in separate departments of Forestry, Game and Fish, and Drainage and Waters (Conservation Commission [CC]1932). The few state parks in Minnesota were administered by the State Auditor (except Itasca, which was under control of the Department of Forestry). As well as having fractured governance, these separate departments were often embroiled in politics.

The State Drainage Commission was created in 1897 to manage the large-scale drainage of swampy "wastelands" into productive farmland (Elazar 1989:342). The commission began cooperating with the U.S. Geological Survey under a 1909 legislative resolution to formulate a plan to manage watersheds that "form one great asset and present one great problem for state supervision" (Ralph 1912). Although the study was charged with collecting information on "the water supplies, water powers, navigation of our rivers, drainage of our lands and the sanitary condition of our streams and their water sheds," most of the reporting from the studies provided information for the industrial development of water-power sites by way of damming rivers (Ralph 1909, Ralph 1912).

The Drainage Commission also sponsored vast projects to drain wetlands for agricultural use and, by 1914 almost three-quarters of Minnesota's northern bogs were drained. Rather than being a boon to agriculture, the results were catastrophic. Drainage projects based on little more than optimism and drain tile created vast areas of environmental and agricultural ruin on infertile peat soils in northern Minnesota (Gardner 2004:176-177, CC 1932:43-45). In the late 1920s and early 1930s, state and federal drainage projects were halted, and farmers stranded with unpaid mortgages on tax-delinquent and infertile land had to be resettled (CC 1932:43-45, Gardner 2004:176-177). Following years of low precipitation, the former bogs became fire hazards and fires fed by dried-out peat simmered for months. Not only was the drainage of northern Minnesota discovered to be a "bitter disappointment" and "folly," but the ditch bonds had to be paid with no revenue source (CC 1932:43).

Ironically, financial collapse in the early 1930s ended up having a profound and positive effect for the emerging conservation movement. In the early 1930s the double disasters of the economic crash and years of extreme drought combined with the relative indifference of U.S. President Herbert Hoover drove the Minnesota electorate to a political party of protest, the Farm and Labor Party (Blegen 1963:522-523). When Minnesota elected Floyd B. Olson as governor in 1930, this change in governance finally found a political leader to champion the conservation movement by enacting legislation to establish a unified state environmental program (Blegen 1963:523-527).

The Conservation Act of 1931 created a unified Department of Conservation with two major objectives: “To bring under one head and correlate all conservation activities of the State and to take conservation out of politics” (CC 1932:9). Thus, the departments of Forestry, Tourism, Drainage and Waters, Game and Fish, Lands and Minerals were united together in the Department of Conservation where they could be more cooperatively and effectively managed. Olson declared a major shift from private corporate extraction to public conservation when he announced the core values of the new Minnesota Department of Conservation: “Commercial exploitation in the past has despoiled our forests, marred our landscape, and dissipated our resources. It has robbed our people of the greater part of their heritage of natural resources. Let us guard what is left diligently and zealously” (Elazar 1989:342-343).

By the early 1920s the State Drainage Commission evolved into the Department of Drainage and Waters, extending their water management beyond drainage. Yet even as annual rainfall dwindled in the 1920s, removal—not conservation—of water remained the department’s focus (Elazar 1989:342). Throughout the 1920s, snow and rainfall was mostly below average. Five solid years of drought leading into 1933 initiated a hydrological crisis (Olson 1934:51). Lack of moisture was the problem facing Depression-era agricultural communities, not how to remove it from fields (Olson 1934:38). The Department of Drainage and Waters had to reverse directions; it was time now to save water by impounding it.

Everything was parched, not only drained agricultural fields. Even the commissioner’s 1932 report sounded ominous: “Whatever its cause, or causes, the steady lowering of the surface and sub-soil water levels, which has been general throughout the state, has created a situation that is well-nigh alarming . . . Entire lakes have dried up completely or become mere swamps or muddy marshes, while many small streams, trout brooks and rivulets have disappeared completely” (CC 1932:46).

More than 200 requests were made to Department of Conservation engineers for lake improvements between 1931 and 1932, and a comprehensive program in coordination with the Division of Drainage and Waters was considered urgent. Because the problems of finance hindered a response, only a few dams were constructed “mostly without cost to the department” (CC 1932:38). State-funded relief programs at this point consisted primarily of organizing clothing drives and fund raising for distribution to needy families; fundamental aid for new conservation projects would have to wait for federal support (Blegan 1963:524).

The New Deal and CCC Water Conservation Projects

With a desperate population anxious for change, Franklin D. Roosevelt easily defeated Hoover in the 1932 presidential election. The real change of policies, though, was assured only by Roosevelt's long-term commitment to federal aid projects, particularly conservation undertakings within the New Deal platform. Weeks after his inauguration in March 1933, the new president pushed through the passage of legislation organizing the Emergency Conservation Work (ECW), allowing the Civilian Conservation Corps (CCC) to be immediately organized by executive order. That summer, the War Department enrolled 12,200 Minnesota men between the ages of 18 and 24 to serve on conservation projects in Minnesota's remote rural areas (Anderson 1993). The CCC's primary goal was employment and support, thus most of CCC funds went into wages, clothing, food, and housing. The Department of Conservation's staff funding, however, was limited to state sources, and it scrambled to organize projects from existing programs that required little in materials or funds to complete.

The first water control project was a drought relief project approved by the ECW that cleared blocked and dried channels of the Red Lake and Otter Tail Rivers. Not surprisingly, the ecological aftereffects of the extraction and transport of timber was still apparent on these rivers. Alluvium dumped into the river channels by years of logging had contributed to silting and the remains of old logging dams were obstructing flow. During the summer of 1933, hundreds of men from three camps labored to clear 348.5 miles of sediment from river channels and the remains of eleven abandoned driving dams to bring water down to the towns of Fergus Falls and Thief River Falls from upstream lakes (Olsen 1934:69-72, Stearns 2003:27). The CCC project had low overhead costs beyond shovels, but the expenditure of labor was huge: men from the three camps put in 36,083 man days of work to finish projects that brought water downstream to thirsty towns in western Minnesota, lowering lake levels by several feet (Olsen 1934:69-72, Stearns 2003:27).

Releasing water from lakes for use in downstream communities raised another issue: Could water in those natural reservoirs be retained through winter and spring for summer needs? The economic cost of crop failure was obvious if not easily quantifiable, but conservationists also wondered about the effects of drought on natural resources. Would exposure of shorelines be injurious to spawning areas in lakes? Would fish die by being concentrated in small areas during cold seasons? Even as the Depression deepened, recreational fishing licenses were sold at record levels bringing much needed revenue to the Department of Game and Fish. But fish depended on stable water levels (Olsen 1934:73). Balancing the needs of lake-resort owners (who continued to bring in millions of dollars in revenue during the 1930s) with downriver power plants (that suffered from lack of water) was further complicated by the drought (Olsen 1934:66, 1936:73).

One thing seemed obvious: Minnesota was the headwaters for several of the continent's largest watersheds, and all the moisture not held within the state's water features drained away:

Minnesota perhaps more than any other state in the nation, should be concerned with using the waters which come to it in the form of rainfall, while they are in reach. . . All waters supplied by rain and snow drain away in all directions. With this picture before us we can better understand why we should be concerned with retaining and storing for intensive use as much as our rain and snowfall as possible before it has passed beyond our reach (Olsen 1935:59).

A program of dam building to retain those waters in natural and man-made reservoirs seemed imperative. In his first hundred days in office, Roosevelt had pushed banking reform legislation and agricultural support through Congress, and the ECW/CCC put thousands of young men to work. But the economy was still in decline. In order to stimulate the economy and provide industrial relief, FDR encouraged the drafting and passage of industrial-relief legislation. On June 9, 1933, the contested National Industrial Recovery Act (NIRA) was passed establishing the Public Works Administration (PWA) and the National Recovery Administration (NRA).

The NRA was designed to support federal-level public works projects, and the Minnesota Department of Conservation responded by planning five major water-conservation projects in the western part of the state: Lac qui Parle, Red Lake River, Roseau Water Diversion, Traverse Reservoir, and the Whetstone Diversion (Olsen 1934: 67). A total of \$7,759,144.08 was requested from the federal government to be matched by \$1,777, 590.89 by the state for these projects (DC, Division of Drainage and Waters [DDW] undated list of proposed projects). Because the PWA loaned money to fund large, new construction projects such as canals, subway systems, and sewer plants that would “prime the pump” of industries that hired skilled laborers, most state and local communities could not meet the thresholds required (Anderson 1991:E-7). In addition, the NIRA was flimsily crafted legislation that created the poorly managed NRA, and the program was declared unconstitutional and abolished by 1935. Yet, the Division of Drainage and Waters had the plans in hand and ready to submit for the next federal appropriations to large projects. Three of these projects were eventually built: the Whetstone River Diversion, Big Stone Lake Reservoir, and Lac qui Parle Reservoir, but with funds from the Works Progress Administration (WPA).

The Works Progress Administration and the Type “C” Dam

Although the CCC provided thousands of jobs for young people, the effects of the Depression and limited success of the PWA and NRA spurred the Roosevelt administration to expand federal relief to local communities. In 1935, FDR extended work-relief programming by creating the WPA. The WPA had no age limit, and so extended opportunity to all the able-bodied unemployed, funding projects greater in scope than the CCC conservation projects. The WPA cooperated with states, providing 70 to 90% of the funding needed for locally administered projects, mostly in the form of wages for laborers (Anderson 1991:60). With this source of investment for local projects, the state Division of Drainage Waters finally had the financial resources to build smaller dams needed to maintain the levels of hundreds of smaller lakes. The funds were available to local units of

government, not just the CCC, and set off an unprecedented rush to build small dams across Minnesota. In 1935, more than 60 projects initiated by the State Emergency Relief Administration (SERA) were transferred to the WPA for sponsorship (Olsen 1936:65).

The WPA guidelines gave precedence to projects that were considered useful, and could quickly allocate a considerable percentage of the budget to wage in communities with relief rolls (Anderson 1991:49). Because the WPA was committed to channeling its money to wages for those on relief, the administration favored projects where the sponsor, usually a local unit of government, could cover the non-labor costs. But all projects had to be reviewed by federal government engineers to ensure their design credibility. States were challenged to draw up plans that were adapted to their local environment and did not have high material costs. For example, in South Dakota, a style of earth dam filled with Bentonite was designed that was uniquely suited to the geology and hydrology, and could be economically constructed from locally available materials (Dennis 1998:20).

In Minnesota, unique dam-engineering challenges needed to be met. The biggest problem for planners was that they rarely had hydrological data for the lakes and waterways where dams were proposed. Minnesota still did not have complete topographic or hydrological maps of the state; stream gauging and lake levels had only been sporadically collected; and even the climate, in terms of average temperatures and rainfall, was poorly understood (Olsen 1936). In 1935, a deadline of September 12 was set for presentation of projects to regional WPA reviewers. Hurried plans and estimates were submitted for review by the Department of Drainage and Waters, but most were held in abeyance due to a lack of practical details for construction feasibility (Olsen 1936:67).

State agencies were anxious to get federal money for statewide dams while it was available but they had a sizable obstacle: Plans for each dam-engineering project had to be individually approved by the U.S. Engineer before the project could be authorized and money allocated (Olsen 1936:66). Water managers and dam sponsors needed a flexible design that could be quickly adapted to most situations for speedy federal approval—and they needed it soon. The solution was an ingenious design that was not technically a dam until removable and adjustable stop logs were placed within its piers after completion. This type of structure was adaptable to multiple local, low-energy settings, and dam-crest height could be adjusted even after construction. Called the Minnesota Type “C” Dam, it was likely designed sometime in 1935 (available blueprints date to 1939). The blueprints are signed “W. R.” (for “Water Resources”), but credit is given to “M. A. Sweger of the Division of Water Resources, who prepared the original sketches from which the tracings were made by the Works Projects Administration” (Frellsen 1941).

The 1936 Biennial Report explained the function of the Type “C” dam:

Storage of water in the smaller lakes is to be brought about by the erection of small inexpensive permanent control works in the outlets of lakes. The word “dam” does not properly describe these structures. They are built of reinforced concrete in such a way as to place the sill or low water control at the same elevation as the bed of the natural outlet and of the same or greater width as the natural stream. Thus, by the simple operation of inserting stop logs the elevation of the lakes may be controlled. To gain approval for the use of the federal relief moneys for the erection of these dams it was necessary to assure the federal agencies that flowage would not become an issue. Thus, the elevations to which lakes may be held by these structures is a matter yet to be determined (Olsen 1936:52-53).

At issue was the fact that the state could not flood lands above the normal high-water line. Yet in much of the state, “normal” levels were a matter of conjecture after years of manipulation by logging concerns and headwaters reservoirs built by the U.S. government; years of drought then further complicated the matter. By submitting to the WPA design variations of the Type “C” Dam, which only temporarily raised water levels, the state was able to postpone the issue of flowage easements and fulfill its objective of building as many “control features” as possible using relief money.

In order to capitalize on federal relief appropriations and secure to the state as many conservation development works as possible, it has been necessary to temporize with many recognized procedures and laws. Limitations which would have interfered with many of these projects have been tempered by the fact that so much of their cost has been contributed from federal funds (Olsen 1936:53).

Thus, the Type “C” dam was not only adaptable to a wide variety of environmental and hydrological situations, it also allowed for a legal dodge. In a 1949 memo, the director of the Division of Waters admitted that the Type “C” was adopted as a standard design when lake levels had not been legally established “to safeguard the state’s rights and permit the construction of the dams while federal funds were still available and the need for relief labor pressing” (Jan 18, 1949 Division of Waters memo).

The Type “C” dam is little more than two C-shaped reinforced-concrete abutments around earthen embankments on either side of the outlet or stream. A concrete sill and small apron was built at the natural base of the waterway. Five-foot-wide bays spanned the waterway in groups of two separated by piers. Both the piers and abutments had metal-reinforced vertical slots where wood or cement “stop logs” could be slid into place. The use of stop logs was modular, and allowed for adjustment of the dam to several levels. No gates were needed, as excess water simply flowed over the crest of the dam created by the stop logs. More stop logs, stored on site in small shacks, could be added in increments to adjust water levels as desired (Figure 7).

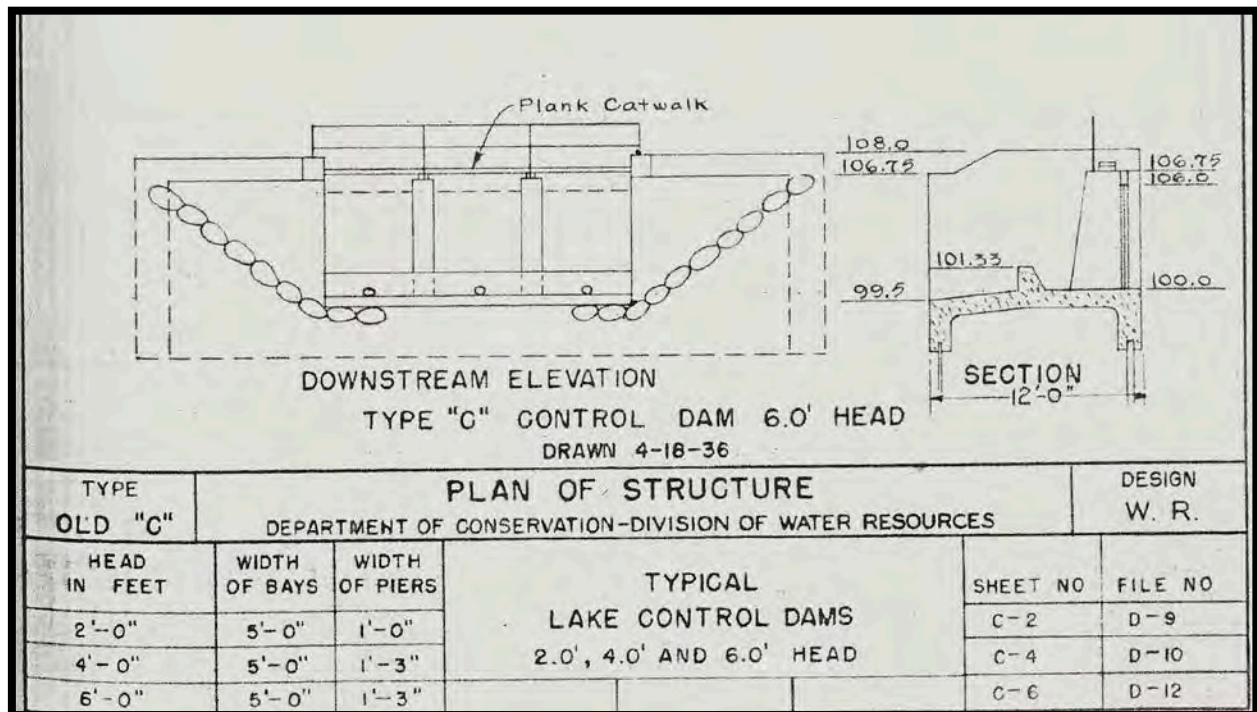


Figure 7: Standard Minnesota Type "C" Dam in Division of Water Resources and Engineering Manual, showing downstream elevation and section without stop logs (Frellsen 1941)

The modular design allowed for several of these bays to be combined to span wide or narrow streams from a minimum of 10 feet to a maximum of 60 or 70 feet. These simple structures generally cost less than \$3,000 to build (Frellsen 1941), partly because they were little more than abutments and required little concrete.

Another advantage of the Type "C" dam was that it could be altered to work with a bridge. In the Type "DB" (dam/bridge), the dam abutments were extended vertically to form bridge abutments that carried I-beam stringers to support the bridge deck (Frellsen 1941). In the drawing above, the core of the water-impounding structure can be seen at the far right. This is the pier with stop log slots connected to the apron/sill. The drawing below (Figure 8) shows a typical dam/bridge that was built at the outlet of Lake Emily near the town of Emily in Crow Wing County. The shared dam element can be seen in section A-A next to the bridge abutment.

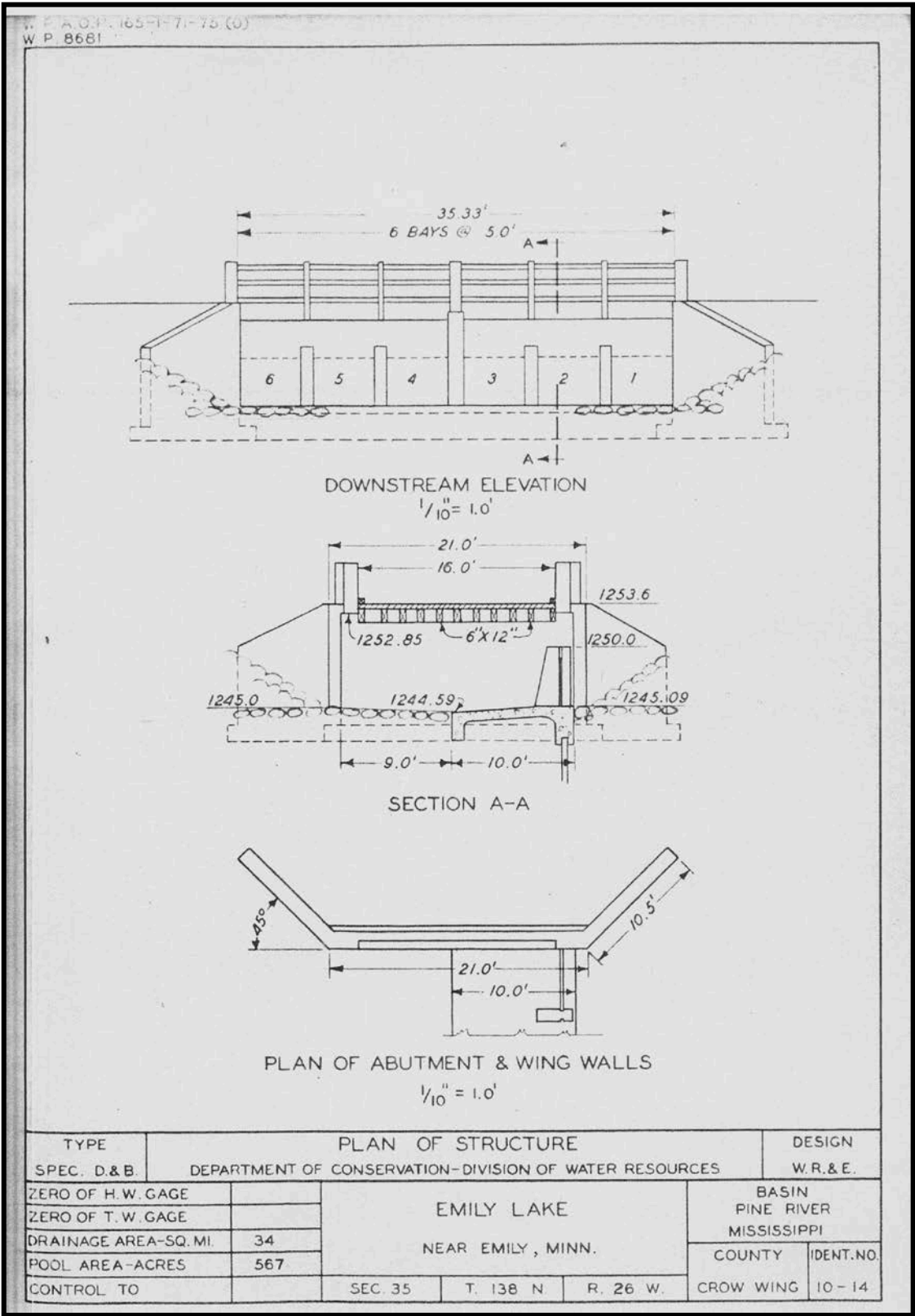


Figure 8: Plan for a typical Type DB, or Dam/Bridge that integrated the modular Type "C" dam with a simple bridge. (Frellsen 1941)

In areas where resorts were crucial to the local economies and unemployment was high, it was big news when WPA funding became available to stabilize lake levels and employ local men on relief rolls. “Lake Levels to be Raised in Cass” announced a *Pine River Journal* headline in January 1936 for a story announcing that the WPA had reached an agreement with the Department of Conservation to build dams for nine lakes in the county. “State Conservationists have been at work on a state-wide plan for sometime and inasmuch as WPA officials found that relief labor is now available . . . it was decided to begin operation at once” (*Pine River Journal*, Jan 23, 1936:1). Type “C” dams were planned for all these lake-outlet dams (Ibid, NID database). It is possible that the Department of Conservation had mobile crews that were skilled in setting up the forms and pouring the concrete, and then local labor was used for the earth moving on individual sites.

The basic Type “C” was built for different applications under various state departments’ sponsorship, such as Forestry, Fish and Game, Drainage and Waters. Use of the Type “C” was eventually expanded to creeks for the purpose of creating public swimming areas in city parks, such as at Pierz, Minnesota. The dams became popular fishing spots and also provided public-access areas to lakes, such as with Mayo and Sibley lakes near the town of Pequot Lakes. These dams are interesting because of their extensive use of local stonework, a feature of some of the more publicly visible dams and a means of acquiring more federal dollars for labor costs.



Figure 9: Construction of a Type “C” dam at Island Lake in Crow Wing County, ca. 1940. The dam has been poured, and unskilled workers appear to be laying cobbles in front of the dam in the background. Note the coffer dam on the upstream side. (Minnesota Historical Society Collections MC10.1 r6)

The WPA preferred to fund labor over material costs, but often the communities with the greatest need to employ local men on relief rolls had the least ability to cover material costs. In order to keep the most men employed for the longest time with the least outlay in material costs, local sponsors hired workers to quarry or salvage stone and integrate them into the dam sites. Although most of the men on the rolls were unskilled, the federal funds could still compensate them to extract and build the stones into dam surroundings. This brought the greatest amount of money in for wages while having the lowest burden of expense on the sponsor (Anderson 1993:60). Thus, an unintended effect of WPA funding was that extensive local materials were often used in building projects.

Dams and dam/bridges designed for the state parks were further “rusticated,” making more extensive use of local stonework on abutments and spillways. This allowed for a distinctive design that coordinated with other park structures. The CCC used men with expertise in masonry to guide the labor of younger recruits and rusticated designs took advantage of their labor while integrating the dams into park landscapes. Figure 10 shows an example of the same dam/bridge engineering structure as the Emily Dam Bridge illustrated above (Figure 8), but with a rusticated surface treatment.



Figure 10: CCC/WPA dam/bridge built at Elk Lake in Itasca State Park. Note rusticated abutments and piers added to the typical Type “C” stop-log slots. (MHS collections photo SD11t r7)

WPA-sponsored dams on Mayo and Sibley lakes and in Pierz all illustrate unique uses of local stone that would not normally be considered of high enough quality for a federally funded project. The Mayo Lake dam, in Cass County, had masonry signage on either side facing a public road and a water-access area crediting the WPA and the Department of Drainage and Waters.²⁷ The cast-concrete signage was placed in low concrete supports embedded with split cobbles. There is evidence that extensive cobblestone paving led down to the lake-access area while cobbled rip-rap still partially paves the creek bed from the outlet toward the road. At Sibley Lake, in Crow Wing County, a broad stairway to the dam was built and the entire west abutment paved—all in local cobblestone. The Sibley Lake dam, like others in the area, appears to utilize a modified logging-dam embankment to support the WPA concrete embankment.



Figure 11: Cast concrete and masonry sign at Mayo Lake from 1936 (tape measure is extended 3 feet). A similar sign on the opposite side of the outlet near the water-access area reads on “Department of Drainage and Waters,” but has been severely damaged; part of it now lies on the dam sill. (July 2012)

In 1935-36, 315 water conservation projects were sponsored by the WPA-ERA in Minnesota; 32 by ECW-Federal Forestry; 60 by ECW-State Forestry; 3 by ECW- National Park Service; 2 by the Department of Highways; and 32 by the Soil Conservation Service, for a total of 444 projects.

As part of these projects, 361 dams were built using WPA support under the sponsorship of a variety of state and local agencies (USACOE 2003:12). Maps and charts of the projects show an intense concentration in Douglas, Becker, Otter Tail, Cass, and Crow Wing counties—a reflection of the numerous small lakes, many with resorts, in these areas (Olsen 1936). Most of these dams followed the Type “C” model, and though use of the design peaked in 1936-37, variations of the dam were built as late as 1968 (USACOE 2003, NID).

²⁷ A September 3, 1936 newspaper article in the *Pine River Journal* mentions this dam: “The construction of another type “C” dam by a crew of WPA workmen was started at Mayo Lake in Cass county last week, according to J.H. Downs, dist. supt., in charge of construction. In addition, the final concrete pouring was completed at Pine Mountain Lake, near Backus and Jewel Lake, near Pine River” (*Pine River Journal* Sept.3, 1936:1).

Today, close to 255 examples of the stop-log dams inspired by the WPA Type “C” survive, including 173 of the classic Type “C” and 20 or more of the Type “DB” dam/bridge combination structures (National Inventory of Dams/DNR database). WPA exceptions to the Type “C” model include large-scale dams such as the Lake Bronson Dam, former New London Dam, and other large-scale higher head dam projects with different means of retaining water, more-complex gates, and spillways.²⁸

End of the Drought and Depression: Beginning of WPA Dam Dismantlement

With the entry of the United States into World War II, the economy rebounded, young men were enlisted into the armed forces, and federal-relief programs such as the WPA and CCC became unnecessary. By the early 1940s, dam-building projects funded by relief funds were no longer needed to keep men employed, and a return to more-typical rainfall patterns made the construction of water-impounding structures in Minnesota lakes less critical.

As early as 1936, the Department of Conservation noted that “a large number of structures are completed or about to be completed without legal authority vested in any state organization for their control or operation” (Olsen 1936:53). Throughout the 1930s and early 1940s, local observer/operators managed the stop logs, but the system was problematic and expensive for the state to supervise. Dam monitors had to contend with maintaining dams, many of which were difficult to access and needed the stop logs removed in fall and replaced after early-spring flooding.

When precipitation returned to normal levels in the 1940s, it became clear that many hurriedly completed WPA dams were raising lakes to unnatural levels. This was problematic because the state could not legally flood land above the ordinary high-water level without acquiring the property, and many “field investigations showed that the state has no right to control water levels above the sill of the dam” (Letter dated April 18, 1949: Frellsen to Wilson). If lakeshore owners made claims for damages, the state could be held liable for the “taking” of land without due process or compensation, and local operators found it difficult to maintain water levels throughout the fluctuating seasons (DNR “Lake Outlet Dams”).

In addition, the stop-log feature, which made Type “C” dams so adaptable, was also easy to tamper with and required extra maintenance. Local lake residents often did not wait for the Department of Conservation to determine how high the state had the right to raise lake levels and “furnished or installed their own stop logs in dams” without the consent of the Division of Waters (Frellsen memo 1/18/1949). Some local residents who desired higher water illegally added stop logs, while others who feared losing shoreline to flooding removed them—all without authorization (a situation that continues into the present).

²⁸ A “Special” Type dam was designed for streams that had a fixed-concrete dam with a curved spillway and “intensity” Tainter gates that rotated to allow excess water to flow out in flood stages, but relatively few were built (Frellson 1941).

In 1948 and 1949, the Division of Waters began modification of “about 50 type ‘C’ dams throughout the state and eliminated annual operation by fixing the stop logs at a definite elevation” (June 1, 1951 Intra-divisional Letter, Sidney Frellsen). The modifications essentially converted the dams back to minimal weirs that could only hold water back at the natural outlet levels. Modification usually consisted of removal of all or most of the stop logs; sawing down the piers at the top of the stop logs; removing the catwalks and support railings; plugging stop-log slots in the dam abutments; and often, the removal of warning signs and “W.P.A. plaques, ornaments or signs” (Inter-office memo re: Revision of Dams August 4, 1948). By 1951, only 34 of 374 lake outlet dams were still adjustable; the rest were either fixed at a set height or completely open to the sill (Division of Waters, List of State Dams for Inspection by the Division of Waters June 6, 1951). In some cases the catwalk was retained, possibly for recreational use.

Despite protests from local residents, the Division of Waters promoted the dam modifications as a “conversion from manual to automatic control” that was more in keeping with natural water levels. Although dams in streams used the same plans, they were more likely to have been sponsored, operated, and maintained by local communities for their own immediate benefit and were less likely to be modified. Examples of these local dams include Silver Creek near Rochester, a dam at Oronoco, and the Skunk River dam in Pierz, which is still in operation.

An example of outlet-dam modification is the Mayo Lake dam alteration made in 1948. At this time, the four piers were reduced in height from 4.8 to 1.2 feet with only two stop logs left in place and the cat walk and plaque removed (Inter-office memo re: Revision of Dams August 4, 1948). In 2013, the cast-concrete sign heralding the Works Progress Administration sat half obscured by sod and poison ivy (Figure 11). At some point, cobbles taken from the extensive WPA stonework were placed across the decaying stop logs to create a small rock weir, covering the pier bases. The cast-concrete Minnesota Division of Drainage and Waters plaque is broken: half lies next to the lake access while its cobble support structure sits fractured next to the water access. Another fragment with the letters “MINN” is just visible in the rock rapids covering what remains of the dam (Figure 12).



Figure 12: Modified Mayo Lake Type “C” dam, Note removal of plaque, gauge, piers and catwalk and remnant of cast concrete plaque in waterway July 2013

Conclusion

Although the Depression was a period of low water and stilted economic activity, the interest in conservation and the availability of both funding and labor made it a period of intensive dam building in Minnesota. From large water reservoirs to tiny outlet dams, the Division of Drainage and Waters within the state Department of Conservation designed, sponsored, and built dams of almost every scale to impound water on lakes and streams throughout Minnesota.

Some large-scale dams were built in Minnesota using federal funding, but the dam design with the most widespread use was the Minnesota Type “C.” An innovative structure unique to Minnesota, it was adapted to a myriad of hydrological and cultural settings throughout the state. Many of these dams are showing signs of aging, and many no longer impound water, yet a few preserve the legacy of federal-relief-sponsored construction throughout the state’s waterways.

Illustrated Historic Dam Construction Techniques

Most historic dams built for logging and milling were expediently built using materials on hand. For this reason, many are hybrids of the types discussed below. Logging and milling dams show adaptation of similar vernacular construction techniques to solve different engineering problems. For example, many log driving dams combined earthen barriers with timber crib structures.

Between the 1850s and the 1870s, the leading published dam hydrologists were millwrights such as Leffel, Evans, and Hughes who educated themselves in order to personally design and build more effective structures. The influence of these experienced-based experts is evidenced by the fact that their books, which described existing dam structures, went through multiple printings (Leffel 1874, Evans 1850, Hughes 1863).

In the later nineteenth century, larger scale dams were needed to power industrial centers, provide water for growing cities, and support large-scale navigation projects. While failures of small dams might only damage a mill, larger constructs could damage entire industrial developments or settlements. Thus, as the scale of water impounding projects grew, dam building increasingly shifted from vernacular plans to engineered construction. For example, the first dams at St. Anthony Falls were simple timber rafter-type constructs designed by millwrights, but following calamitous breaches of the falls between 1869 and 1872, the milling enterprises increasingly looked to educated engineers such as De La Barre to assist in area-wide waterpower development (Kane 1987).

By the end of the nineteenth century, American dam engineers began to more rigorously examine the largely theoretical field of applied science dominated by English and French engineers (Billington et al. 2005:453, 54). The structural theories were little tested, thus late nineteenth and early twentieth century dam designers looked to successful examples of executed designs, both at home and abroad, for guidance. Influential dam construction manuals continued to rely on empiricism, adapting proven methods to new settings—and attempting to understand notable failures. One of the most influential of these books was *The Design and Construction of Dams: Including Masonry, Earth, Rock-fill, and Timber Structures* first published by Edward Wegmann in 1888 and followed by eight updated reprints as late as 1927 (Wegmann 1899, Billington et al. 2005). In the introduction to his approach Wegmann stated that

The theory of masonry dams is based upon a few simple principles and conditions; the mathematics, however, to which they give rise, when applied to the design of an economical profile, are rather appalling. . . . In contradistinction to these scientific methods. . . the writer has thought that a book giving the details of the method employed, and information about masonry dams in general, might be of interest and practical value to engineers (Wegmann 1899:iii-iv).

Wegmann's books disseminated the mathematical modeling that calculated the stress of dams—but more important than the theories—the books presented practical applications of the scientific thinking.

By the early twentieth century, there was a greater understanding of the needs for engineered structures, especially following notable dam failures such as the one that caused the Johnstown Pennsylvania Flood of 1889, which killed 2,209 people. In addition a new building material became readily available to revolutionize construction, concrete. Many historic dams were rebuilt using concrete particularly after 1910.

For these reasons there are not defined styles associated with any one construction technique or historic context for late nineteenth and early twentieth century dams. Instead, there was a tradition of “cutting the coat to the cloth,” using materials at hand, and proven techniques in useful combinations to solve unique local problems.

In contrast to the mix and match diversity of many historic water impounding constructs, WPA dams, were built using a consistent modular design adapted slightly for different settings.

Brush Dams with logs and gravel

Dams made from brush, stone and logs varied from simple constructs of just a few feet high to large and complex structures with adjunct features. These simple dams could only raise the water level about three feet, and needed broad bases, up to 40 feet long. Though they could not impound high water levels of water, they worked well to divert flow, especially for millraces, creating good hydraulic head. Leffel’s 1874 treatise on milldam construction describes how such a dam was built:

In constructing the dam, the first step taken was to throw in large quantities of brush, which was piled up until it reached, as it lay in its loose state, a height (sic) of ten feet or more. Boulders and coarse stone were then thrown in, crushing down the brush, and toward the top of the dam finer rock and gravel were put in. The brush and stones, being thus piled and mixed together, had the effect to hold each other in place; and it should be observed that the brush was of all sizes, trees and saplings, some of them forty feet in length, being laid in with the butts down stream (Leffel 1874:90).

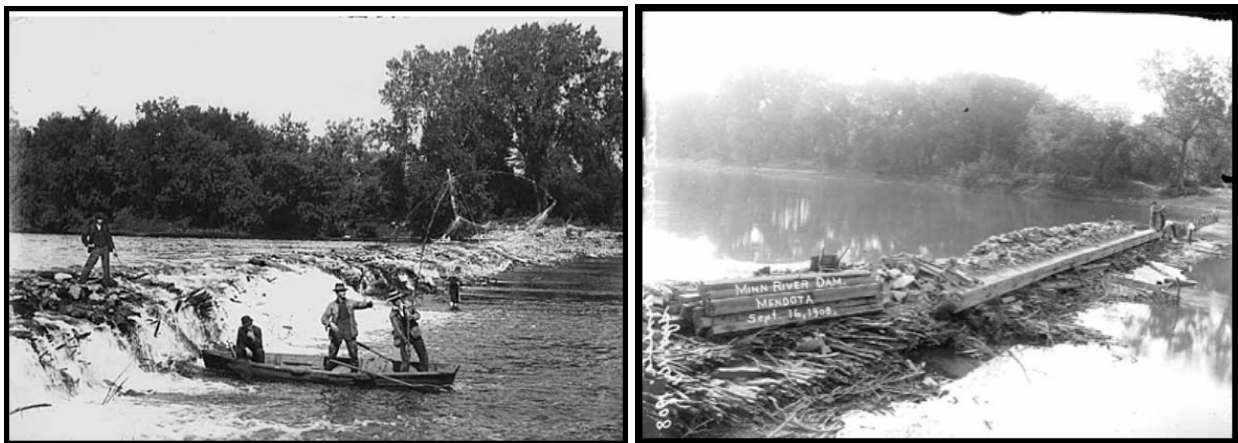


Figure 13: Brush and stone dam with fish traps in Mendota 1895 and under repair 13 years later (Minnesota Historical Society collection)

Saplings were sometimes put in with the larger root side downriver so that the stream had to gradually climb the dam, making it resistant to downstream force. A brush and rock dam could channel water into a hydropower channel, assist upstream navigation, or support fish traps. A simple brush and stone dam was easy to rebuild after flooding and could increase in size by trapping sediment or floating bogs, but they could not support gates and were impractical for logging dams.²⁹ Wooden stakes were often used to pin the brush to the streambed. More complex brush-based dams are also recorded. For these dams, layers of brush and sod appear to have been layered systematically to impound water while timber crib structures anchored within the structure supported gates.

Brush and log dams are mentioned several times in the 1880 waterpower census of Minnesota. They could be improved with plank coverings and hydraulic head increased by diverting water into a canal (Greanleaf 1887). For example, a dam on the Minnesota River at Granite Falls was described in the 1880 waterpower census: “An old log and brush dam gives a head of 4 feet, and a race running along the left bank 600 feet increases the head to 11 feet” (Greanleaf 1887:191). By the time the Drainage Commission made their first water power report in 1909, only one brush dam is mentioned (Ralph 1909: 317).

Loose Rock Dams

Loose rock dams could be built in a similar manner to brush and stone dams and were useful where stone was plentiful. Large rocks were simply placed in the river and then gravel and other finer particles were added to decrease permeability. To increase water-resistance, the upstream side could be covered with planks, earth or other materials. One advantage of loose rock dams over earth fill is that leaks do not lead to rapid erosion and failure. Loose rock dams cannot usually raise more than 5 feet of head, but the State Drainage Commission recorded that, “The Jarrett Roller mill has a loose rock dam 7 feet high which diverts water into a canal several hundred yards long leading to the mill. In this mill is installed a 48-inch Leffel turbine of 60 horsepower capacity under the available head of 11 feet” (Ralph 1909: 303).



Figure 14: Modern loose rock dam with a head of about 3 feet built to raise lake levels at Pine Lake near Cross Lake, Minnesota for recreation. (July 2013)

²⁹ Wing dams of this construction type were commonly used to maintain a thalway (i.e., the fastest flowing part of a river) speeding the flow of water and reducing sedimentation. In Minnesota, brush wing dams were built to aid navigation particularly in the Mississippi River.

Timber and Timber Crib Dams and support structures

Timber crib dams used locally available materials to make a variety of simple to complex structures capable of damming up small to large rivers. Timber dams were considered the cheapest and easiest to build and when well built and maintained could be expected to last from 5 to 50 years (Craik 1877, Creager 1917:15). Another advantage of timber crib construction was its ability to conform to unstable streambeds as it settled. As the rock fill gradually sank into spaces in the foundation, more rock and gravel could simply be added to top off the crib structures. Timber dams were not built to be watertight. In fact, movement of water through the structure was essential for preservation of the timber (Creager 1917: 15). Thus, a disadvantage was that they were sensitive to failure in settings where they seasonally dried out and were exposed to the elements. They also wasted water.

The tradition of building timber dams was common and continued well into the twentieth century for both expediently designed vernacular structures and semi-permanent engineered dams. Some, such as the Nevers Dam on the St. Croix near Arcola, and the dam at the Falls of Saint Anthony were highly-engineered complex structures (Daniels 1990). The timber crib dam on the Mississippi River in Minneapolis was 40-50 feet wide at the base and cost 25,000.00 to build in 1871 (Greanleaf 1886:176). In some instances a timber dam was intended to be temporary and to serve as a coffer dam for a later masonry structure (Creager 1917:15).

There was no one type of timber construction, rather a pragmatic approach was used that adapted elements for specific settings (Leffel 1874). All cribs had to be anchored to prevent sliding or overturning. Timber frame dams were usually weighed down with rock fill and were usually pinned to the streambed as well. On remote sites, wooden pegs were sometimes used, more frequently, timbers that served as sills were pegged to the streambed with iron stakes or rods. The sill at the St. Croix Lumber Company Dam Site (21LAOg) for example, was pinned down with iron spikes (Schoen 2004). On large dams on soft-bottomed streams, such as Nevers Dam, extensive pilings were driven into the channel base to anchor the crib structures.

Both milling and logging industries built timber crib dams. Logging dams funneled the water and logs through large gates and extended log-lined sluiceways or aprons in the middle of streams. Excess water was also released through these facilities. Timber framed milldams usually diverted water to a water-power raceway next to the natural stream and allowed excess flow to simply pass over the crest of the dam. Logging dams typically used timbers that were hewn or squared off on site, and not dimension lumber.

A basic type of timber dam was the *rafter type* used for milling and logging dams into the twentieth century on small to large scales.

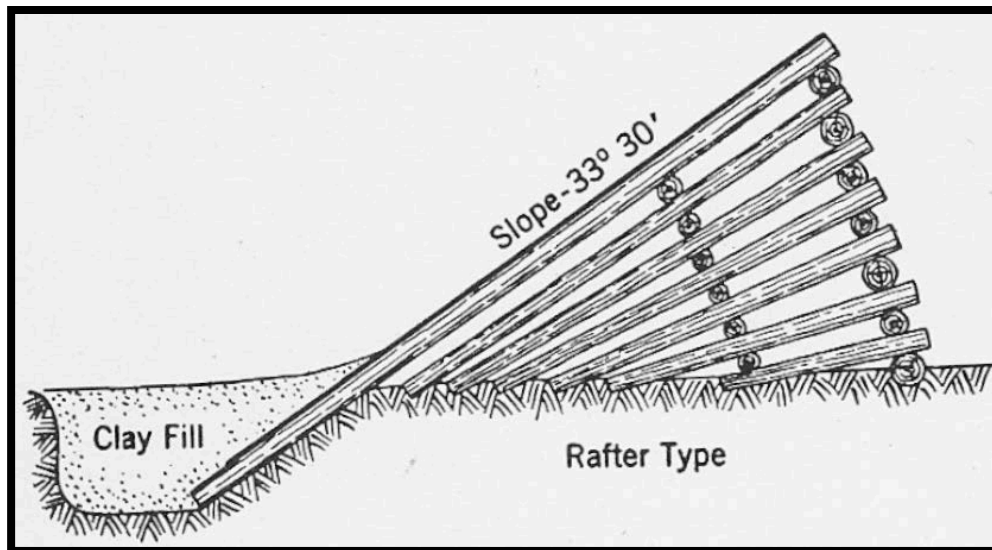


Figure 15: Basic Timber Rafter construction method from Brown (1936)

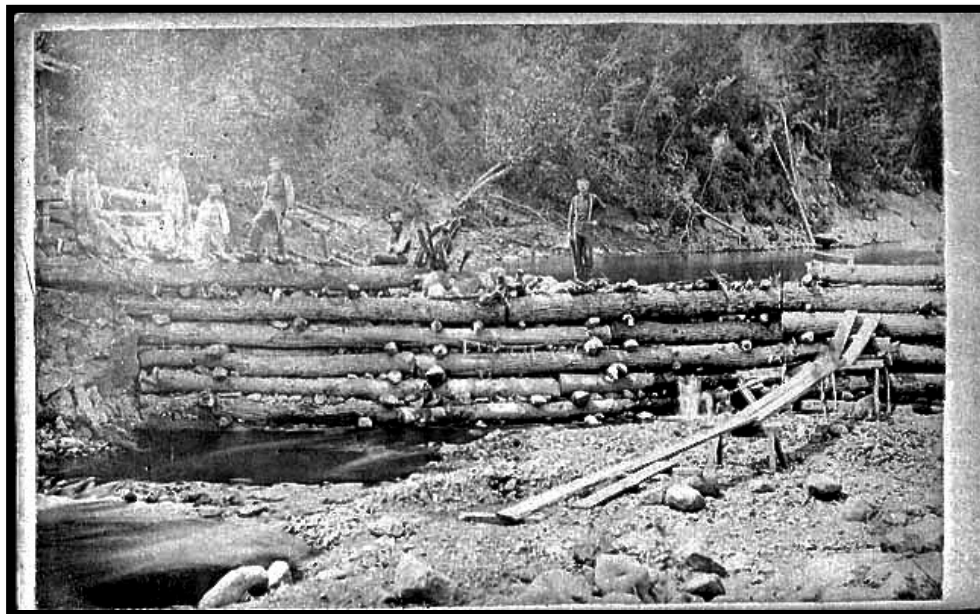


Figure 16: Redwood Falls Rafter style Timber dam from circa 1869 (MHS Photo HD5.5W r2)

A sturdier type of *timber crib* dam was built with substantial horizontal log structures filled with stone and earth for mass and water resistance, and pinned to the stream or riverbed with pilings or iron rods.. Photos and books illustrate a wide variety of crib structures some of which stood 6 to 18 feet high. In some versions the upstream sides of the dams were covered with plank sheathing embedded in the riverbed or even with brush or earth.

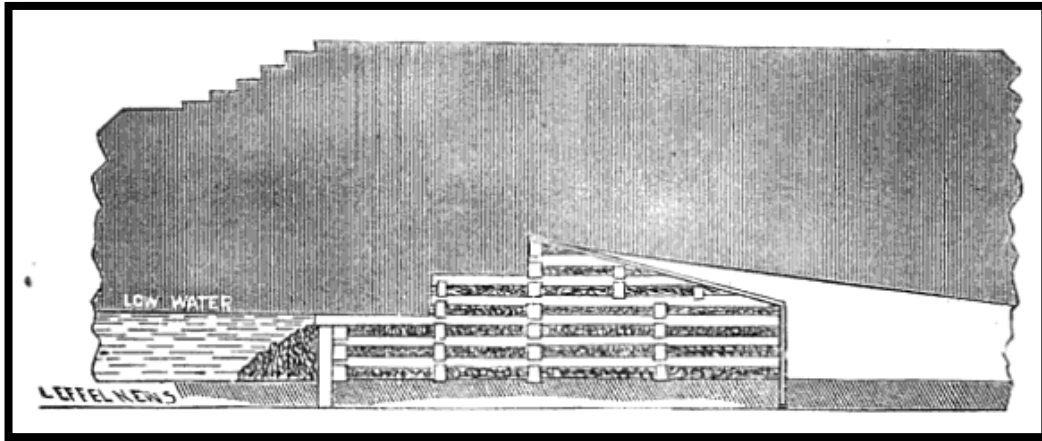


Figure 17: Side plan of a rock filled crib dam, with upstream plank covering. This was a common dam type and was probably used at Schech's Mill up to the 1920s. (from Leffel 1874:152)

Timber dams could last for last 4 to 16 years, but if consistently kept under water they might last up to 50 years or more. Cracks were commonly caulked with moss, rags or other organic materials (Brown 1936). Filling the cribs with rock and then fine gravel made the structures hold water (Wilson 1893:115). Rock-filled cribs were also used as foundations for dams with masonry superstructures (Wilson 1893:124). The dam at the St. Anthony milling district was a timber crib construct (Kanbe 1987:43). The archaeological remains of a crib dam built for milling were recently found in the Minnesota River at Granite Falls after removal of a downstream dam lowered water levels.

Timber Crib Dam Elements

Crib piers, constructed of horizontal logs, were sometimes built at the river's edge as embankment reinforcement for timber, earth and plank dams. They were wedged at the edge of banks, filled with rock and gravel for stability and held in place with gravity, pegs, or pilings.

Crib Elements in Logging Dams

Log driving dams had gates and sluices to control the release of water and logs. The floors of a sluiceway (spillway, log chute, or flume) were made of heavy timbers laid lengthwise in the stream and commonly pinned to the sill with wooden pegs. A sluiceway might be 5 to 12 feet wide and up to 40 feet long, the downstream end acting as a protective apron for the streambed to ensure that water and logs exiting the gate did not undercut the box or the wings of the dam and (Stearns 2003:14). The

side of the sluiceways were usually timber cribs, timber frame or plank walls. When the water was too high for the sluice box to be constructed in-stream, it was sometimes built onshore and then sunk in its proper place (Stearns 2003).

The sluice was typically closed with a heavy wooden control gate, a plank door that could be raised and lowered with an overhead windlass (Vogel 1983, Brown 1936:236; Coy et. al. 1992). Other types of gates, including a hinge-style gate, were also used (Ryan 1976:56). Some dams were gated with just stop logs. The stop logs:

are heavy planks, probably 6 x 12 inches, which spanned the flume and slip into a slot [end slots] for that purpose. These were placed one on top of the other and the water ran over the top, holding a permanent level. Sometimes they were placed five high (Stearns 2003:14).

The bottom or sill of the sluice box was usually located below the normal low water level of the lake or stream to be impounded. In that manner, when desired, all stored water behind the dam could be drained (Brown 1936:240). This arrangement dictated that the dams be built during periods of low water. Because of their size many driving dams were also used as bridges. One of the best descriptions of the construction and operation of a gated driving dam appears in Alton Stearns book on logging on the Otter Tail River (Stearns 2003:14).



Figure 18: 1912 River Driving Dam at Clam Falls on the Clam River, Wisconsin. The gate on the right is swung up and open. Cribs support the sides of the sluiceways. The dam itself is an earth-filled timber crib that transitions to an earthen dam. The gates are constructed from 8" by 8" timbers. (MHS photo HD5.41 p 22)

Except for ropes, iron spikes, and other metal apparatus, these dams were made of all natural, locally available materials. The most common dams were earth, rock, brush, and timber constructs sometimes built using these materials in alternating layers. Only a few iron spikes to pin the gate to the stream bed and ropes to raise the gates were not made on site (Stearns 2003:14, 27). Most

wooden elements of dams probably lasted less than 8 years often leaving few traces except on smaller continually flowing streams (Brown 1936:236).

Earthen Dams

Earthen dams are the oldest type in the world and rely upon their weight (gravity) and friction to stay in place. (See more on gravity dams below in Masonry section.) Earthen dams tend to have large mass, with broad bases, often 2-4 times greater than their height. Most historic earthen dams found in Minnesota are the archaeological ruins of logging dams, none of which currently function as they were originally intended. Earthen dams can be extremely stable in the proper setting, but easily fail due to erosion if overtopped.

Water...should never be permitted to flow over the face of a loose-rock or earth dam. The outer slope of an earth dam is its weakest part, and if water is permitted to top it will speedily cut it away and cause a breach (Wilson 1893:301).

Engineered earthen dams typically have a hydraulic fill core of moistened earth pumped in place or a “puddle” created by thoroughly wetting and mixing clay and gravel and then compacting the material into an “earthen concrete” (Bassell 1904:14). Historically, puddle was often dumped into a trench, sprinkled with water and compacted in place by horses. Logging dams were not meant to be permanent and were likely built with any available nearby earth using draft animals to compact it in place (Bassell 1904).



Figure 19: Earthen Logging Dam abutment on Sand Creek, a small tributary to the St. Croix River. (April 25, 2013)

Modern earthen dams always have a means of removing excess water, usually sluices and outlet pipes or tunnels (often well removed from the dam structure to avoid seepage). Historic earthen dams, however, usually relied on a single, manually operated sluice gate. Earthen mill dams need

sluice gates to safely release excess water and flush away silt from head gates. Earthen log-driving dams needed a gate or sluiceway to move water and logs downstream and to release water pressure. Logging dams used timber gates that were wedged into the earthen dam. Squared timbers (typically 8 X 8 inches) with cross pieces mortised and pinned together at the top created a box structure to support a gate. These uprights were pinned to the sill or connected to timber cribs at their sides (Stearns 2003:14).

Although sluice gates acted as a release valve for water pressure above the dam, they also introduced stress to the earthen dams by funneling water next to the gates, which could never be completely bonded with the earthen segment of the dam (Wilson 1893). Seepage in earthen dams erodes expanding voids in the structure. As the volume of water leaking increases, the integrity of the dam is weakened. Many logging dam “blow outs” were likely caused by this seepage and erosion between the dam gate and the earthen dam.

Cut-away dams, had no gates and were often opened or deconstructed with dynamite. These dams will only preserve the earthen water impounding barriers. Because wooden gate features in older earth dams that are not permanently underwater are usually decayed, it may be difficult to distinguish between an earthen dam that released water as a cut-away, and a stop log, or gated dam.

Example of Earthen Log-Driving Dam

The Tamarack Logging Dam (21PN096) preserves many aspects of a late nineteenth century earthen log-driving dam. Located on the the Lower Tamarack River in Pine County, it consists of two long, projecting earthen embankments and remnants of a central wooden sluicing/gate structure. The northwest embankment extends 309 feet, and the southeast is 142 feet long. The former sluice gate area at the center, now partially washed out, is 25 feet across. Thus, the total length of the structure is roughly 476 feet.

The dam is approximately 15 feet in height, 10 feet wide at the top and about 25-30 feet wide at the base (depending on topography). Borrow pits in the higher ground at the outer ends of the embankments provided over 5000 tons of earth needed to build a dam of these dimensions.

A rapid now flows through the former dam structure with a drop of about 1 foot. The embankments on either upstream side of the washed-out dam are covered with deeply sodded cobble rip-rap, especially near the center. One area on the northwestern side of the dam embankment has signs of overtopping and erosion, from the time period that it impounded water.

Some sluiceway remnants are extant at the center of the former dam. A square hewn timber is pinned or pegged to the streambed. Large drilled holes in that timber may have been used to stabilize other dam elements, including the sluice floor and the center uprights of a sluice. Two more squared timbers are secured on the southeastern side of the dam opening one with two drilled holes and a hand forged iron spike. These timbers likely supported the eastern side of the sluice.



Figure 20: Cribwork timber at Site 21PN096 with peg holes affixed to the middle of the streambed on the Lower Tamarack River. (May 2013)

Dam failure has swept away the gate-box superstructure leaving only some timber sills pinned to the stream bed. Remains of timber crib structures are immediately downstream of the dam center on either side of the stream. It appears that the timber crib structures filled with large stone cobble ballast on the western side of the stream were overturned when the dam “blew” falling into the center of the sluice. Compare to the photo of a logging dam in Figure 18 above.

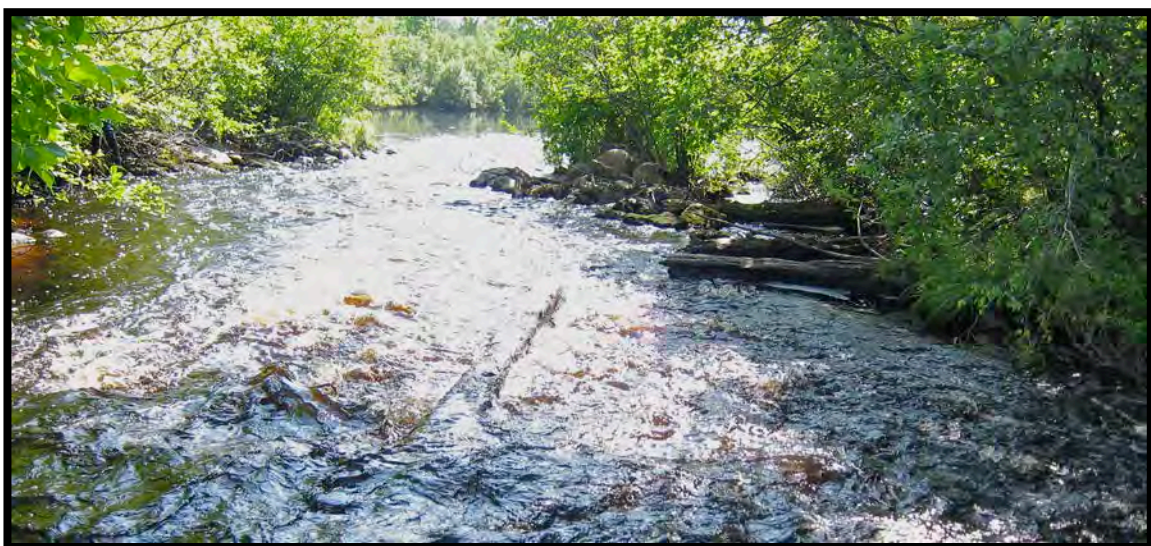


Figure 21: Tamarack Logging Dam (21PN096) ruins facing south. Timber with a center sill pegged to the stream bed is in the middle of the stream. Remains of crib structures and spilled rock ballast are visible just downstream. (May 2013)

A number of smaller poles are fixed in place parallel to the river's flow at the downstream terminus of the sluiceway or apron . Although these poles are probably still connected to a dam sill, it is not visible.



Figure 22: Farthest downstream remains of the log apron at the outlet of a log sluice at the Tamarack Logging Dam (21PN096), facing west on southwest side of ruins. (May, 2013)

Earthen Milling Dam

The dam at Lake Louise in Le Roy, Minnesota preserves a record of changing dam building techniques including remnants of a nineteenth century earthen dam and sluiceway. The original construction of the 1854 saw mill dam was not recorded, nor was that of the grist mill that replaced it. By the late 1890s, however, two turbines had been installed, most likely powered with water from a new, large earth-fill dam, part of which still remains (Frame 2013, *Mower County Transcript* 28 September 1898:9).



Figure 23: Lake Louise Dam at the former site of the LeRoy Mills facing west. In the foreground the limestone and turf (upstream) and concrete (downstream) facing of the earthen fill dam is visible. The 1925 reconstructed concrete dam is in the background as are the modern sheet piling abutments. August 1, 2013.

Earthen dams cannot have water spill over their crests and must have discharge sluices to divert excess flow. Dams in sediment-filled streams, such as those in farming areas, often lose the ability to impound enough water volume for hydropower. A dam building manual contemporary with the Lake Louise Dam recommended that sluices extend to the dam base or sill to flush out silt:

Scouring- or undersluices are placed in the bottom of nearly every well constructed weir or dam, at the end immediately adjacent to the regulator head. The object of these is to remove, by the erosive action of the water, any sediment which may be deposited in front of the regulator (Wilson 1893:133).

At the Lake Louise Dam, a massive sluice appears to have been built to release overflow in flood stages, and scour away sediments. Remains of the “regulator” gates that would have funneled water into the mill turbine area are upstream next to the sluice gate (Skarr 1997).



Figure 24: Lake Louise Dam at the former site of the LeRoy Mills facing north in masonry sluiceway with mill ruins to the right and sluice wall in earthen dam on the left. The upstream side of the sluice appears to have been repaired, reconfigured and narrowed circa 1925 and is closed with the replacement metal gate. August 1, 2013.

Earthen dams are extremely sensitive to erosion following overtopping (and seepage next to sluiceways). To counteract this effect, the upstream side of the Lake Louise Dam was paved with a side-laid limestone facing.³⁰ Even with this huge sluice/waterway to release excess high water, the western half of the dam failed sometime after 1911 and the milling enterprise appears to have been abandoned at that time. The LeRoy Commercial Club funded the construction of a new concrete dam where the earthen dam failed. At the same time, a concrete bridge appears to have been built over the old sluice way and the sluice gate area replaced with new concrete and a metal gate. (For more information see page 47).

³⁰ The original downstream side has likely eroded and has more recently been protected with rubble plastered over with sloppily applied concrete.

Plank Dams

One of the most popular types of milldams in the nineteenth century was the plank dam. They were sometimes built with timber crib abutments. Multiple versions are illustrated in Leffel's *Construction of Mill Dams* (1874). It was also presented as the best dam for sites with soft stream bottoms and limited stone materials in Hughes' *American Miller* (1862) and the only dam in Craik's *The Practical American Miller and millwright* (1877).

A plank dam required more money, effort, and skill to build and anchor to the stream floor than a brush and rock or simple timber dam, but they were less expensive than stone construction. If the mill was successful, the dam might later be rebuilt with masonry, and finally concrete.

The photo below shows a milling dam in Twin Valley, Minnesota with “log-pens” (crib reinforcements) on either side, and a central plank dam with wooden buttresses similar to that described in nineteenth century manuals. When plank dams fail, the superstructure completely washes away leaving only stones from the cribbing and some of the streambed foundations or sills. There are no extant functioning examples of this dam type in Minnesota today.



Figure 25: Milldam with timber crib abutments and a plank dam ca 1920. (Minnesota Historical Society Collection negative number 79747)

Masonry Dams

Most historic dam building methods used stones to add mass or weight and protect surfaces. True masonry construction in the nineteenth century depended on the stones, with or without mortar, laid in place to create a stable, water resisting structure. After Portland cement became widely available masonry dams increasingly used it to cast dam structures.

Stone

Like other vernacular building methods, stone masonry dams were built in a variety of styles. Based on the “best practices” in milling technology, the variant styles were disseminated both through construction and use, as well as in the trade literature.

For thousands of years, builders intuited that masonry dams gained much of their resistance to water pressure from their weight. The force of gravity pulls the mass of dams vertically down to oppose the horizontal stress from the impounded water. For this reason, dams that rely on their size and weight are referred to as *gravity dams*. The basic principle underlying the tradition of masonry dam building is elementary: use as much stone and mortar as possible to build a dam that will rely on its mass to not overturn, slide, or break (Billington et al. 2005:50). Thus, gravity dams need to be bottom heavy to resist tipping, have a solid connection to the streambed ensuring that friction will prevent the dam from sliding, and have the strength to resist stress.

Building a strong masonry structure depended on several factors: good stone building materials, a solid connection to the channel floor and firm banks, and a design adapted to the setting.

The below example is a cross section of a dam built on the Housatonic River in New Hampshire for a milling district. A massive construct that still stands, its basic building method was similar to that employed in all types of construction—with finished stone containing a mortared rubble core. The major difference from a masonry wall was the angle of the walls and use of gravel and earth to support and coat the upstream side.

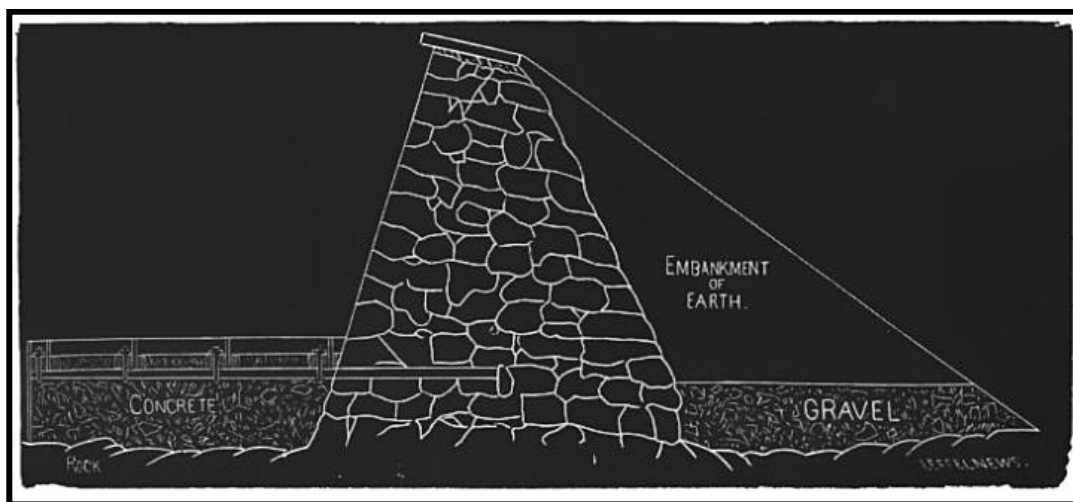


Figure 26: Section view of masonry dam built for the Housatonic Dam. Earth embankment is on the upstream side. (Leffel 1874: 68)

The masonry ruins of the Ard Godfrey Dam (21HE386) in Minnehaha Park on the Minnehaha Creek in Minneapolis evidence that this style of dam construction was brought west by the Maine-born miller.

Ard Godfrey first built a dam to power a saw mill on the creek in 1853. The next year a gristmill was constructed farther downstream. The dam was a limestone masonry structure that powered a wooden overshot wheel within the downstairs of the frame mill. After Godfrey operated the mill for 15 years, he finally received a land patent, and then, in 1871, sold the property (Dunwiddie 1975). The Godfrey Mill ruins are a very rare example of a typical dam and mill site from the 1850s that was updated in the late 1870s. Near an area of expanding population, wheat farming and settlement, accessible by road from their farm in the area of the current Veteran's Home, and in a valley with strong stable banks and a terrace for ancillary structures, the property has all the requisites of a good mill site.



Figure 27 Ruins of the Ard Godfrey Milldam on Minnehaha Creek (21HE386), facing northeast on north side of creek (March 2013).

Although the mill is completely gone, the ruins of the gravity masonry dam are preserved. A solid masonry face on the upstream exterior gives structure to the looser interior construction. The entire structure, which stands 4 feet high, appears to have been drywall construction (laid without mortar) and is securely integrated into the earth of the stream banks. The permeability of this dam may have allowed seepage throughout the entire structure preventing excess stress being placed on any vulnerable area. Most masonry dams surveyed on larger streams have been completely washed away

although stubs are sometimes visible on stream edges such as on the island across from the Dundas Mill on the Cannon River (SHPO inv. number RC-DNC-009).

Masonry structural dams gain their strength through shape and structural configuration and not mass, and are rarer than gravity dams—especially in stone construction. The most notable exception in Minnesota is the Lanesboro Dam in Fillmore County. This structure was designed with lighter walls than a gravity design, but the upstream arch shape transfers the pressure of the impounded water to the solid stone valley sides surrounding the dam. At the time that it was built, this technique was still experimental for structures of this height, and the dam is one of the first successful examples of a true arch dam in the United States (SHPO Hydropower MPDF 1993: E:8, Billington et al. 2005:60-61).

Concrete

The invention of Portland cement had a huge impact on masonry dam building and many historic dams were rebuilt using this material. Sometimes masonry or timber frame dams were covered over with concrete sheathes and concrete cores were used to create a water barrier in earthen dams. As an engineering publication on masonry dams explained, concrete was lighter and less resistant to water than stone, but as it could be made into a homogenous and monolithic form, it was superior to a structure put together with many smaller stones (Gould 1897:73).

This was most influential effect of concrete: it could be poured to a myriad of shapes and profiles realizing new developments in dam design. Yet, along with the revolution in dam design and construction, there was an understanding, well into the twentieth century that masonry dam building was an inexact science.

Of all structures designed and built by engineers, a masonry dam is probably the one about which there is the least amount of exact knowledge. . . . A masonry dam is usually assumed and designed as an entirely homogeneous structure. The only tests are use and failure. Use, however long continued, is a negative test which conveys very little information; failure conveys only a sharp admonition to be more careful next time and usually leaves the specific cause unsatisfactorily determined. We do know that many masonry dams have stood for years, and that some have failed (Smith 1915:1).

Early examples of concrete construction do evidence the experimental nature of concrete use soon after its introduction. While concrete is excellent to resist compression from water pressure, it does not have tensile strength and must be reinforced with iron or steel rebar. The dam ruins at on the north Branch of the Zumbro River in Zumbrota (GD-ZBC-023) preserve a solid masonry structure, that failed by cracking due to use of inferior materials, reinforcing, and design, probably around 1910 (Frame 2013).

The Zumbrota dam is an imposing structure, 9 feet tall, built into the deeply incised North Fork of the Zumbro River just upstream from a covered bridge. The dam has a simple triangular shape with a squared off top. The dam has an interior core that appears to be comprised of lime-based mortar; the material was moist with absorbed water and crumbling when surveyed. Over this core a concrete

sheath about 1 foot thick has been very roughly formed. The concrete has a few reinforcing iron bars vertically bent to shape but the spacing appears uneven and insufficient.



Figure 28: Dam ruins at Zumbrota showing two stages of masonry construction (June 2013)

The dam may represent an older dam that was rebuilt with concrete or one that was built in two stages with two types of concrete. As dam builders experimented with Portland cement they found that a solid mass of fresh concrete sometimes built up too much heat during the curing process. In order to avoid this problem and use less of the expensive material it was recommended that dams be constructed with a lime-based mortar core and a Portland cement based outer sheath. Inclusions of small cobbles, called “plums,” in the concrete contributed to the mass and are an example of Cyclopean concrete construction.

Almost all milling enterprises that survived into the 1920s rebuilt their dams with new concrete structures replacing old timber crib dams at sites like the Ames Mill in Northfield (not inventories) and Schech’s Mill (HU-CDT-001) on Beaver Creek in Huston County (Ralph 1910). The dam at Lake Louise (Figure 23) evidences how concrete was used to reinforce the downstream side of the original earthen dam, rebuild sections of the sluiceway, and build an entirely new dam in the 1920s.

Plank Additions and Flashboards

Even as innovations in masonry transformed dam design and construction, wood was still a convenient means of building temporary dam structures and additions. Wooden additions to the crests of dams have been used on turbine-powered sites since the nineteenth century to temporarily raise water levels above masonry construction.

One of the oldest documented examples was also found at the Godfrey milldam. After Ard Godfrey sold his mill, it passed to Franklin Steele, who bought the site and dam flowage in 1877 (Dunwiddie 1975:165). Steele added a plank addition on top of the existing dam and earthen embankments to raise the head of the dam another three feet—likely in conjunction with an upgrade to turbine power (Dunwiddie 1975).



Figure 29: In this photograph of the Godfrey Mill Dam from the 1890s, the plank addition built by Franklin Steele on top of the original masonry dam was falling into ruin. The original limestone base and embankments are still visible at the site.

Plank flashing, such as that built at the Godfrey dam could be cheaply added to the crest of existing dams to raise the water pressure without rebuilding the entire structure. If damaged during spring freshets, plank additions were more easily rebuilt than masonry. Unlike the original water wheels, new turbines could efficiently operate under varying levels of hydraulic head—that of either the original dam, or levels created by the plank addition. A plank dam like this might last five years but rebuilding was relatively easy and cheap should it become necessary (Brown 1936).

Some wooden additions were actually designed and built to fail in situations of flooding thus creating a type of release valve to reduce pressure on the overall structure. These “flash boards” consist of a series of dam sections that can fail individually or as a group. The planned failures are not only easier to fix than a solid dam, but they are a simple way to reduce the risk of a catastrophic failure on dams without an overflow sluice. The water resources commission reports in 1910 and 1912 mention that numerous water powered industries utilized flashboards to raise head in the early 20th century (State Drainage Commission 1910) and flash boards are still used during summer in some hydroelectric plants.³¹

Leffel described flashboard additions to the crest of an existing dam as:

“a self-acting dam. . . consisting of a massive frame of planks carried across the river and attached by hinges to the crest of the dam. This plank is maintained in a vertical position in ordinary conditions of flow by balance weights attached or hung over wheels upon the wing walls, so as to retain the maximum desirable head of water. In floods, the increased pressure of the overflowing water overcomes the balance weights and throws down the plank into a horizontal position, opening a free passage for the water” (1874:125).

Schech’s Mill Dam at Beaver Creek is a good example of a milldam built for use with turbines that uses flashboards to raise the head of the dam. When there is excessive pressure on the dam from high water volume, small metal pins holding the boards up shear off and hinged sections independently fall down to release pressure (Edward Krugmire personal communication, August 2, 2013). The boards can also be removed in inclement weather such as flooding or during ice build-up.³²



Figure 30: Schech’s Mill Dam on Beaver Creek showing flashboards on top of concrete dam in low water. Photo courtesy of Edward Krugmire.

³¹ <http://www.youtube.com/watch?v=rDgsTSQO2F4>

³² An overflow tunnel has recently been built on the eastern side of Schech’s dam so that the flashboards will not fail as frequently.

WPA Minnesota Type “C” dams

Variants of the Minnesota “Type C” dam can be found across the state in a variety of hydrological settings, from streams to lake outlets. The head is never more than 6 feet. The dams were altered for unique and changing conditions at each site even while using uniform materials and standardized forms. Initially the Type “C” dam was designed at three heights: at 2’, 4’, and 6’ head (Frellsen 1941). At some point, the plans were slightly altered and designs for dams of 3 and 5’ head added. Yet, the basic plan was retained and the New “Type C” Dams as well as the Stone-Concrete “Type C” Dams were essentially the same engineering structures as the “Old Type C.”

The name may have derived from the distinctive C-shaped abutments seen in plan below. Two different styles of abutments were used. One, shown above, had wing walls at 90-degree angles to the dam. The second had a 90-degree abutment at the upstream side and a 45-degree wing wall at the downstream side.

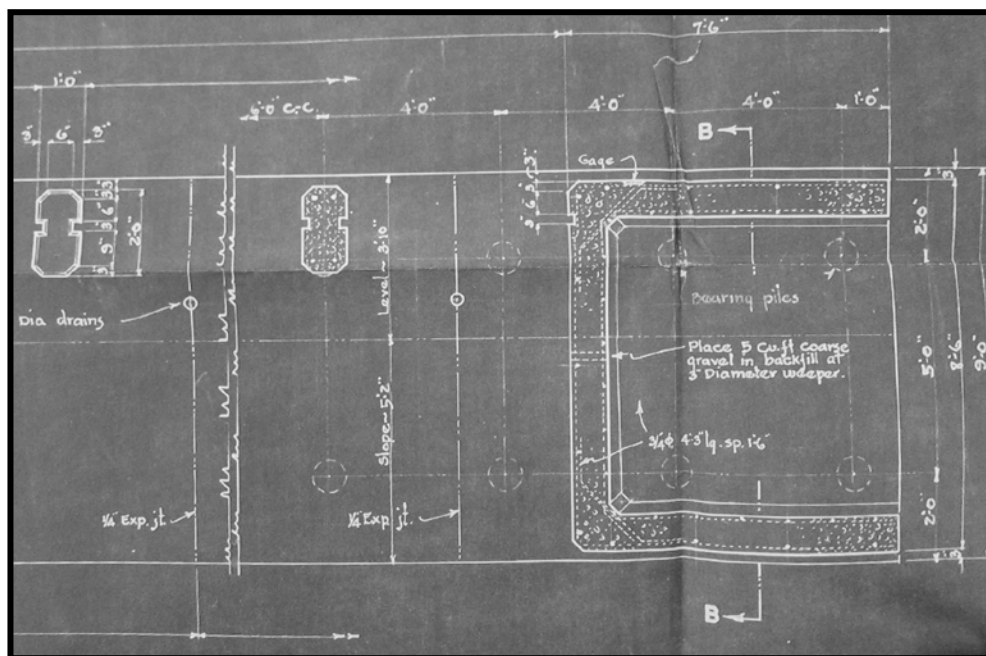


Figure 31: 937 Blueprint for Typical Lake Control Dam Type “C” 6’-0” Head. Department of Conservation Division of Drainage and Waters (MHS collection)

Each five-foot bay could originally be blocked to various heights with wood or cast cement stop logs that slid into metal-reinforced slots in the concrete piers. The insertion of stop logs controlled the level of the water feature at any desired height. The bays are usually made in groups of two, with a short piers alternating with tall, walkway-supporting piers. A narrow “operator’s platform” with a simple metal handrail spanned the dam from one abutment to the other supported by the bay piers allowing for the operator to monitor and adjust the stop logs as needed. The Type “C” dam could be adapted for other settings. In park settings, for example, the piers could support footbridges. Sometimes the dam was placed above a change in elevation and a stepped spillway was added below for a waterfall effect.



Figure 32: WPA "Type C" Ossawinimakee Dam. A good example of an intact concrete operator's platform with railings. This dam has been altered by fixing stop logs in place and sawing off the intermediary piers spaced 5 feet from the main pier and abutment. (Photo facing southwest on July 2013)

A cross section of the dam design for this style and height of dam is shown below. On both sides of the central pier and the inside of the upstream (or lakeside) abutments, metal reinforced slots provide apertures to hold stop logs in place. Additional piers spaced 5 feet between the abutment and central pier provided support for stop logs.

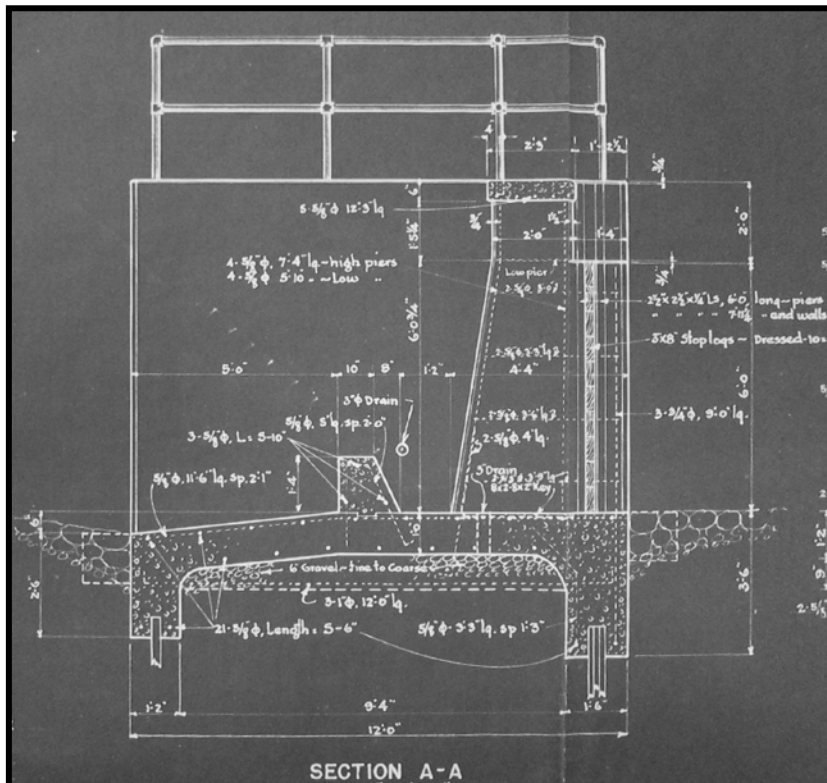


Figure 33: 1937 Blueprint for Typical Lake Control Dam Type "C" 6'-0" Head. Department of Conservation Division of Drainage and Waters (MHS collection)

The Skunk Creek dam in Pierz, Minnesota (MO-PIV-033), is a good example of a well-maintained Type “C” dam still in operation in a city-owned WPA-designed golf course/park. The dam forms a picturesque pond and swimming area surrounded by long earth abutments that are covered with roughly quarried (or perhaps salvaged) granite slabs. Besides the concrete operator’s platform, the dam also supports a footbridge between two sides of the park with simple pipe handrails.



Figure 34: This view of the Skunk Creek Dam in Pierz Minnesota shows the ten-foot bays supporting the concrete operator’s platform with the intermediary piers spaced five feet apart holding stop logs. The bridge also serves as a footbridge between two sides of a WPA golf course, so there are additional supports for the pedestrian walkway.

Extra labor went into extensive paving of the abutments/bridge approaches with what appears to be salvaged granite that is somewhat unevenly laid at the Skunk Creek dam in Pierz. Extensive paving of the areas next to WPA dams with local stone has also been recorded in the environs of Mayo and Sibley Lakes dams in Cass and Crow Wing Counties.



Figure 35: Dam embankment and footbridge approaches leading to the C-shaped abutments are roughly paved with salvaged granite at the Skunk River Dam in Pierz. The stonework extends down to the streambed on the upstream side providing erosion control. (October 2013)



Figure 36: All WPA dams originally had a dated WPA plaque. Most also have a surveyor's benchmark and may also credit the state level sponsor. Dams originally also had water level gauges.

Dam/Bridge

Sometimes the Type "C" dam was combined with much more complex features. Two dam/bridges were built by the Department of Highways that used a simple Type "C" dam water-impounding method were combined with complex box culvert/roadway supports and long stepped spillways. Like many other WPA projects, these dam/roadways were placed next to public parks in Clearwater and Champlin, Minnesota (Frellson 1941).

Most dam/bridges were simple designs that combined the functions of water impounding and stream bridging in a concrete, steel and wooden structure. The bridge approach also serves as the dam embankment and is covered with rip-rap on the upstream side of the structure. The concrete dam/bridge abutments support the bridge girders and support the dam piers. The abutments have wings that slope out at 45-degrees, down to a height of 3 feet.

A central concrete pier runs crosswise through the width of the dam supporting the deck stringers and dividing the dam and culvert into two bays. I-Beam girders run the length of the bridge from one abutment to the other to support the bridge decks. The dam structures are a simple variation of the Type "C" with stop logs in reinforced slots to adjust the dam height. On both sides of the central piers and the inside of the upstream (or lakeside) abutments, metal reinforced slots provide apertures to hold stop logs in place. The Emily dam/bridge in Crow Wing County is a simple variation of the

Type “C” designed by the Division of Waters that uses a hybrid bridge approach/dam embankment. A central concrete pier runs the width of the dam supporting the deck stringers and dividing the dam and culvert into two bays.



Figure 37: Emily Dam/Bridge in Crow Wing County, Minnesota. Note crest of dam underneath far side of bridge. Construction was sponsored by the state Emergency Conservation Works but funding came from WPA.

Identification, Survey, and Documentation Strategies

Light Detection and Ranging (LiDAR) Methods

LiDAR data analysis was a primary method used to search for and identify dam sites for this project. LiDAR is remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. The method is commonly employed to produce high-resolution digital elevation maps that are used in a variety of scientific applications. Airborne LiDAR surveys illuminate the earth's surface with pulses of laser light (usually a near infrared wavelength) and measure the time it takes for reflections to return to the aircraft. Location information is provided by an onboard GPS system. Time data are converted to distance, enabling calculation of the elevation of the target. Reflections occur from trees, vegetation, buildings, the ground surface, and other surface phenomena. After careful parsing of this information, it is possible to construct an extremely accurate digital elevation model representing the surface of the earth.

The recent availability of aerial LiDAR data from the State of Minnesota's High Resolution Elevation mapping project has revolutionized archaeological investigations in the state. These data have allowed archaeologists to depict micro-topographic patterning over large areas, resulting in the identification, assessment, and documentation of cultural resources within the natural and human-altered landscape. For this reason LiDAR has emerged as a cost-effective method of archaeological reconnaissance and adjunct method for assessment.

The processing, display, and analysis methods applied to aerial LiDAR survey data during this project utilized the recommendations and best practice guidelines presented in several recent publications [Arnott et al. (2013a, 2013b), Artz, et al. (2013); Bennett, et al. (2012); Challis, et al. (2011); Gallagher and Josephs (2008); Hesse (2010); Riley et al. (2010), and Romain and Burks (2008)] as well as the personal experience of the analysts. In general, multiple visualization techniques were utilized at each site. The use of more than one display technique facilitates the identification and interpretation of archaeological features much better than any single visualization method alone. A flexible tool-kit based approach was emphasized. This visualization tool kit included the following methods.

1. Shaded relief (or hillshade) images. Hillshade is a black-and-white image showing a digital elevation model (DEM) as if the elevation surface were illuminated by a hypothetical light source. Illumination of a DEM from multiple light source azimuths and inclinations typically provides a more thorough understanding of the surface topography.
2. Constrained shading. Grayscale (or color) shading is constrained to the elevation range of target features, maximizing the representation of detail within this limited range.

3. Local Relief Modeling (terrain filtering). This data processing and display method reduces the affect of macro-topography while retaining the integrity micro-topographic patterning and is particularly useful on sloping terrain.

4. Two-dimensional cross sectional profiles of mass point cloud data. This method of data display was used to create cross sectional profiles across topographic features of interest. Profile plots were created using the full discrete response LiDAR data files and include reflections from trees, brush and other above ground phenomena.

LiDAR data at three different levels of detail were utilized during the project. These included: streaming WMS data, one-meter (1-m) DEM data, and raw discrete response LiDAR data in LAZ format. LAZ formatted files are compressed version of standard LAS format LiDAR files. Lossless LAZ data compression reduces the file size and transfer rates of these very large data files. Large area reconnaissance was conducted using Web Map Service (WMS) data provided by the Minnesota Geospatial Information Office (<http://arcgis.dnr.state.mn.us/gis/mntopo/>). WMS is a standard protocol for serving geo-referenced map images over the Internet. Using WMS data means you don't need to download and store these very large files on your own computer. The data are streamed for specific locations as the user navigates. Google Earth is a well known example of WMS streaming data. Minnesota's LiDAR derived 1-m DEM hillshade WMS imagery is illuminated from an azimuth of 315 degrees and an inclination of 45 degrees. These data are very effective for fast and efficient archaeological reconnaissance. WMS hillshade image quality is relatively poor, however, due to lossy JPG image compression. Another drawback is that the hillshade data may only be viewed from a single illumination azimuth and inclination.

In areas where additional resolution was required, LiDAR derived 1-m DEM data were acquired from the MN Department of Natural Resources Data Deli interactive data download site (http://deli.dnr.state.mn.us/data_search.html). These data were used to view bare earth surface topography as either hillshade maps or as constrained shading images. A primary advantage of downloading 1-m DEM data for analysis is that hillshade maps may be illuminated from multiple directions and azimuths.

When maximum image resolution was required, or when elevation profiles across features of interest were desired, the raw discrete response LiDAR data files were downloaded from the MN GEO Land Management Information Center (LMIC) FTP site (<ftp://ftp.lmic.state.mn.us/pub/data/elevation/LiDAR/>) and analyzed. These LAZ format data files contain all LiDAR responses, including those from trees, buildings, and standing ruins. Analysis of LAZ files enabled the use of 2-D and 3-D mass point cloud visualizations and constrained shading displays designed to map the extent of dams and associated structure ruins in planview.

LiDAR Results

LiDAR data analysis was used in a number of ways: to search for previously undocumented dams and related features; to document and investigate the relationship between dams and the topographic

configuration of valleys and drainage basins; to examine the relationship between dams and historic railroad grades, roads, mills, and other industrial or historic features; and to produce high-resolution maps of dams, dikes and dike systems, flumes and sluiceways, mill races, and other associated features. These graphics may be used as interpretive aids by researchers, site managers, preservation specialists, and the general public.

LiDAR analysis was a particularly effective method for identifying and analyzing previously undocumented logging dams. Prior to this study fewer than 50 logging dams were documented in the SHPO archaeological sites and historic structures databases. LiDAR analysis identified and mapped an additional 219 probable logging dams.

It should be mentioned that field verification of dams identified in LiDAR imagery is required to confirm the source of the observed signal. A total of fourteen logging dams identified in LiDAR imagery were field verified during the 2013 field season. Seven of these were located in Pine County including: four dams on Sand Creek (LoggingDams_ID_346, 356, 357); two on Tamarack Creek (LoggingDams_ID_361 and NID_MN00395); and one on Crooked Creek (LoggingDams_ID_342), and an additional seven dams were field verified in Cass County including: three log drive dams on Lizzie Creek (LoggingDams_ID_134, 135, 137) and four cutaway dams on the Upper Pine River (LoggingDams_ID_129, 397, 398, 399).

The general procedure used during field verification was to digitize the UTM coordinates of the dams, then input these coordinates as waypoints into a global positioning system (GPS) navigation device. The GPS was then used to navigate to the dam locations (some of which were quite remote) in conjunction with traditional navigation methods such as topographic maps and a compass. The success rate of field verification was one hundred percent although the integrity and level of disturbance of the visited dams was variable.

Limitations

LiDAR was a very useful tool during this project, but several issues did hinder its effectiveness. Dams are located near water, and the wavelength of light (near infrared) used in aerial LiDAR surveys is not suitable for penetrating water or accurately recording reflections from the surface of water. For this reason the signal response from water covered in-stream areas is often absent due to signal attenuation, or is excessively noisy. This issue may be dealt with by using a different wavelength laser (usually green light in the visible spectrum) such as is typically used during bathymetric LiDAR surveys. Unfortunately bathymetric LiDAR data is not widely available in Minnesota.

A second issue affecting the usefulness of LiDAR is the fact that many dams are located in areas of large topographic relief. Areas having steep terrain often require higher density LiDAR data, as deep gullies and abrupt topographic features are not often clearly represented by lower density data. Fewer pulses hitting the ground surface equates to greater interpolation between returns, and steep features may not be clearly defined within the LiDAR response, even at the highest samples densities

available in Minnesota. Hydropower sites, including milldams are more likely to be located in these settings, often limiting their detection.

A final issue affecting the usefulness of LiDAR data is the variability of data sample density in Minnesota. Sample densities vary from county to county and range from less than one pulse per square meter up to eight pulses per square meter. In regions of very thick vegetation, lower sample density LiDAR data produces fewer ground returns because the ability of the laser to penetrate the thick canopies and branches is diminished. In such situations LiDAR data was less effective for locating and identifying dams.

LiDAR examples of logging dams

Several detailed examples of logging dams identified in aerial LiDAR data are presented in this section. The objective is to familiarize the reader with logging dam morphology and how this is expressed in LiDAR data. The ruined dams have a series of externally-visible landscape elements: borrow pits, dikes, central opening and a reservoir area that create an archaeological site. Logging dams were designed to hold a large volume of water in natural reservoirs. For this reason the dams often cross the entire first terrace of a stream and usually connect to a natural land form on either side, such as the second terrace, a hill or glacial esker that act as dikes or abutments. Logging dams are typically identified by this linear earthwork spanning the stream or floodplain of a river valley, usually with a gap near the center of the current stream channel that represents the location of the cutout or failure point of the dam. A second characteristic of logging dams is the presence of borrow pits. Borrow pits commonly occur immediately adjacent to the outer end points of the linear earthworks on both sides of the stream channel, although sometimes there is only a single borrow pit on one side of the channel, and occasionally the borrows are offset some distance from the actual dam site.

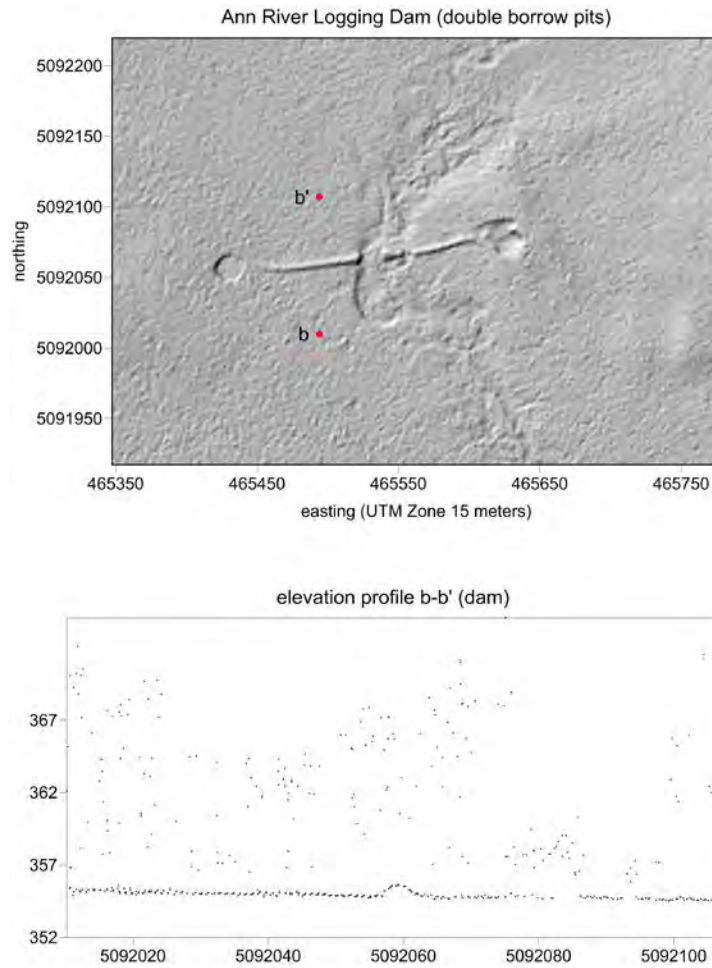


Figure 39: Hillshade image of a logging dam with borrow pits occurring on both sides of the stream channel. This example is from the Ann River in Kanabec County. The dam measures 215 meters from borrow pit to borrow pit. The borrows are 1.5 to 2.0 meters deep. The dam earthwork rises to a height of about one meter above the local ground surface. A south-to-north elevation profile crosses the dam between b and b'. All elevations are in meters.

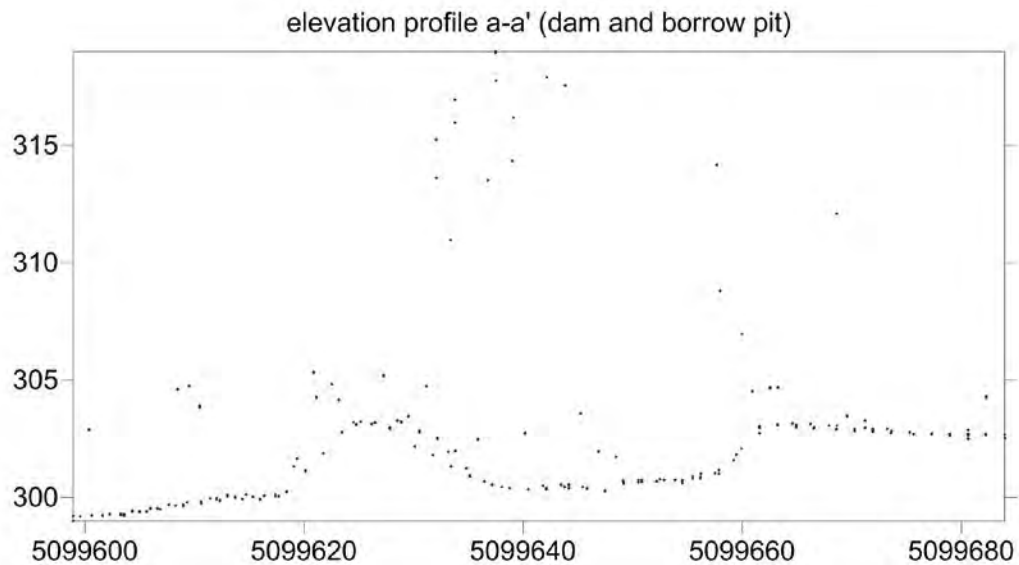
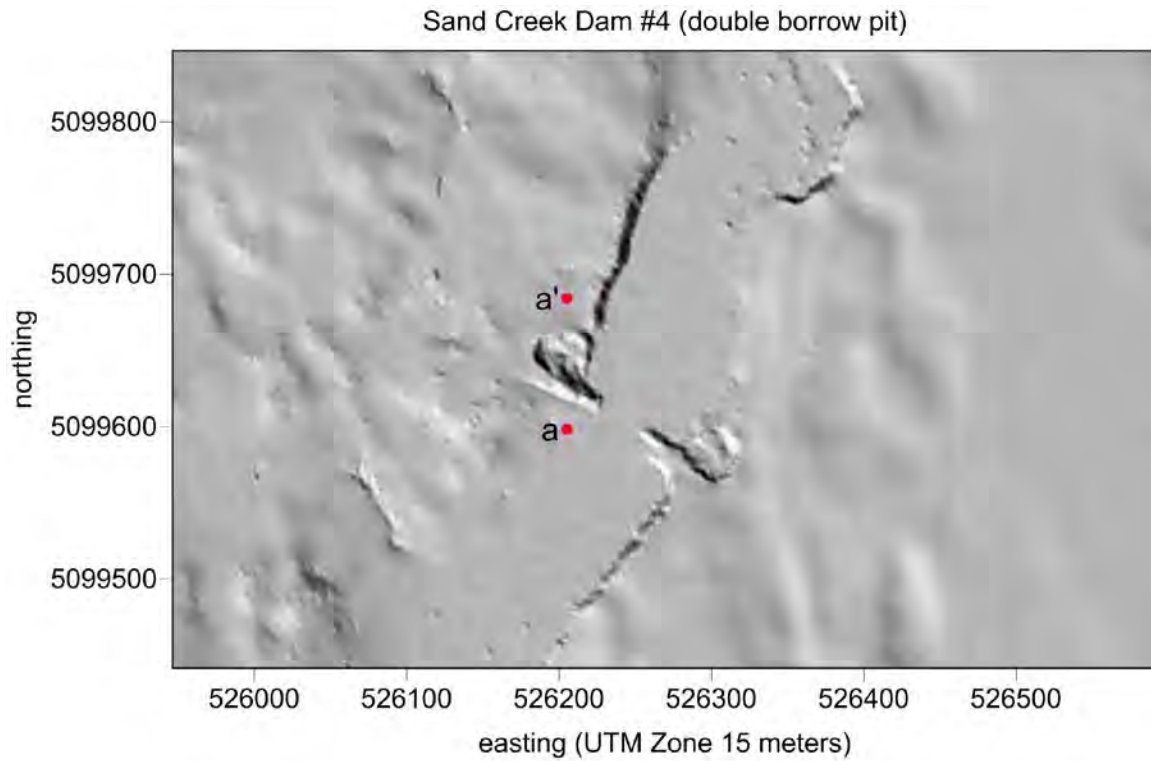


Figure 40: An example of a double borrow pit logging dam 147 meters in length located on Sand Creek in Pine County. The borrow pits are located on the upstream side of the dam immediately adjacent to the stream channel. The design utilizes the steeply sloping stream banks to prevent water from making an end run around the borrow pits. A south-to-north elevation profile begins at the level of the stream and moves north across both the dam and the western borrow pit. The lower density of ground points compared to the Ann River site presented in Figure 39 is due to differences in LiDAR data sample density.

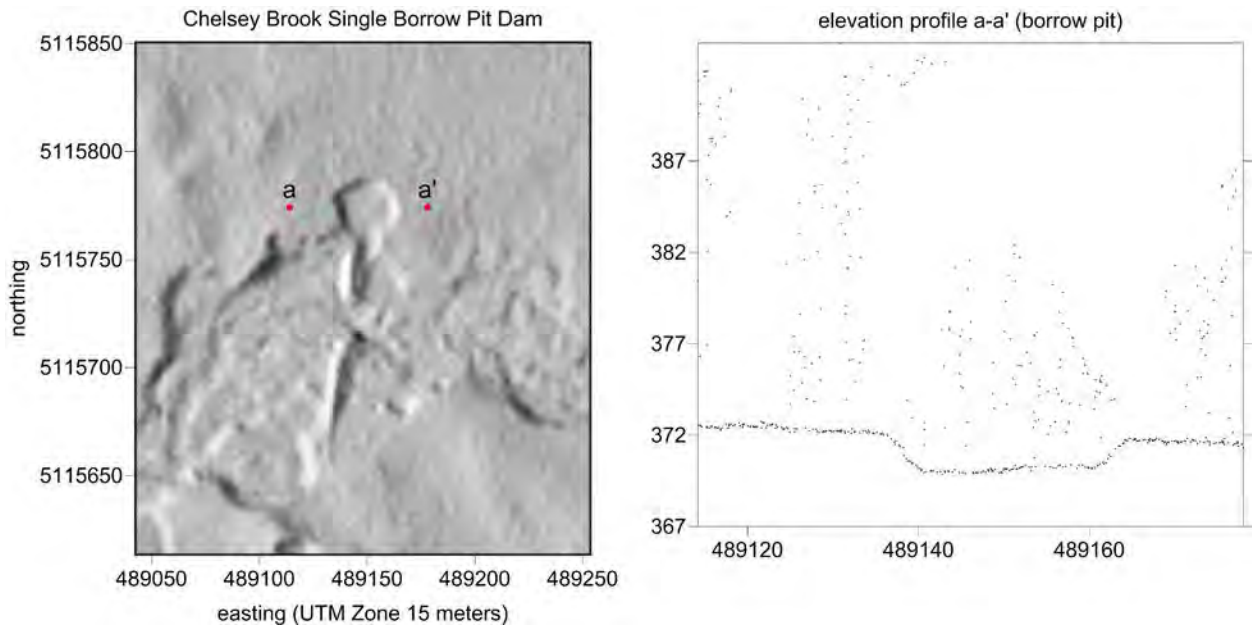


Figure 41: Example of a single borrow pit logging dam located on Chelsey Brook in Aitkin County. The dam extends approximately 100 meters across the stream channel. A single borrow pit located on the north side of the channel is about 23 meters across and was excavated to a depth of 1.5 to 2 meters below surface. An east-west elevation profile was used to quantify the extent of excavation. Note the response from trees and branches in and around the borrow.

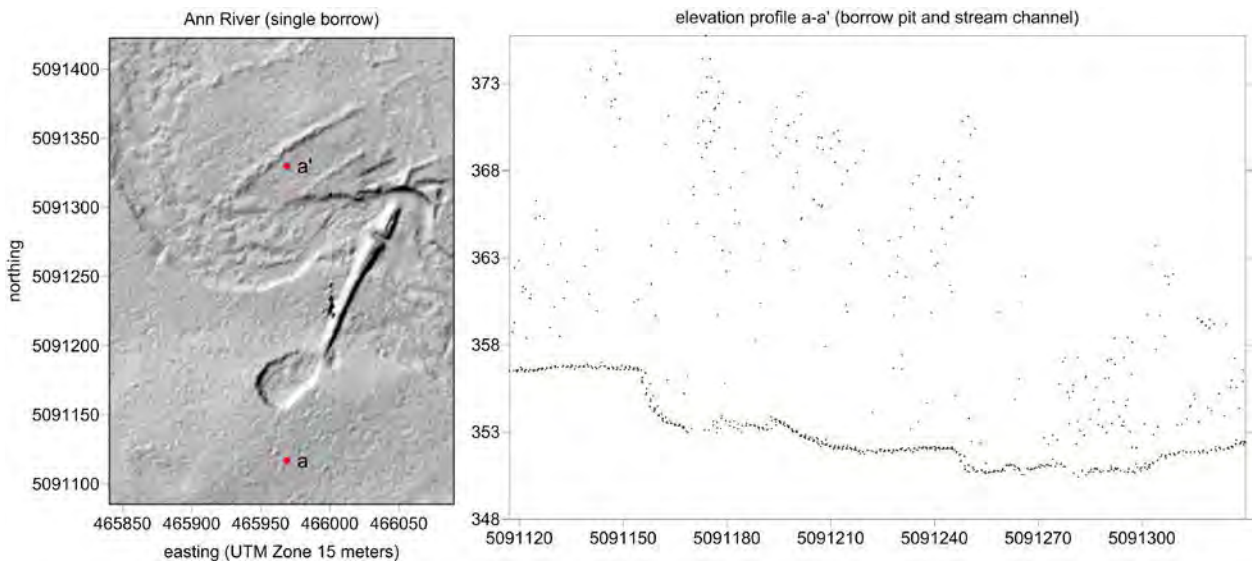


Figure 42: Example of a single borrow pit logging dam located on the Ann River in Kanebec County. The dam extends north from the single borrow a distance of about 145 meters. The oval-shaped borrow measures 48 x 35 meters and has a maximum depth of 3 meters below surface. A south-to-north elevation profile crosses the borrow and stream channel. The profile documents how the borrow was excavated from the second terrace above the stream, while the linear dam spans the first terrace. Note also that the dam has failed in two different locations, possibly due to overtopping associated with beaver dam activity.

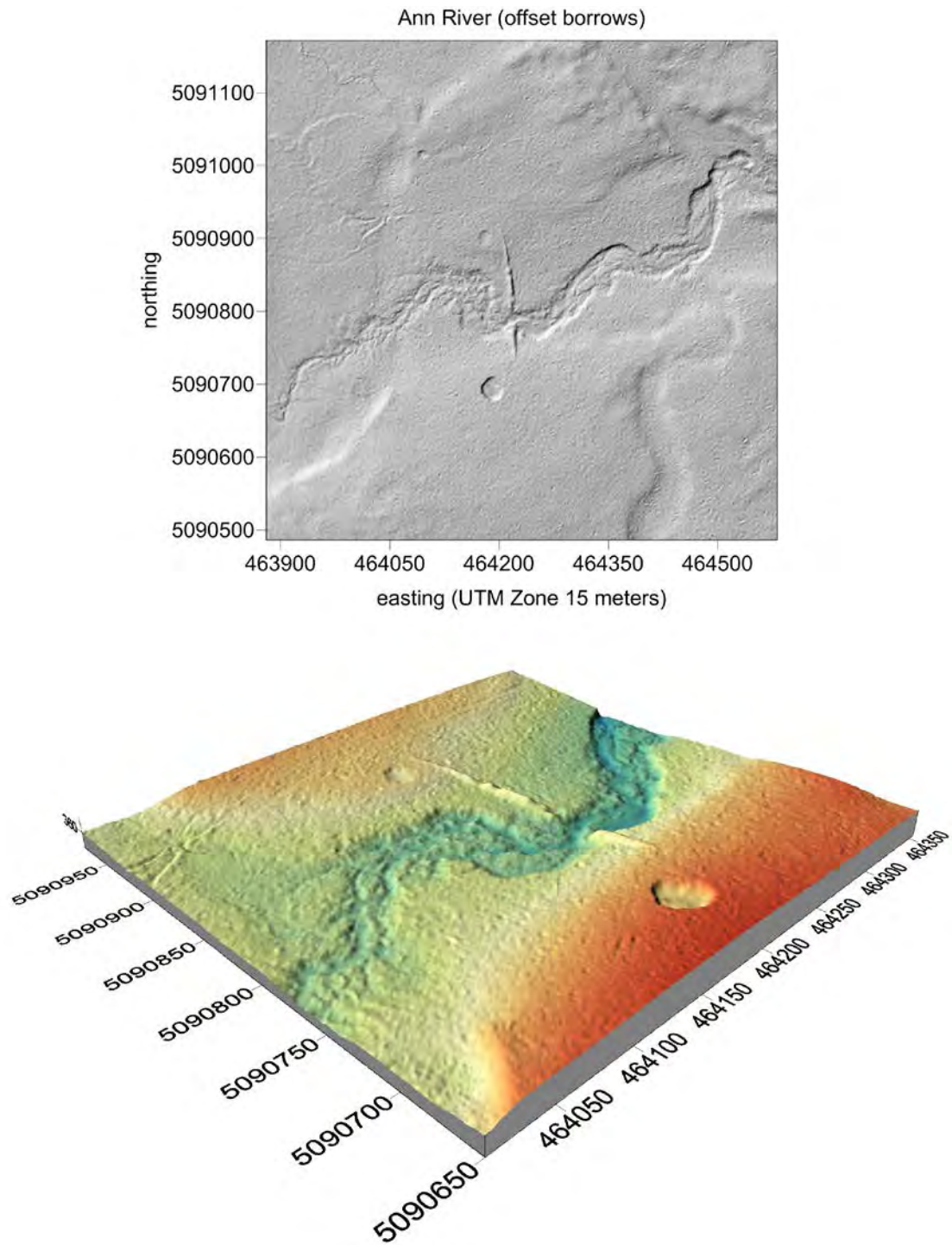


Figure 43: Example of a double borrow pit logging dam located on the Ann River in Kanabec County. The borrow pits are spatially offset from the linear earthwork. The south borrow is located approximately 40 meters southwest of the south end the earthwork and the north borrow is located 20 meters west of the north end. A 3-D surface plot shows how a natural constriction point in the stream channel was utilized during dam construction.

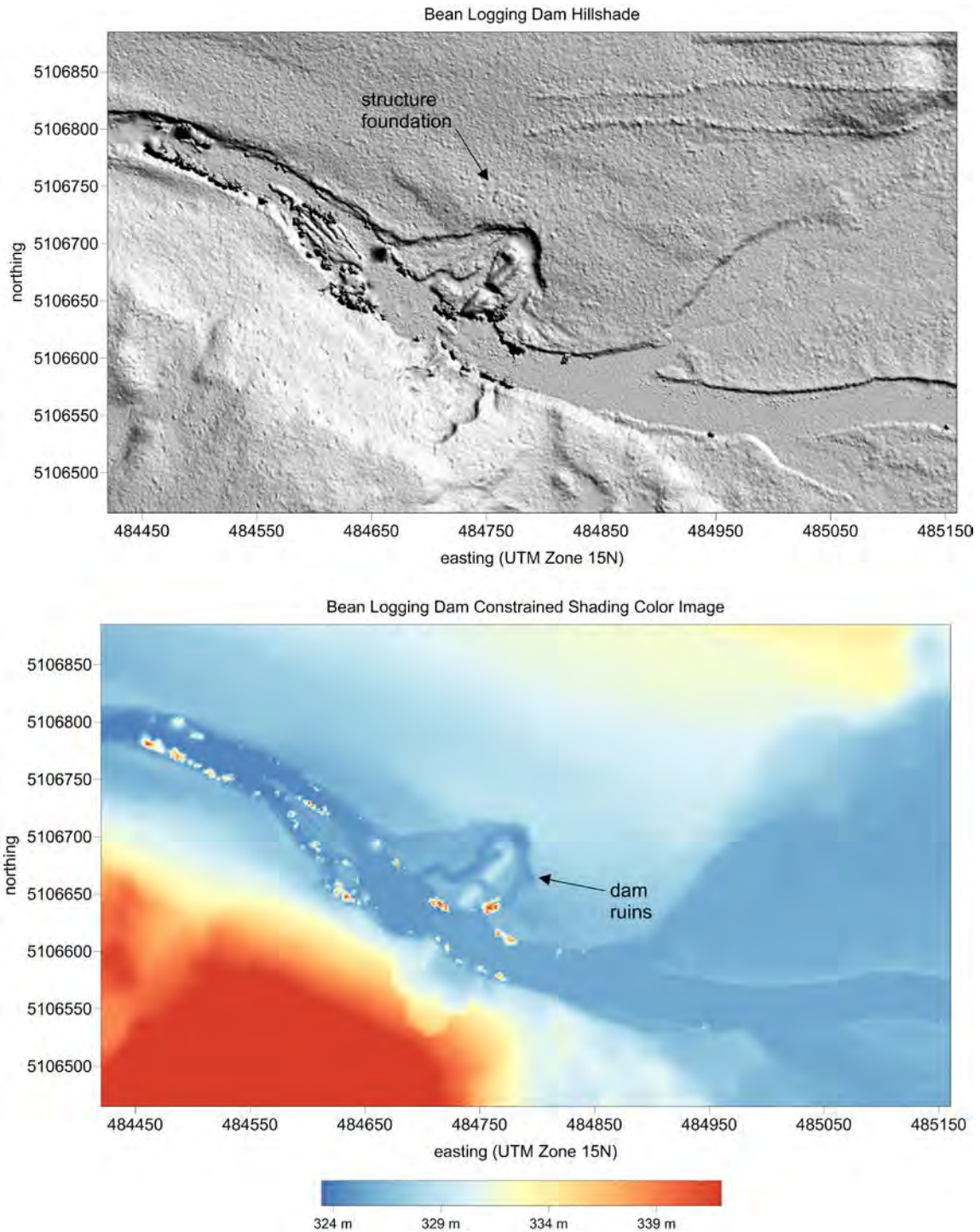


Figure 44: This example depicts Bean Logging dam located on the Snake River in Kanabec County. The rock remnants of this dam hold back about three feet of head. This continued impoundment has caused the dam to fail at several locations, impacting the integrity of the structure. The Bean Dam ruins provide a good example of a situation where using two LiDAR imaging methods provided more information than any single image. The steeply sloping complex terrain near the dam ruins did not lend itself well to hillshade imaging so a constrained shading color image of the dam was used to more effectively document the site. The hillshade map did identify a rectangular anomaly just north of the dam ruins however. This anomaly is not readily visible in the color image map and may represent the foundation of an associated logging era structure.

Snake River Logging Dam & Dike

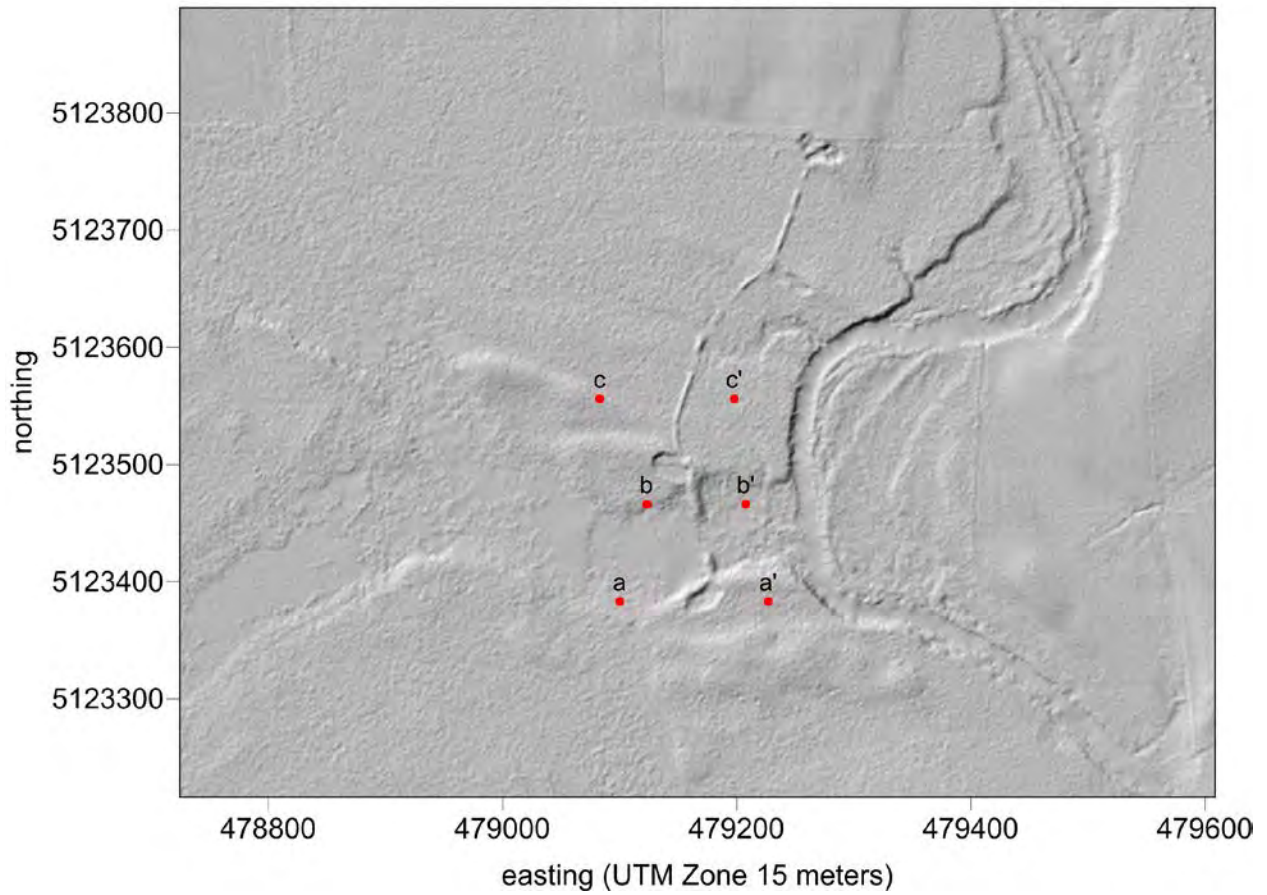


Figure 45: Hillshade map image documenting an example of a logging dam, borrow pits, and associated dike. The dam, located on the Snake River in Aitkin County, spans the river channel for a length of approximately 90 meters and has oval shaped borrow pits located at either end, each measuring approximately 30 meters along the long axis. The borrows are excavated to a depth of approximately 1.5 to 2 meters. A 280 meter long dike was added to the dam to prevent water bypassing the dam over low terrain to the north. The dike has an additional borrow located at its north end. The locations of three elevation profiles are plotted in red. These profiles are presented in Figure 46.

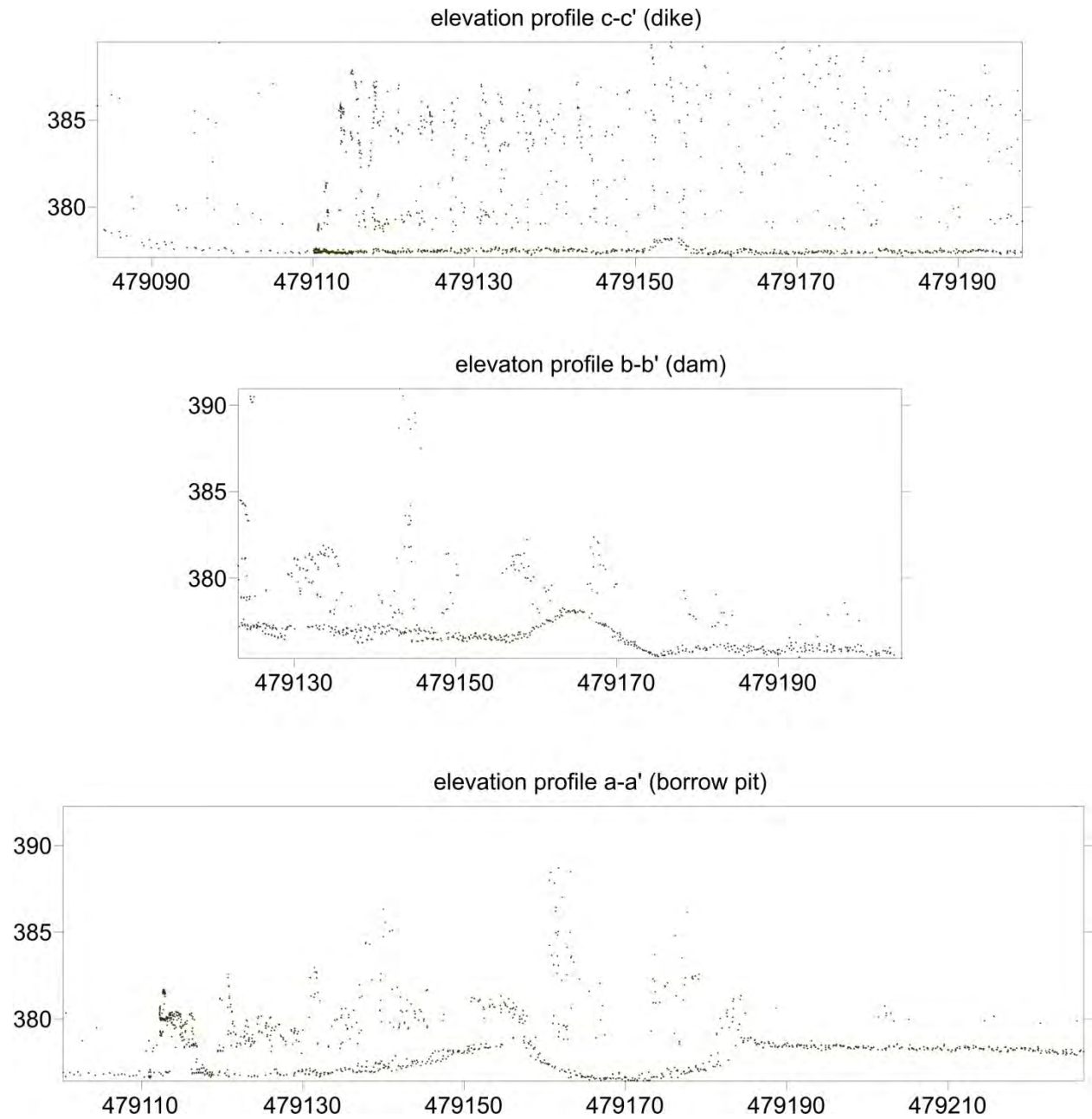


Figure 46. Elevations profiles associated with dam and dike system presented in Figure 45 above. These profiles show relative elevation changes associated with the dam, borrow pit, and dike. All profiles are from heavily wooded terrain.

LiDAR examples of mill dams

LiDAR was less effective in locating previously unknown mill dams. This was largely due to the nature of mill dam ruins which lack large-scale earthworks and are smaller in scale than logging dams, usually only impounding or redirecting enough water to fill the headrace of the mill turbine. Mill dams are also frequently located in urban areas that have experienced extensive redevelopment. That said, LiDAR data did provide a fast and efficient means of mapping and analyzing mill dams in certain situations. The following graphics discuss several examples where the use of LiDAR mapping methods for documenting and mill dams was effective.

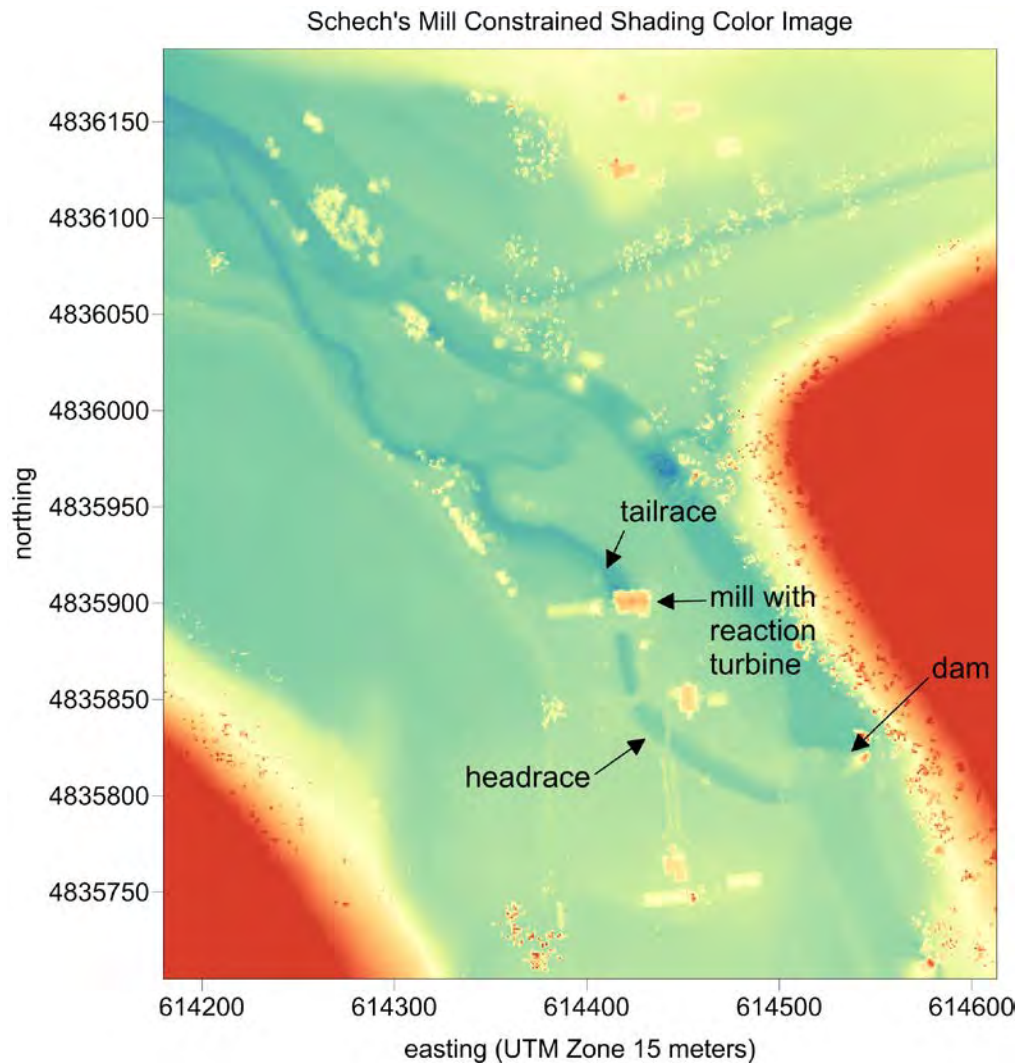


Figure 47: LiDAR map of Schech's Mill, located on Beaver Creek in Houston County. This plan view map depicts the layout of Schech's Mill and its relationship to the dam. The function of the dam is to raise the head upstream just enough to fill the 140 meter long headrace to the mill. The mill is run by an adjustable reaction turbine that is capable of operating under variable hydraulic heads. Water leaves the mill and then, after passing through the tailrace, rejoins Beaver Creek approximately 160 meters downstream.

Godfrey Mill Hillshade Map

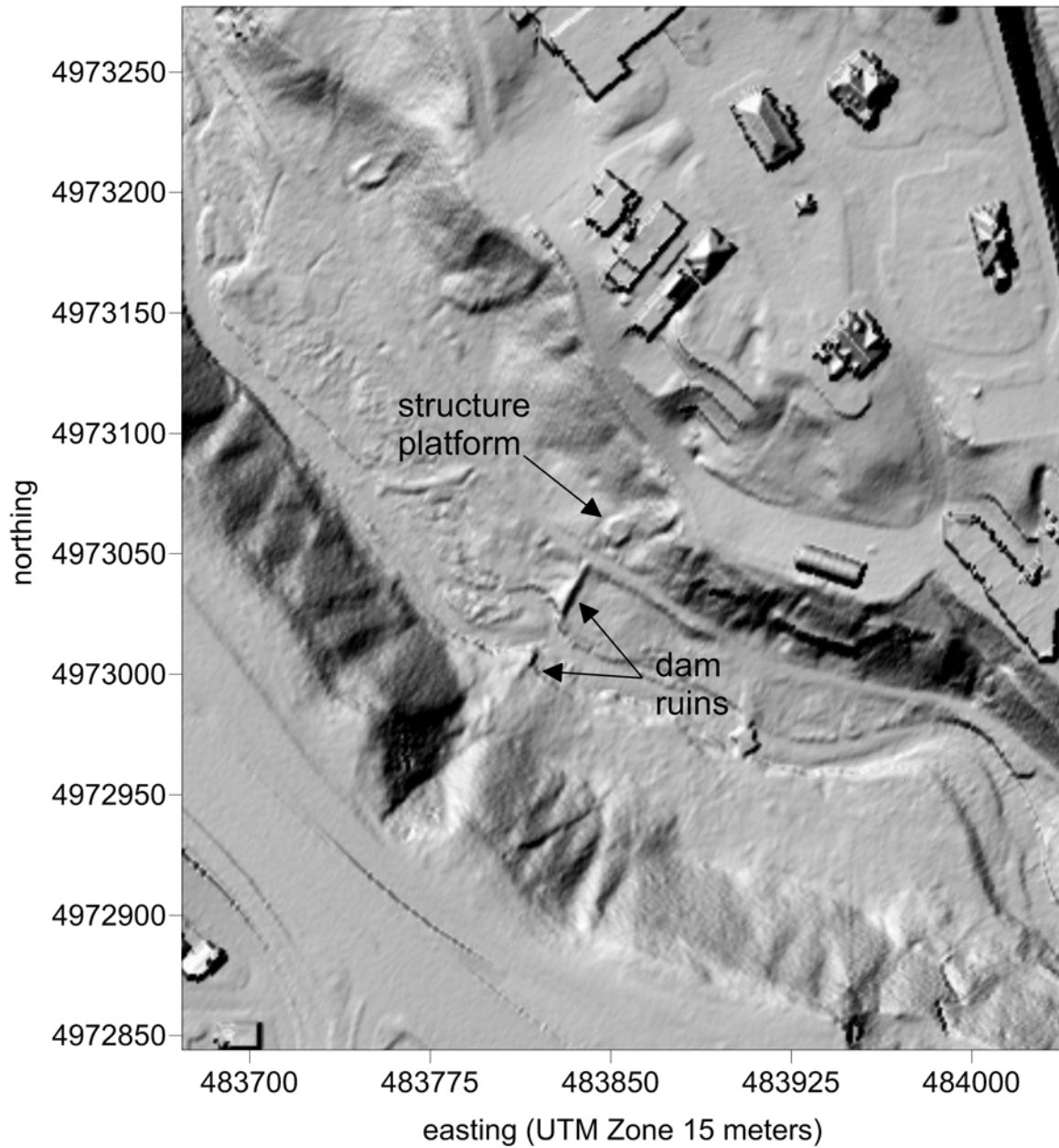


Figure 48: Hillshade LiDAR image depicting the ruins of the Godfrey Mill located on Minnehaha Creek, Hennepin County. A level platform just north of the dam ruins represents the location of the millwright's home. Two masonry and earthwork segments of the dam remain. The northernmost segment measures approximately 27 meters in length, the southern is only about 7 meters long. See Figure 28 for a photograph of the north dam segment.

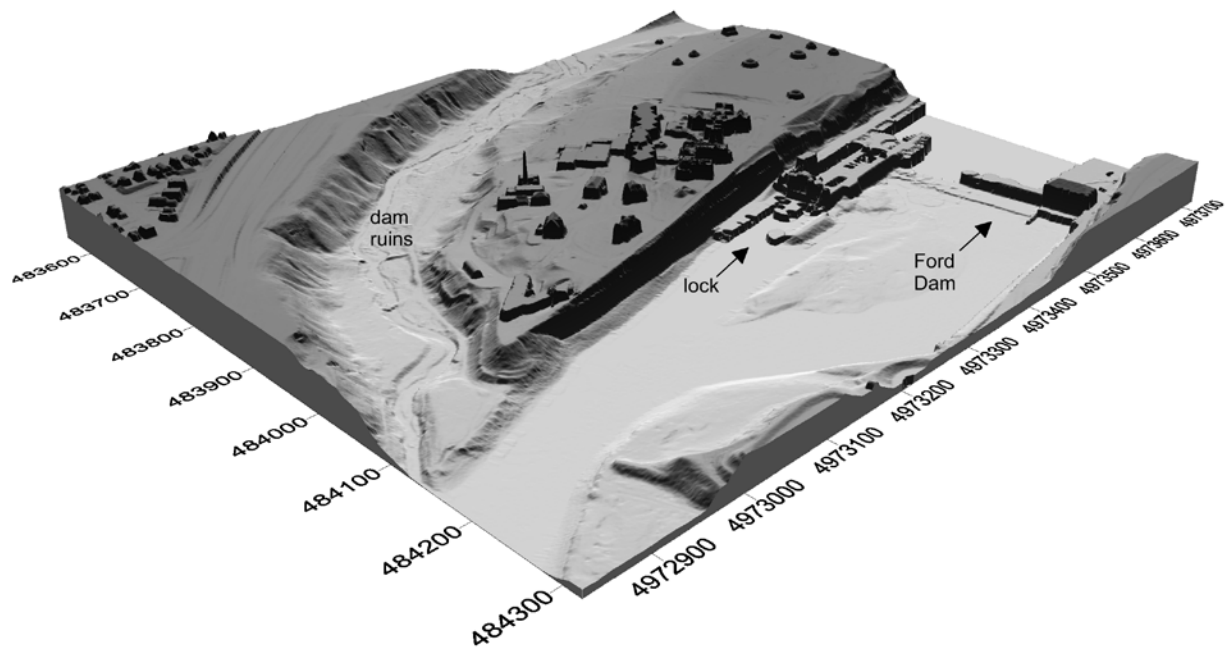


Figure 49: 3-D surface map depicting the environmental context of the Godfrey Mill dam ruins. The map shows this historic mill location in relation to the confluence of Minnehaha Creek and the Mississippi River. Lock and Dam #1 (Ford Dam) is visible 600 meters upstream on the Mississippi River. Note that Ford dam appears to have a missing span due to signal attenuation caused by water spilling over the dam.

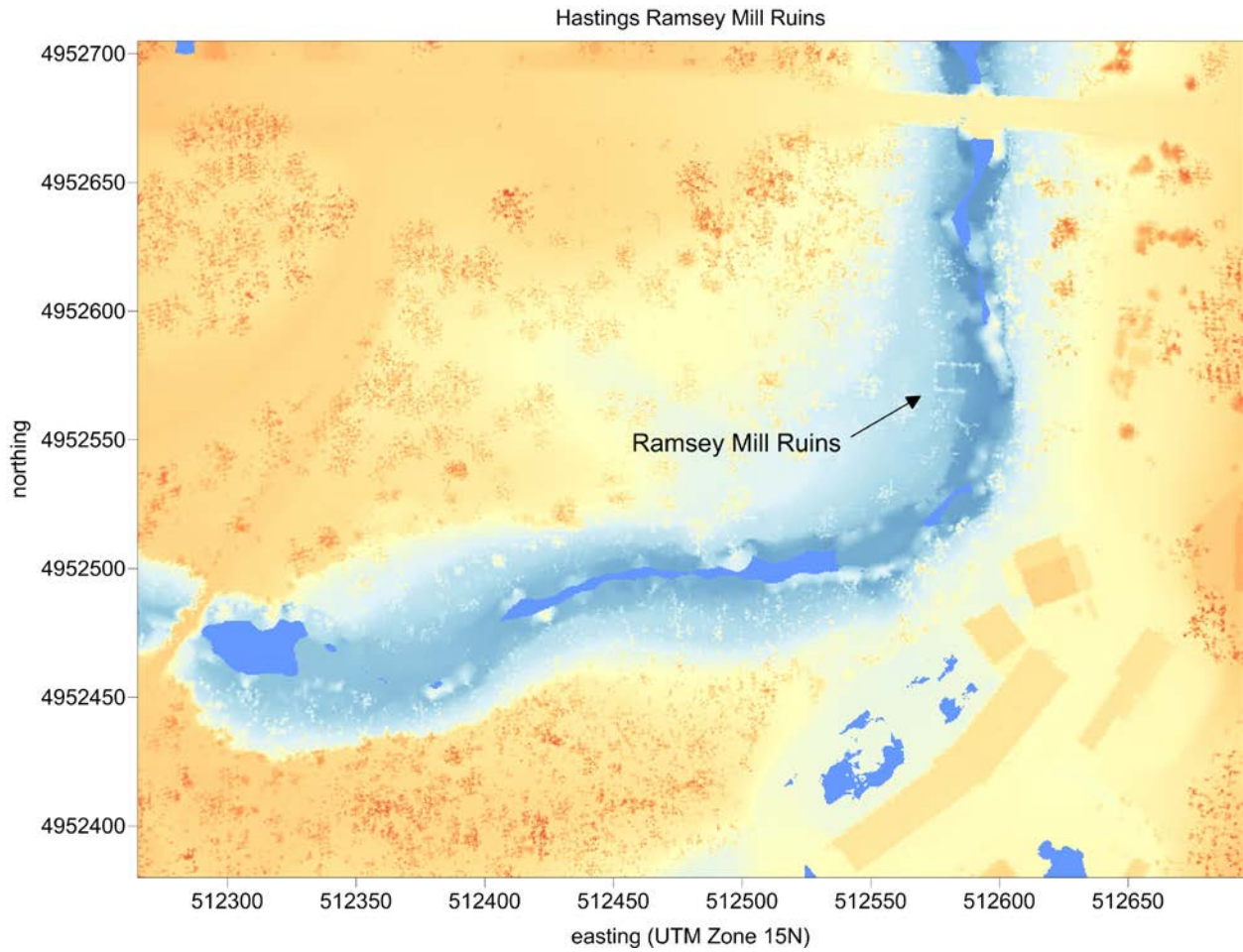


Figure 50: Constrained shading color LiDAR image depicting the Ramsey Mill ruins on the Vermillion River, Washington County. No evidence of the mill dam remains at this site, but photographic evidence suggests the dam was located immediately adjacent to the southeast corner of the structure (now missing). This map was constructed using the full discrete response LiDAR files contained within the LAZ format data files. Bare earth LiDAR hillshade maps are not capable of mapping structure ruins as returns from above ground objects are classified as either vegetation or structures and are filtered out.

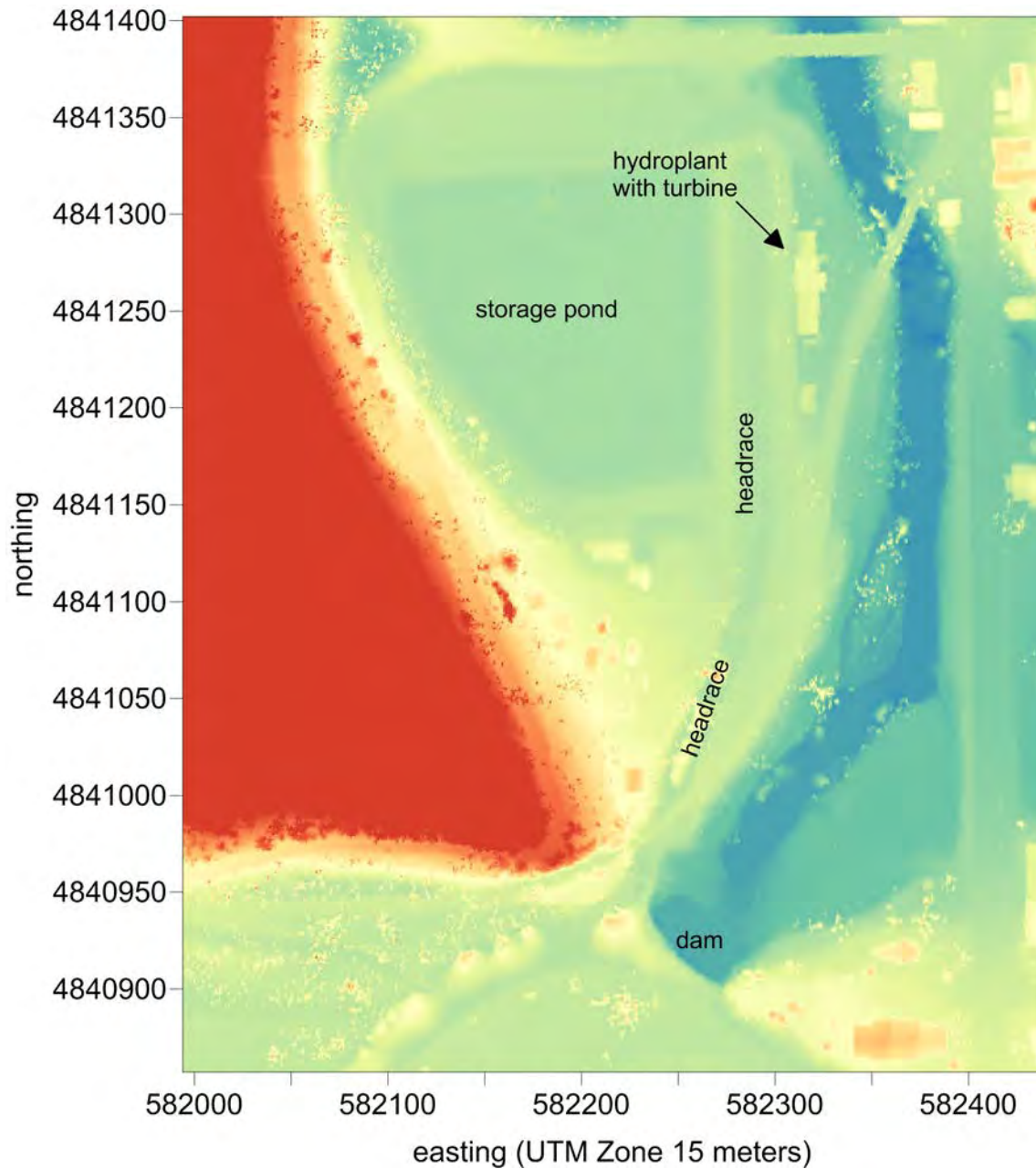


Figure 51: LiDAR color image map depicting the relationship between the 1868 Lanesboro dam and its associated headrace on the Root River, Fillmore County. This dam system is interesting in that water is diverted down a 300+ meter long headrace and stored in a pond adjacent to the hydroplant. Originally, water was diverted into mills on the east side of the headrace and was released through a subterranean tailrace to the river after passing through the mills turbines. Today, a hydroelectric plant is located in a structure just east of the headrace in the former milling area.

LiDAR example of a hydroelectric dam

LiDAR can also be used to assess hydroelectric dams, although that historic context was not part of this study. LiDAR mapping methods are an effective means of understanding the relationship between dams and hydroelectric plants and as a form of assessment and documentation. The following example depicts a hydroelectric dam in plan view.

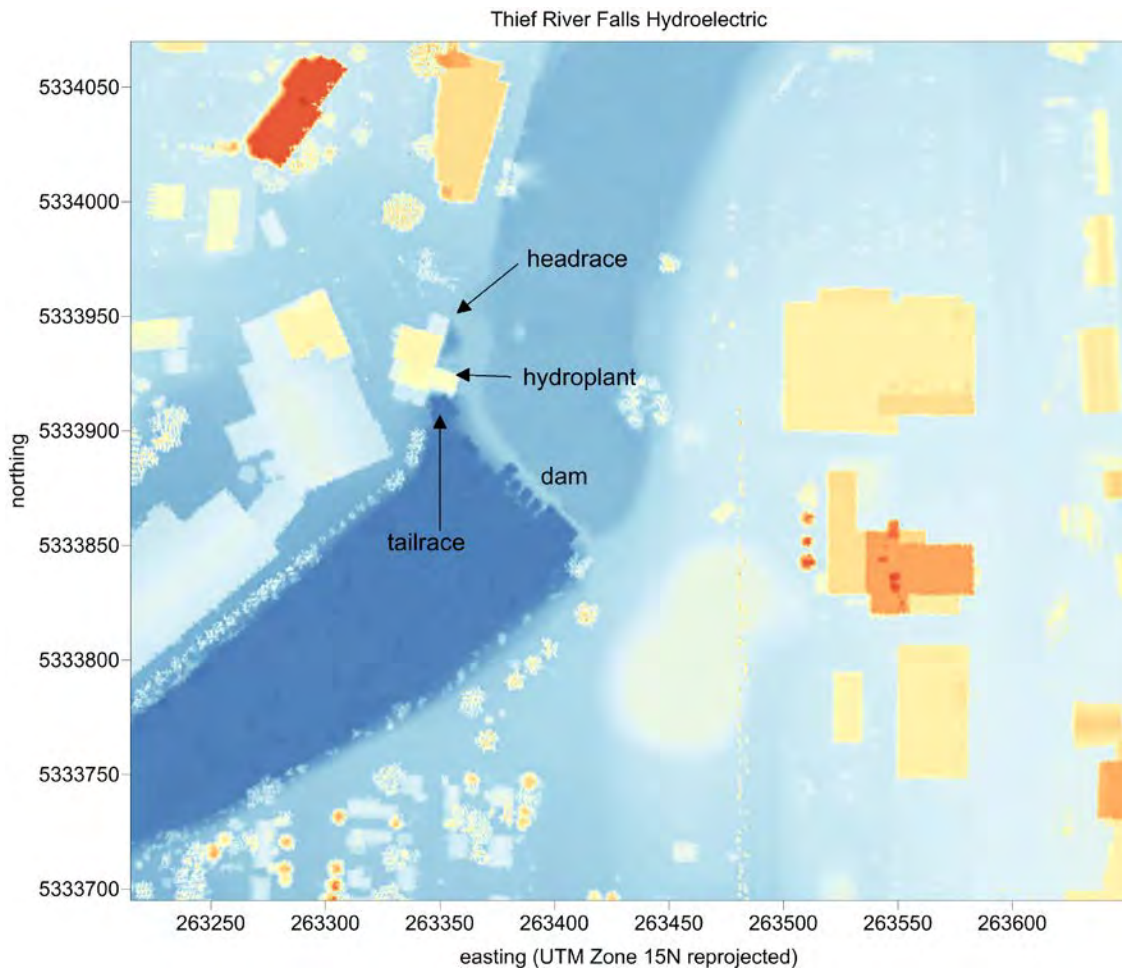


Figure 52: Color LiDAR image depicting the Thief River Falls hydroelectric dam located on the Red Lake River, Pennington County. In this case the hydroplant is located immediately adjacent to the dam. The headrace is located less than 60 meters upstream from the dam face and water is released at the base of the dam on the west bank of the river after passing through the plant turbines.

Summary of LiDAR Mapping for identification and documentation of dams

LiDAR mapping methods proved remarkably effective in identifying, mapping, and documenting both the archaeological ruins of dams and actively functioning dams. The method was particularly effective in searching for and identifying earthworks associated with logging dams. LiDAR also proved useful as a means of creating detailed plan maps of milling dams, allowing for a better understanding of the relationship between dams and associated industrial infrastructure. The complexity and scale of many sites documented during this project would have made mapping by traditional means prohibitively time consuming and expensive.

Ground Penetrating Radar Investigation

A ground penetrating radar (GPR) investigation was conducted at the Lizzie Creek Logging Dam 2 site (21CA0757). GPR is a geophysical method that uses radar pulses to image the subsurface. The GPR functions by sending high frequency electromagnetic waves into the ground from a transmitter antenna. Some of these waves are reflected back to the surface as they encounter abrupt vertical changes in the dielectric permittivity or electrical conductivity of the matrix through which they are traveling, and are detected by a receiver antenna (note: diffuse vertical changes in these properties do not produce significant reflections). The amplitude and two-way travel time of these reflections are recorded and used to construct a two-dimensional plot of horizontal distance versus travel time. Data collected in the field are stored for later analysis, and may be viewed as two-dimensional profiles in real-time during data collection.

A GPR profile was obtained along a 27 meter long segment of the northernmost earthwork at Lizzie Creek Logging Dam 2. Data were collected every 5 cm along the top of the earthwork using a pulseEKKO 1000 GPR system. Profiles were collected at two different radio wave center frequencies, 225 MHz and 450 MHz. The lower frequency results in greater depth of penetration while the higher frequency has greater resolution but less depth penetration. The location of GPR data profiles are shown in relation to aerial LiDAR maps of the site in Figure 53. A photo showing data collection in progress at the site may be viewed in Figure 54.

Results of the GPR investigation are presented in Figure 55. The first two images in Figure 55 present GPR profiles at each frequency. The top of each image represents the ground surface while radio wave reflections from objects and strata beneath the ground surface are displayed in grayscale. The two-way travel time and estimated depth of these reflections are provided on the left and right vertical axis. The horizontal position is located on the top axis. Each profile starts on the north end of the earthwork and ends at the south.

The original ground surface appears as a very strong horizontal reflection in both profiles. This is labeled as HR 1 in Figure 55. Examination of this horizontal reflector shows that the distance between the ground surface and the bottom of the earthwork varies from 1 meter in the north to 2 meters below surface at the south end. Two additional horizontal reflectors are visible in the profiles (HR 2 and 3). These horizontal reflections may represent different strata, fill materials, or possibly internal structural components such as horizontal beams in timber cribbing. Three areas of unusual signal response are also visible. These anomalous areas, labeled AA 1, 2 and 3, could represent changes in the internal structure of the dam or isolated objects. One very strong reflector has characteristics suggestive of a metal object (metal has very strong reflectivity in GPR surveys).

Although it is not possible to determine the source of these reflections by examination of the GPR profiles alone, these data do provide the horizontal position and depth to targets that could be selected for testing during future investigations. Such testing would help us better understand nineteenth century logging dam construction methods. Recommended testing methods include soil coring, hand auguring, shovel testing, formal excavation units, or mechanical trenching.

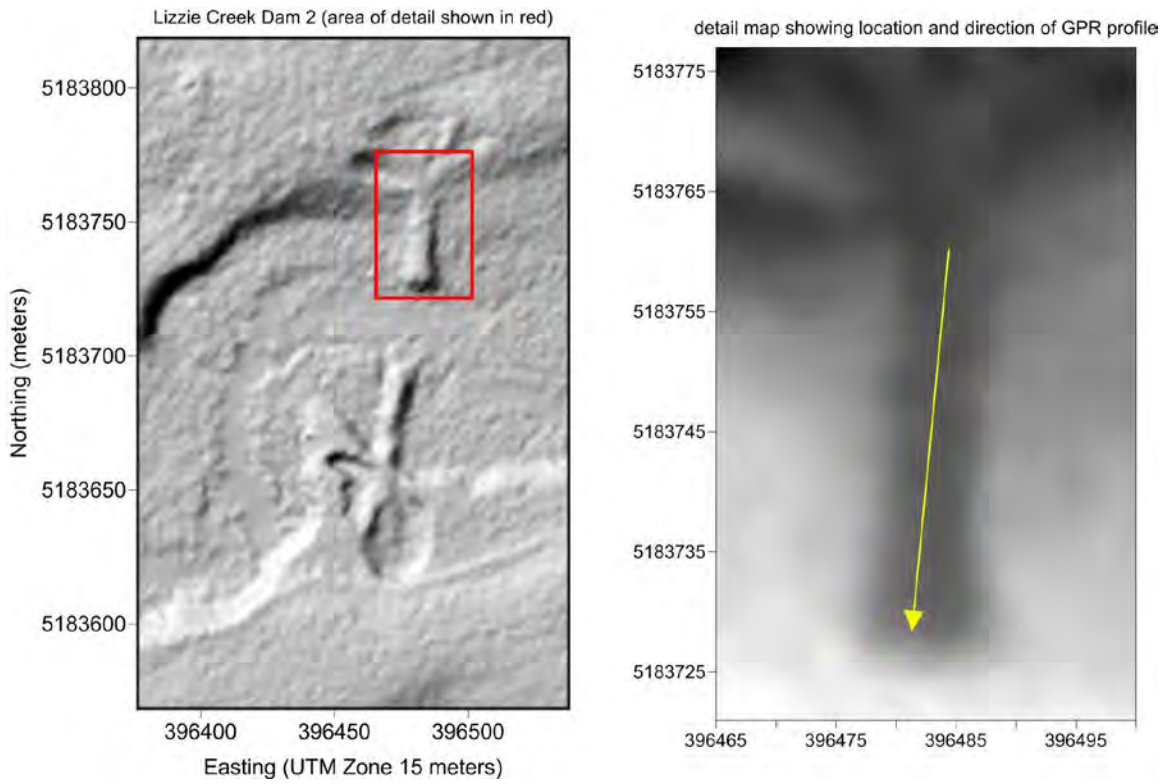


Figure 53: Location of the GPR subsurface profile at Lizzie Creek Logging Dam 2 in Cass County.



Figure 54: South view of GPR survey in progress on the north wing of the Lizzie Creek Logging Dam 2 site.

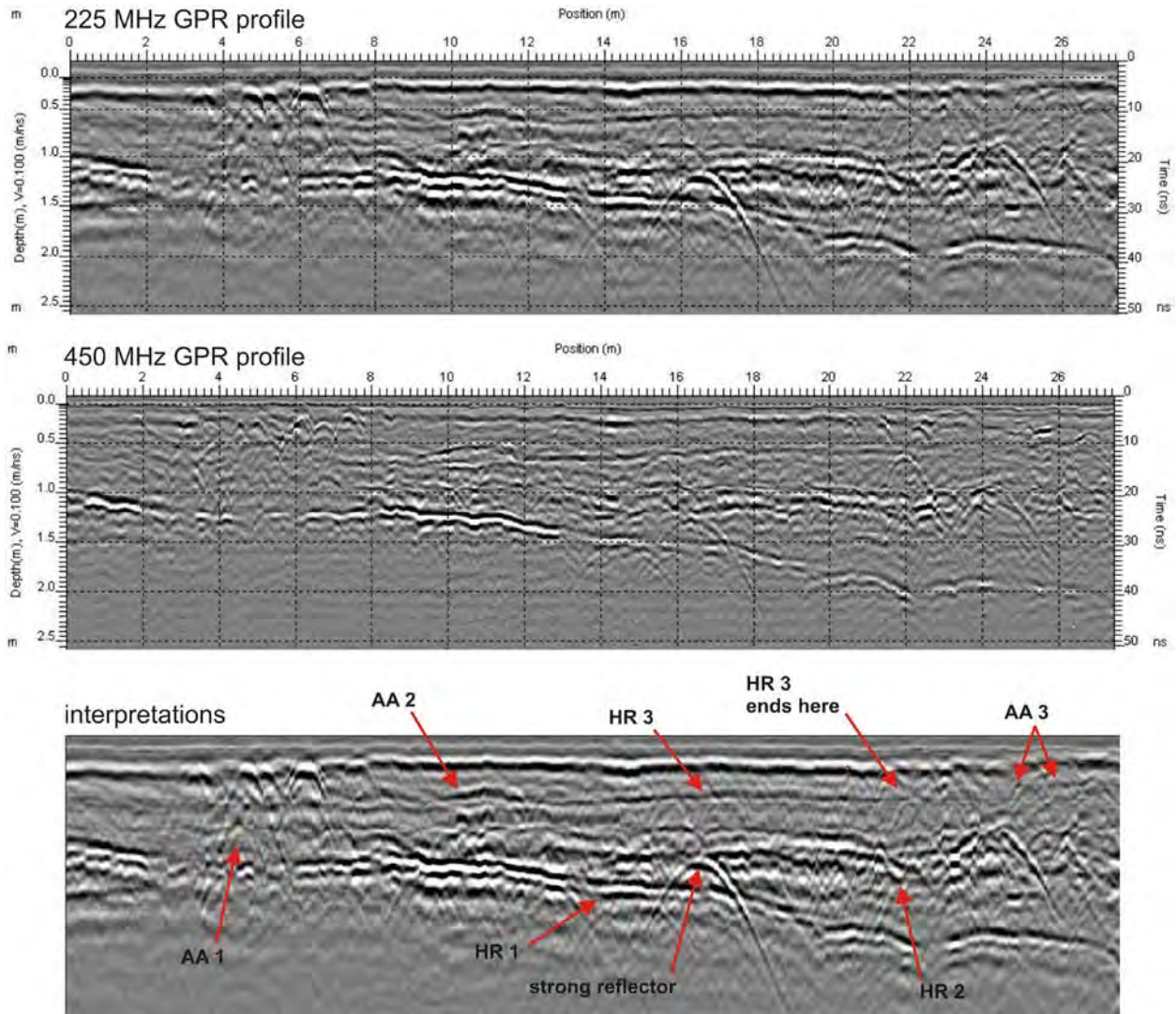


Figure 55: Results of the Lizzie Creek Logging Dam 2 GPR investigation. Three distinct horizontal reflections (HR) are labeled. The strongest of these (HR1) represents the original ground surface. Three anomalous areas (AA) likely represent buried objects or changes in the type of fill. A very strong reflector may be caused by a buried metal object.

Three dimensional Laser Scanning

Ground-based three-dimensional (3D) laser scanning was performed at a sample of five dams to assess the usefulness of this technique for recording historic dams. A 3D laser scanner is a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (i.e. color). The collected data can then be used to construct digital, three dimensional models. The dams selected for laser scanning were: Godfrey Mill on Minnehaha Creek, Hennepin County; Skunk Creek dam in Pierz, Morrison County; Tamarack Creek logging dam in Pine County; Glensheen Mansion dam on Tischer Creek, St. Louis County; and Lizzie Creek Logging Dam 2 (21CA0757) in Cass County. Static two-dimensional examples of scanning results from these sites are presented in the graphics below. Three-dimensional point cloud data from each site are included in the database accompanying this report.

Instrumentation and scan parameters

Laser scanning was performed with a FARO Focus 3D S 120. This instrument is capable of very high resolution and spatial precision, and records the intensity of the reflected signal along with spatial coordinates of the reflective surfaces. Because only surfaces in direct line of sight from the instrument are scanned, objects must be scanned from multiple points of view to be fully modeled. The instrument can also take color photographs during the scan, and color values can be mapped to each data point. In order to spatially integrate scans taken from different positions, targets recognizable to the processing software – usually spheres – are placed in the survey area to provide points of correlation between scans.

Configurable scan parameters include settings for environment and target distance, point density, and whether to collect color information. Higher point densities and color data lower survey speed while increasing storage and computing requirements and processing time (which can be substantial). Most of the data collection in these surveys used the setting “1/4 scan,” or one quarter of the maximum point density that can be collected by the instrument. Likewise, the number of scans taken from different positions increases the quality and completeness of the data at the expense of time and computing requirements. Each site was scanned from several positions, between five and ten, depending on the complexity of the site and the degree of obstruction. Color data was not collected at the Pierz and Lizzie Creek 2 dams because of low light, and at the Glensheen Dam, the color data are of limited usefulness because the survey was conducted at dusk, resulting in low and inconsistent lighting.

Data processing, editing, and imaging is accomplished with FARO Scene software. Data can be filtered, multiple scans can be assembled, and imagery and animations can be generated within the software. Data can also be exported for use in other software packages that handle scattered point data.

Presentation modes

Data may be viewed within the FARO Scene software in several modes. The modes most useful for interpretive purposes are referred to within the software as “quick view” and “3D view,” which may be rendered in grayscale (intensity) values or in color. Quick view shows each scan only from the point of view of the scanner, but it is quickly rendered on the screen, and shows data coherently and in high resolution. It essentially allows viewing of panoramic imagery on screen with little distortion, with exploration limited to rotation and magnification.

In 3d view, the data from multiple scans are integrated into a three-dimensional model that can be explored from any point of view and in motion. Examples of multiple perspectives are shown in Figures 57 and 58, depicting the Pierz Dam. The coherence of the imagery can be disrupted by missing surfaces that were not visible from any scanning positions, but viewing three-dimensional models in motion and from unique angles can give a sense of form that is difficult or impossible to achieve using two-dimensional static imagery.

For comparison of the relative image quality, a color quick view image from the Godfrey Dam (Figure 59) can be compared to Figure 60, a 3D view from a similar perspective. This shows the superior resolution of the quick view image, and the gaps in the data where surfaces are out of view of the scanner positions. The static two-dimensional image does not show the great advantage of shifting perspective within the 3D view.

Color imagery and grayscale intensity imagery each have advantages, and it can be valuable to compare the two. The grayscale intensity differs from conventional black and white photography in that it recorded the reflectance of laser pulses of near infrared wavelength. It does not depend on ambient light conditions, and in fact low ambient light can yield better results. The intensity of the reflected laser signal can show form and texture in a way that standard photography cannot. The color information can complement intensity data in analysis as well as representing the real-world appearance of a site. Figures 61 and 62 are images of the Tamarack Creek Dam, illustrating intensity and color imagery in quick view mode.

Data in its original format can be viewed in a freeware version of the SCENE software (FARO SCENE LT), which has limited functionality beyond display. Data can also be imaged from a web server at limited resolution with FARO Webview software.

Advantages and potential applications

Laser scanning has the potential to record historic structures and landscapes in far greater detail than conventional mapping and photographic methods. Beyond the level of detail and precision, laser scanning can record information that is not perceived by the unaided eye or by conventional photography. Conventional mapping involves subjective selection of what is mapped, and laser scanning can potentially record important information overlooked by investigators in the field. Multiple points of view and three dimensional modeling may aid in identification of phenomena that might be ambiguous in conventional photographs. The software also has tools for measurement of distances and dimensions, allowing accurate metrics to be obtained, and for slicing and profiling the modeled data indifferent dimensions. Figure 63 shows a 3D view of data collected at the Lizzie Creek 2 Logging Dam, that has been cut away to schematically show the location of a GPR data plot on the landscape.

Although heavy vegetation at the sites scanned in this investigation proved problematic, under good conditions the response from bare ground can be isolated. Extracted bare-ground points can then be used to construct very high-resolution topographic maps. Other objects and features can be similarly isolated and modeled in three dimensions.

Ground-based laser scanning has advantages over airborne LiDAR not only in point density and precision, but also in the ability to scan from perspectives not achievable from the air. This is particularly useful where vertical surfaces are present. For example, the level of information from from ground-based and airborne scans at the Glensheen Dam (Figures 64 and the 65) are significantly different.

Another possible application of laser scanning is in temporal studies, showing changes to a site or structure over time. An example of this type of study in a riverine environment (although not archaeological in nature) can be found in Vaaja et al. (2011).

Limitations

As in conventional photography, objects in the foreground will mask objects behind them from the laser scanner. Although these gaps in coverage can be filled by scanning from multiple locations, under field conditions it is unreasonable to expect to fully map all surfaces.

Heavy vegetation can be problematic in many ways, and was nearly ubiquitous at the sites scanned in this investigation. Although some of the laser signal may penetrate even heavy brush to reach bare ground or structures that may lie behind, the point density reaching the targets of interest may be very sparse and difficult to isolate. Where trees and brush obscure targets, survey may only be feasible in seasons when leaves are not present. Thick grasses can effectively block all signals. Brush clearing and mowing may be necessary preparation for useful imaging of some sites.

Although airborne LiDAR data is generally lower in precision and resolution, it may be more effective at mapping topography. Because it is collected from a near vertical perspective, airborne LiDAR is generally less impeded by vegetation. That said, it should be mentioned that laser scanning is an emerging technology and the software systems designed to process and interpret the data are in their infancy. Methods of extracting bare ground data are currently being developed and should be available soon.

Laser scanning datasets are very large; a single survey could easily comprise multiple gigabytes of data. Handling survey data is very demanding on computer resources, and may be impracticable on machines without relatively high specifications (at the time of this writing). While it is likely that practitioners will have invested in appropriate computers, this may be an impediment to data sharing and presentation.



Figure 56. Laser scanning at the Tamarack Creek dam site in Pine County.

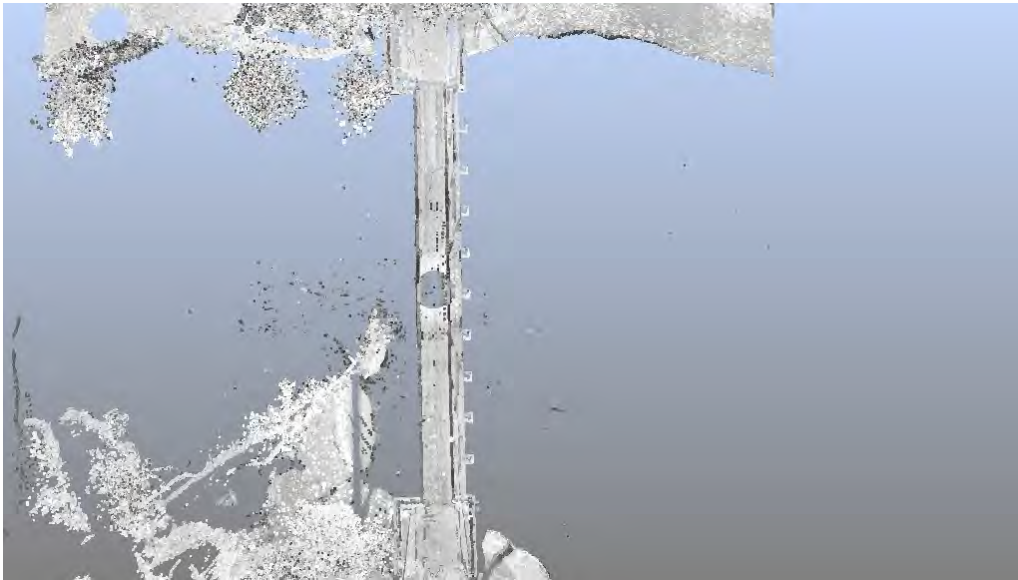


Figure 57. Intensity 3D plan view of the Pierz Dam (MO-PIV-033).

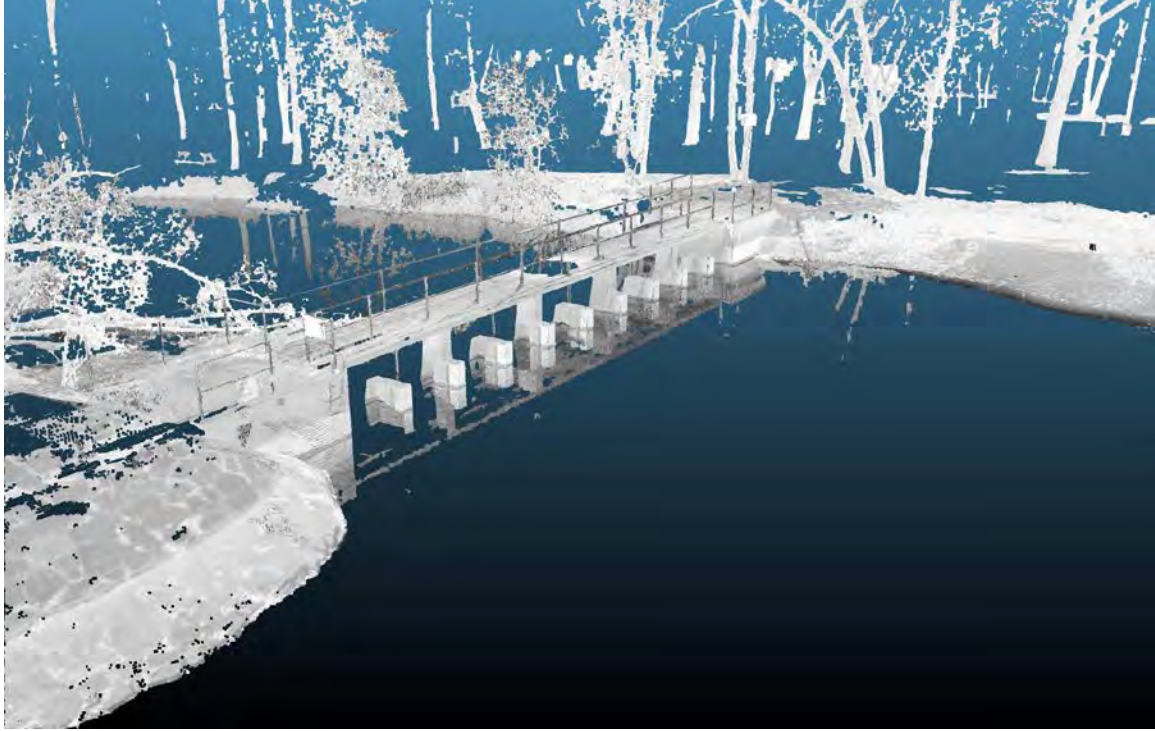


Figure 58. Intensity 3D view of the Pierz Dam (MO-PIV-033), looking north.

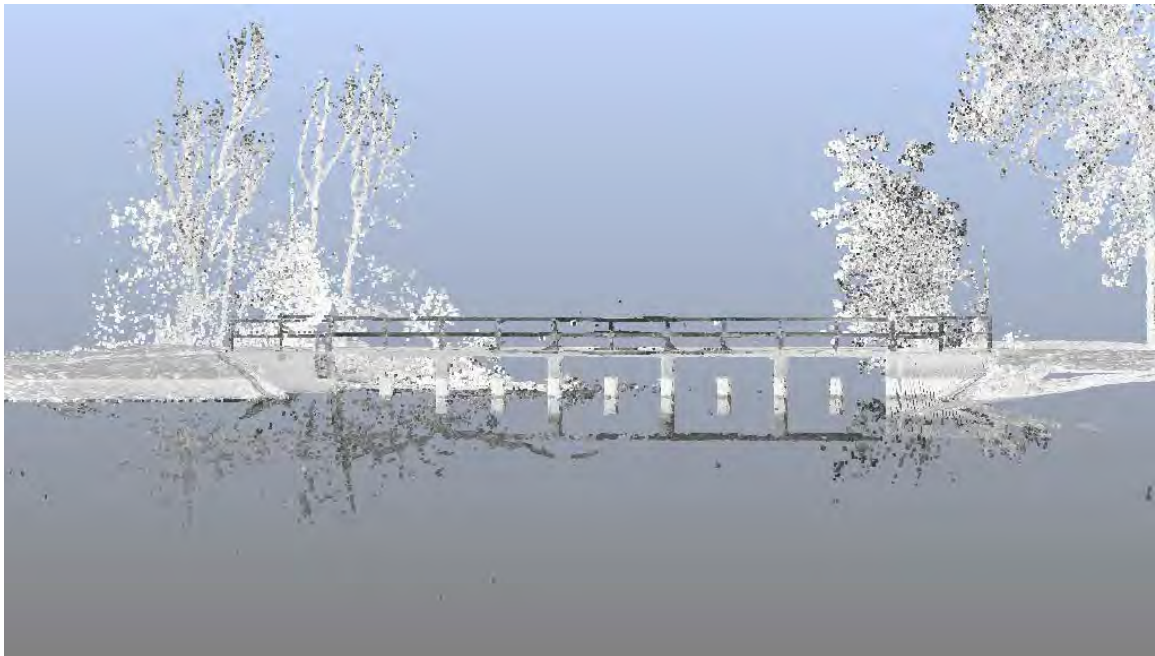


Figure 59. Intensity 3D view of the Pierz Dam, looking northwest.



Figure 60. Color quick view of the Godfrey Dam, looking southeast.



Figure 61. Color 3D view of the Godfrey Dam, looking southeast.



Figure 62. Color quick view of the Tamarack Creek Dam (21PN096), looking east. The image shows log ruins of the sluiceway.



Figure 63. Intensity quick view of the Tamarack Creek Dam (21PN096) sluiceway, looking east.

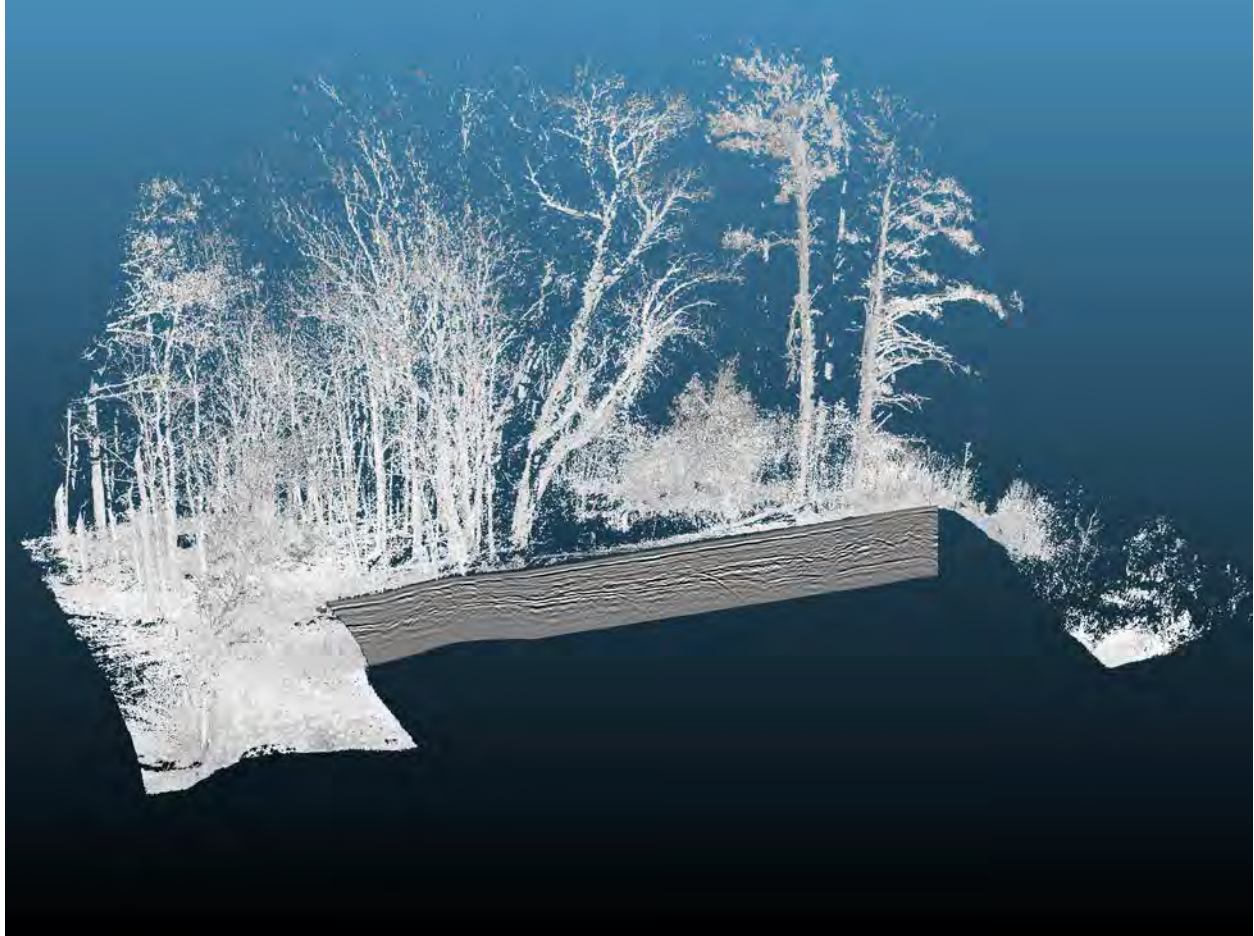


Figure 64. Intensity 3D view of the north wing of Lizzie Creek Logging Dam 2 looking southeast, cut away to show the location of the 225MHz GPR data profile (vertical scale exaggerated). See Figure 55 for a detailed view of the GPR data.

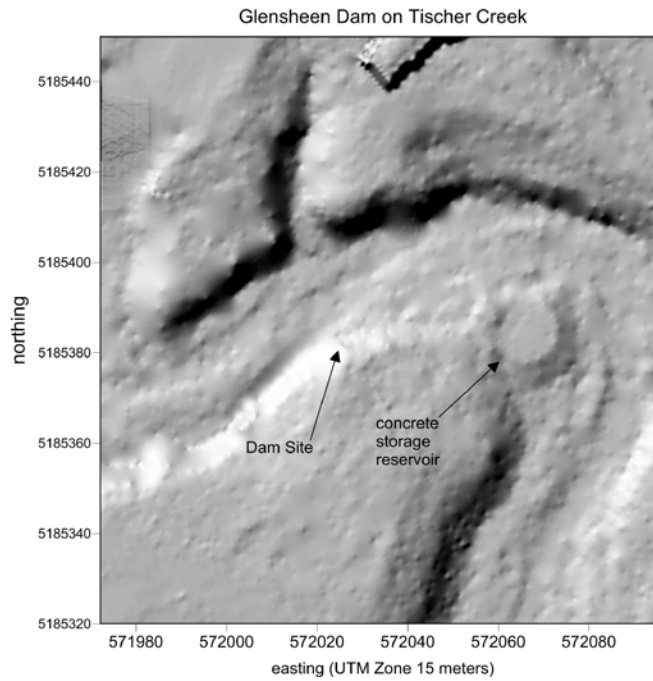


Figure 65. Aerial LiDAR hillshade map of the Glensheen Mansion dam on Tischer Creek. The extreme topography combined with heavy tree cover resulted in a ground point data density too low to effectively map the dam site, although a large cylindrical concrete storage reservoir is visible. The function of the Glensheen dam was to raise the head enough to spill water into a ceramic pipe that filled the concrete reservoir located downstream. This reservoir was the source of water for the mansion gardens and fountain.



Figure 66. 3D intensity view of the Glensheen Dam, looking southwest. The water intake and filtration system is visible to the left of the dam. A 30 meter long concrete dike is partially visible to the right of the dam.

PROPERTY TYPES AND EVALUATION GUIDELINES

Resource Categories and Property Types

What makes a dam “historic”?

In general, a historic Minnesota dam is at least 50 years old, and preserves enough of its original form and materials within a compatible setting to evoke a connection to significant events in history. Dams can also be significant if they materially preserve important design or engineering features. The level of recognizable preservation is referred to as *integrity*.

Historic dams will meet one or more of the National Register of Historic Places (NRHP) significance criteria, most commonly association with historic events (NRHP Criterion A) or distinctive design (NRHP Criterion C). A few dams may also be eligible for their potential to answer important research questions (NRHP Criterion D). In rare cases dams may be eligible for their association with an important individual (NRHP Criterion B).

For this study, historic dams and dam sites are properties built between 1850-1941 that have extant dam structures or remains with historic, architectural, or archaeological significance. Such properties can be evaluated or interpreted as singular sites and as parts of broader site complexes or systems.

Three basic resource categories were defined as part of this study: *archaeological dam sites*, *historic dam structures* with or without ancillary historic buildings or structures, and *historic dam districts* consisting of groupings of historic water control structures within designated historic districts. These resource categories and their integrity thresholds correlate to the categories of historic properties and their attendant integrity elements as defined by the National Register of Historic Places (NRHP) guidelines (Shrimpton 1991).³³ Archaeological sites are required to convey significance through integrity, but will have lower integrity thresholds than structures. Water control structures can be evaluated as singular sites (or site complexes) or as parts of broader technological systems set within dynamic landscapes depending on their historic use.

In this study, three basic property types are defined in relation to their associative historic contexts of *Logging*, *Milling*, and the *Civilian Conservation Corps (CCC)/Works Progress Administration (WPA)*.³⁴ The property types are: *Logging Dams*, *Mill Dams*, and *WPA Dams*. These property types define groups of common resources and provide a link between individual properties and the historic contexts needed to evaluate historic significance (U.S. Department of the Interior 1991:14). Historically, there were many shared vernacular building methods used in logging and mill dams, and these property types can include several of the building materials and techniques described in the section above. WPA dams, on the other hand, have a more defined physical property type.

³³ Available online at <http://www.nps.gov/nr/publications/bulletins/nrb15/>

³⁴ Among historic contexts and property types not addressed in this report are Mississippi River Navigation and Headwaters Dams, agricultural-related reservoirs, check dams, soil-saving dams (e.g., Granger and Kelly 2005, 1:6-131, 132), and diversionary structures like dikes, wing dams, and coffer dams that might not cross an entire channel.

Archaeological dam properties will typically be classified as *sites* or *districts*. Within the NRHP guidelines, archaeological sites are defined as *the location of significant past events where the remnants of a past culture survive in a physical context that allows for the interpretation of the remains regardless of the value of any existing structures* (Townsend 1993).

For this study, archaeological dam properties are defined as the ruins of water impounding structures more than 75 years old that have lost their material integrity to the point that they cannot function as originally intended. Archaeological dam sites and districts contain material evidence of past events within a physical context that allow historical interpretation. Minimally an archaeological dam site could consist of remnants of a ruined dam, but other probable associated features include head gates, borrow pits, embankments, pilings and timbers directly related to the dam. Associated non-dam features could include structural remains of habitation or industrial structures, coterminous artifact scatters, and evidence of contemporary land-based transportation systems. The area where water was impounded could also be part of the dam site if the artificial body of water and associated shoreline can be detected and there is solid evidence that it was historically related to the dam and culturally significant. Typically, the impounded water area will contribute to the setting, but will not be included in site boundaries. In Minnesota, most archaeological dam sites likely date to the 80-year period between 1850-1930. Historic dams at lake outlets often impact precontact sites. These sites should be recorded as multicomponent resources.

Historic dam structures are water impounding constructs that are functioning, or could function with limited repairs. In general historic dams are historically or architecturally significant water-impounding constructs more than 50 years old that are still in use or that could function with repairs. (The 50 year cut-off is derived from NRHP guidelines, but this document only considers dams built before 1941.) Dam-related properties include historic structures like mill races, head gates, embankments and tailraces as well as contiguous buildings such as mills and hydroelectric plants. In cases of reused dam sites and modified dams, older dam-related features or materials might survive as archaeological components underlying or comingled with newer dam structures.

Dam properties, whether structures or archaeological sites, often fall within historic districts and are sometimes pivotal to their significance. The appreciation for evaluating and interpreting dams in relation to historic landscapes is underscored by the fact that of the 25 Minnesota dams presently listed on the National Register of Historic Places, 23 are contributing resources to historic districts. Examples include dams within the St. Anthony Falls Historic District, the Lanesboro Historic District, the Terrace Historic District, and several state parks.

A **historic dam district** is a unified series of dams that work (or worked) in concert on a waterway or in a watershed to regulate water flow of an hydrological area and where the relationships of the individual resources to each other and the hydrological system is intact. The National Register defines a *district* as a *significant concentration, linkage or continuity of sites, buildings, structures or objects united historically or aesthetically by plan or physical development* (Shrimpton 1991:5). A district of dams or dam sites significant for engineering and/or history within a delineated landscape

or watershed area could vary greatly in size from many contributing properties to just a few. For a district, the functional and distinguishable whole is more important than the components, which may individually lack distinction (Shrimpton 1991:17).

Systems of dams (e.g., logging and navigation dams) linked by a waterway or within a watershed district that shared a common water use and historical development can also be evaluated as *discontiguous historic dam districts*. Dams within such districts might be spatially discrete, individually lacking significance, and the geographical gaps between them may be unrelated and non-contributing, but the properties are most meaningful and best understood as an inter-related group of water-control features. Visual continuity between or among the properties is not a factor of significance in this case (Townsend et. al 1993).

Guidelines for Evaluation for Eligibility to the NRHP

First, What is a National Register eligible property?

A property determined eligible for listing in the National Register of Historic Places (NRHP) preserves enough original physical attributes (integrity) to convey their historical association, significant design, or research potential. Properties can be determined eligible under Section 106 of the National Historic Preservation Act of 1966 (as amended) when the State Historic Preservation Office (SHPO) concurs with a federal agency's recommendations, following formal evaluation of the property's historical significance and integrity. The keeper of the Register can also determine a property to be eligible for listing. Eligible properties not listed in the NRHP but are afforded many of the same protections.³⁵

Under the guidelines of this document, dams, dam ruins, and dam districts built between 1850 and 1941 can be evaluated for eligibility to the NRHP through four Significance Criteria as defined by the NRHP: Criterion A: Association with Event(s); Criterion B: Association with Person(s), Criterion C: Distinctive Design/Construction, and Criterion D: Information Potential. This section applies the Evaluation Criteria to cover dams built for logging and milling, and dams built using WPA funding.

Dams can be evaluated under all four National Register of Historic Places criteria, but typically standing structures will be evaluated under Criteria A and/or C, while archaeological properties may be evaluated under Criteria A, C and/or D. Association with a person important in history, Criterion B, may be difficult to establish, and usually requires a long-term connection to the property not found at most dam sites. Dam properties can be eligible at local, state, and national levels of significance.

Other existing resources for dam evaluation outside the contexts of this study include the Multiple Property Documentation Form (MPDF) for *Hydroelectric Power in Minnesota, 1880-1940*, which gives an excellent overview of that context and provides additional useful sources. The *Upper Mississippi River 9-foot Navigation Project, 1931-1948* assesses the significance of large navigation

³⁵See: <http://www.nps.gov/nr/faq.htm> for Frequently Asked Questions regarding the National Register.

dams on the Mississippi. The *Upper Mississippi River Headwaters Reservoirs Damsites: Cultural Resources Investigation* looks at the six headwaters dams (Zellie 1988). These studies cover most dams found on the Mississippi River.

Integrity Considerations for Dams

A property must have integrity to be eligible to National Register of Historic Places. Integrity is defined by the National Register as “the ability of a property to convey its significance.” The seven aspects of integrity are *location, design, setting, materials, workmanship, feeling, and association*. Combined, these elements communicate the historic identity of the property. All dam properties are assumed to have integrity of location and this element will not be discussed. Archaeological dam properties typically have different integrity thresholds, usually requiring fewer aspects of integrity than dam structures.

Following the National Register, **Design** is the *combination of elements that create a form, plan, space, structure and style of a property* (Shrimpton 1991:45). For dam properties, *design* will be expressed as the structural organization of water-impounding elements including dam, dikes, sluiceways, gates and abutments within a human-altered hydrological setting. For districts, *design* is defined as the planned and built relationships between water control structures and related buildings or ruins within an altered natural space.

Setting is the *physical environment of a historic property* and refers to the cultural and natural space where a dam was built. Setting defines how a dam property or district utilized topography, hydrology and landscape to create a technological system adapted to its surroundings. Dam properties may be located in industrial or wilderness settings, but they will always evidence alteration of natural systems.

A dam property with **Material** integrity retains the physical elements used in a particular configuration to build within a specific historic period or tradition. The choice of building materials will be a balance between what was locally available and what was preferred for design, engineering, or economy. Materials will vary from earth and hand-hewn timber, to dimension lumber, to cast concrete.

Workmanship is communicated through the physical evidence of the craftsmanship used to build dams within specific historic contexts. Dams may evidence craftsmanship through details or methods of construction such as timberwork, masonry, metal working, and concrete finishing techniques.

Feeling is a dam property’s communication of the aesthetic or historic spirit of the cultural context within which it was built and used. *Feeling* is an impression created by physical elements of integrity, informed by the historic context and integrated into a sense of a historical quality.

According to the National Register guidelines, “**association** is the direct link between a property and an important historic event or person and a historic property” (Shrimpton 1993). All dams are

associated with the event of their construction and use but rely on physical features to communicate the connection.

A dam property must maintain at least some, and preferably most, aspects of integrity in order to be eligible for the National Register. The aspects of integrity most important to dams are *design* and *setting*, which together convey the intersection of a human-designed water control structure with the natural hydrological setting.

Overview of Criteria for Dam Property Evaluation

Criterion A

All dam properties considered under Criterion A must be associated with an identified event or broad patterns of events that have made a significant contribution to the history of the United States, the state of Minnesota, or a local community. As dams were important elements in industrial, transportation, and community development it is expected that they will be associated with long-term historical movements, particularly economic and industrial developments. All Post-Contact Statewide Contexts identified by the SHPO are potentially related to dam building, but the dam's individual historic significance must be researched and defined.

For historic structures, archaeological sites and districts considered under Criterion A, integrity of *design*, *setting*, *materials* and *feeling* are integral to communicate the association of the property to its historic events. Because dams are water control structures, the property should retain a connection to the historic hydrology, for example the area where water was impounded should be topographically intact.

Criterion B

Dam properties eligible under Criterion B, are associated with the life of a person significant in the past, if they were designed, built, or managed by an individual significant in the relevant history. The dam construct must directly illustrate that person's contribution to history, and be the property *most* relevant to their productive career.

For historic structures, archaeological sites and districts considered under Criterion B, integrity of *design*, *materials*, *setting* and *feeling* are integral to communicating the association of the property to the person. Integrity considerations are similar to Criterion A, and the place should retain enough of the historic dam elements and setting that it would be recognizable to the historic person.

Criterion C

Dam properties are eligible under Criterion C if their design embodies the distinctive characteristics of a type, period or method of construction, or is the work of a master. Dams or dam districts are potentially eligible under Criterion C: if the property embodies a defined type, especially if it is a rare surviving example or was the first of a type; if it illustrates an engineering solution to a unique problem; or if it was designed by a notable designer.

For historic structures, archaeological sites, and districts considered under Criterion C, integrity of *design* and *setting* are overriding. Whether an archaeological ruin or a standing structure, the dam or group of dam constructs must retain their place at the intersection of a hydrological and technological system, and preserve the components that clearly communicate the workings of the water-impounding complex. Integrity of *materials* and *workmanship* are also important to overall integrity under Criterion C.

Criterion D

Criterion D, information potential, requires that an archaeological property or standing dam have the potential to yield significant information important in national, state, or local history. Significant information could fill gaps in our understanding of dam site selection, dam construction techniques or use, local economic development, material use, undocumented ecological effects, or technological change.

Overall integrity of a property may be lower under Criterion D, especially in terms of *setting* and *feeling*, but the integrity of *materials*, *design*, and *workmanship* need to be intact enough to allow the property's physical attributes to be studied and to address research questions. As dams were often rebuilt, information could be contained in older portions of a dam that are inside the existing structure, but care must be taken to assess modifications made outside the period of significance.

Registration Requirements: Logging Dams 1850-1930

Logging dams were integral to the national lumber industry, but were built at remote areas of extraction. Logging dams and dam systems can communicate their association to broader state and national economies that had the capital to fund huge amounts of labor to build massive temporary structures. The massive structures, which are frequently found in physically removed sites, can convey the ways that entirely local materials were used to construct physical structures that served a larger world economy.

Thousands of logging dams were likely built over a period of almost 80 years in Minnesota. Dams followed the logging industry from the St. Croix Triangle to the Mississippi and St. Croix River Basins, and finally to the northern reaches of the state in the Lake Superior and Hudson Bay Drainages. Evaluation of logging dams is complicated by their ubiquity and common lack of documentation.

Logging enterprises constructed dams over an extended period using expedient construction techniques in vernacular configurations that altered little through time. All logging dams that were not rebuilt for another purpose were expected to fail. In fact, cut-away dams were designed to function by induced catastrophic failure. Loss of original integrity was the final stage in the historical event of timber extraction. For this reason, all logging dams in the states of Minnesota, Wisconsin, and Maine are either reconstructions or in ruins. Evaluation of logging dams using the standards of standing structures and not archaeological properties will ensure that properties related to the significant

events related to the large-scale extraction of lumber will rarely if ever qualify as NRHP eligible “historic properties” under Section 106 of the NRHP.

Dams designed by folk laborers may or may not be individually distinctive for engineering or design. The dams can be most easily documented as parts of a linear series on a waterway, but likely worked together as larger systems with other dams in adjacent tributaries as well. For example, dams in several Sub-watershed 6 level creeks that feed into the same waterway likely worked together especially if they are part of the same landownership section. In situations such as this, a single cut-away dam is not eligible on its own, but might be as part of a largely definable system or district—especially if it contains other logging sites, such as log driving dams and camps.

Logging dams, designed by folk engineers, will not typically be distinctive for engineering or design. They were used as individual elements as part of a watershed or stream-based systems. The dams can be most easily documented as a linear series on a waterway, but likely worked together as larger systems with other dams in adjacent tributaries. For example, dams in several Sub-watershed 6 level creeks that feed into the same waterway likely worked together especially if they are part of the same landownership section. In situations such as this, a single cut-away dam is not eligible on its own, but a largely intact system—especially if it contains other logging sites, such as camps—is potentially eligible as a district linked by the waterway.

Recent evaluation of multiple in-stream logging properties in the Superior National Forest, for example, found that: “Log procurement features should not be evaluated with a focus on the extant timber components of the dam that remain in the waterway, but rather as a complex of features that relate to each other as well as to a potential district of structures constructed to work in conjunction during the transport of logs” (Reetz 2012: 11-4). Unfortunately, logging districts may be difficult to evaluate as they can encompass large areas. The Superior National Forest study suggests that researchers look at waterways and watersheds to understand the visibility and integrity of related resources, especially when making a determination of NRHP eligibility (Reetz 2012: 11-4).

Districts, therefore, could be a contiguous grouping of logging related properties including dams within an historic timber catchment landscape. In this case, National Park Service Bulletin 30 *Guidelines for Evaluating and Documenting Rural Historic Landscapes* can provide guidance (McClelland nd.) and use of LiDAR mapping within a watershed can help define both resources and catchment areas.

Logging dams may also be part of districts defined by their place in an engineered water control system. In some cases, the space between the dam elements was not significant to their historic functioning as a transport system. In such a discontinuous district, water control features can be spatially discrete and visual continuity is not a factor in evaluation.

A MPDF *Commercial Logging in Minnesota (1837-1930s)* treats the larger historical pattern, and places dams within the property type classification of transportation properties (Birk 1998). Related

statewide contexts include: *Indian Communities and Reservations* (1837-1934); *St. Croix Triangle Lumbering* (1830s-1900s); and *Northern Minnesota Lumbering* (1870-1930s). A MPDF for the *Historic Logging Industry Sites in the Chequamegon-Nicolet National Forest* also provides background for evaluating logging dams within the context of the lumber industry in neighboring Wisconsin (Moffat et al. 2011).

Under this context logging dams are eligible under criteria A, B, C, and/or D in the following cases:

- 1) Under all criteria the logging dam or dam system was built for the purpose of commercial transport of logs. A single dam (particularly a cut-away) that depended on a larger system of water control structures to move logs on a waterway is not eligible as a stand-alone resource.
- 2) *and* the property is significant at the local, state, or national level, as defined in a site-specific context.
- 3) *and* the dam or series of dams preserve original large-scale configurations of log cribs and/or earthen features, even if the dam or dams have failed. Individual logs and rocks need not be in their original place, but they are close to where the water historically moved them from.
- 4) Under Criterion B, the dam or dam system has a significant on-site association with the productive career of a person important in logging history over the course of several years in construction and operation
- 5) Under Criterion D, dams and dam sites convey significant information not found within documentary evidence. The data may be in the form of large-scale features as they related to the local ecology, engineering of river driving systems, or dam construction methods, and may not depend on artifact patterning.

Integrity requirements: logging dams

For a logging dam property to be eligible under Criteria A, B and C all of the following integrity elements must be met. For dams eligible under Criterion D, crucial integrity qualities include *materials* and *design*, combined with *association* to an identified research area.

Design

Under all criteria, a logging dam site or district is eligible when intact features communicate its complete planned spatial configuration and the functional design within a specific hydrological situation. In particular, embankments are visible on the sides of the streambed, and earth borrowing or moving features are intact. Visible crib work, rip-rap, stone work, aprons, sluiceways or sills pegged or pinned to the stream bed may be in ruins from hydrological failure (a final event for almost all logging dams), but have not have been significantly altered by demolition or reuse. Note that in-stream timber and stone resources that only represent the gate and sluiceway to release water and logs from a larger dam structure do not define a dam.

Setting

The original setting is similar to the historic period. The dam is still on a flowing waterway. All logging dams capitalized on topographic features such as hills, steep banks and even glacial eskers to maximize water containment. For an eligible dam property, these elements and their connection to the dam are intact. Logging dams impounded massive quantities of water in swamps and other natural water reservoirs: in eligible dam sites or systems, the water storage area is not damaged and the surroundings of the flowage are of a similar character to the historic setting. Under Criteria A and B, enough of the landforms and setting are unspoiled so that persons involved in dam construction or use could recognize the location. Finally, other logging property types found in association with the dam can contribute to the setting.

Materials

In eligible logging dams original *materials*, primarily earth, rocks and logs, are largely sound even if the central gate structures were “blown out.” Later additions such as bridge abutments, roads or the addition of new materials detract from archaeological visibility and integrity especially under criteria A, B, and C. If additions are also historically significant, the dam site should be evaluated under a dual period of significance.

Workmanship

Elements that express the character of the dam construction, such as long linear earthen mill embankments, signs of hand hewing of wood elements, and forged iron pins contribute to the sense of workmanship for eligible archaeological structures.

Association and Feeling

An eligible dam or dam system is associated with a developed context of the logging industry specific to the site with a defined period of significance. Dam construction dates to the locally significant period. Proximity to coniferous forests may help communicate the association to lumbering.

Registration Requirements: Mill Dam Properties

Milling dam properties diverted water from streams to power flour and saw mills during a period of statewide industrial development that peaked in the 1870s and 1880s. Potentially hundreds of dams built between 1850 and 1900 are directly associated with this significant period in milling history and some dams were repaired and reconstructed to power mills and hydroelectric plants well into the twentieth century. Because the dams themselves were often unrecorded and built using vernacular building methods, these once ubiquitous properties can be difficult to document.

In addition, milldams can be difficult to physically identify. Logging dams had to be massive enough to store reservoirs of water and logs for months. Conversely, most mill dams were only large enough to impound enough water to power a mill for a day, usually in a flowage of water within an incised stream bed. For this reason, mill dams, are much more difficult to see in LiDAR and, when washed out, may completely disappear. The smaller size, location only within the channel margins, and use

of impermanent building methods means that only a small percentage of mill dams are preserved either as structures or ruins.

Mill dam properties may exist as dams, dam ruins or as part of larger properties that include mills, raceways, tailraces, and transportation networks. Existing mill dams listed in the National Register, such as the dams at St. Anthony Falls and Lanesboro Historic Districts are part of larger milling districts. Related statewide contexts are: *Indian Communities and Reservations* (1837-1934), *Early Agriculture and River Settlement* (1840-1870), *St. Croix Triangle Lumbering* (1830s-1900s); *Northern Minnesota Lumbering* (1870-1930s), and *Urban Centers* (1870-1940).

Under this evaluation framework, Milling Dams or dam sites can be considered under criteria A, B, C and D when:

- 1) The dam or dam system was built for the purpose of storing or diverting water to power a mill. The dam was built during the period of significance for the mill that it served within a developed historical milling context significant at the local, state, or national level.
- 2) The essential features of the dam property are not modified and preserve a record of labor and materials from the period of significance. Older dams may have been repaired, but the structure retains the historic configuration and a majority of features and materials from the period of significance. Archaeological dams preserve the original large-scale configuration of features, even if the dam has failed. Individual structural elements need not be in their original place, but they are close to where the water historically moved them.
- 3) Some association to the mill served by the dam is preserved.
- 4) Under Criterion B, the mill dam had a significant association with the productive career of a person important in milling or millwright history and is the best or first extant example of their work.
- 5) Under Criterion D, mill dams and dam sites convey significant information not found within documentary evidence. The data may be in the form of large-scale features as they related to engineering a water-powered milling systems or dam construction methods, and may not depend on artifact patterning.

Integrity Requirements: Mill dams

For a mill dam property to be eligible under Criteria A, B, or C all of the following integrity elements must be met. For dams eligible under Criterion D, *materials* and *design*, combined with *association* to an identified research area are crucial integrity qualities.

Design

Under all criteria, a milling dam site or milling district preserves intact dam features designed to impound flowing water and transfer power to a mill. At a minimum a dam site conveys a sense of where water was impounded in relation to a mill. Especially under Criterion C, tunnels, raceways, canals, and tailraces or ruins of these features indicate the transfer of water or waterpower from a dam to a mill.

Setting

The original setting is similar to the historic period. For example, the dam is on the original waterway or mill pond and the topography and land use do not detract from the historic feeling. In some cases, milling dams capitalized on topographic features such as deeply incised banks, waterfalls, rapids and stone stream margins. Some mill dams created mill ponds which enhance the historic setting. Under Criteria A and B, enough of the landforms and setting are unspoiled that persons involved in dam construction or milling at the site could recognize the location. Finally, other milling property types found in association with the dam contribute to the setting.

Materials

Under all Criteria original building materials are intact. For archaeological sites, visible crib work, rip-rap, stone work, masonry, aprons, canals or sills pegged or pinned to the stream bed may be in ruins from hydrological failure, but have not been significantly altered by demolition or reuse. For structures, the original building materials are visible unless the dam is being evaluated for information potential. Modifications outside the period of significance are often needed for the safe continued use of a dam, but these modifications do not detract from the historic construct.

Workmanship

Elements that express the character of dam construction from the period of significance are intact.

Association and Feeling

Typically an eligible dam property conveys its association and feeling when the above aspects of integrity are intact. Proximity to a mill or mill site will confirm the association to milling.

Registration Requirements: Federal Relief/WPA Dams

WPA dams built with the assistance of Federal Relief and are part of a historically significant event that took place on national, state, and local levels. Most Minnesota dams built between 1935 and 1941 are directly associated with this significant event. Because the State Department of Conservation, Division of Waters assisted local units of government by providing dam designs that would be easily approved for Federal assistance, hundreds of dams were built on a modular design making certain types ubiquitous and difficult to assess. In some examples, WPA dams integrate earthen logging dam elements into their design especially embankments. These elements could contribute to significance.

The related statewide MPDF for *Federal Relief Construction in Minnesota, (1933-1941)* provides an excellent background on federal relief construction in Minnesota and is a good starting point for research (Anderson 1993). This document states that federal relief conservation structures should be either: 1) significant for large scope; 2) distinctive of a type; 3) the only known type; or 4) part of a larger complex (Anderson 1993:F20-F21). These registration guidelines best suit larger projects.

Widespread dam modification by the Department of Conservation, Division of Waters later altered many of the dams and some landscaped surroundings have been vandalized.

This document defines registration guidelines for the family of Minnesota Type “C” dams. Dams funded by the WPA are unlikely to be eligible under Criteria B or D, thus those criteria are not covered by this document. WPA dams were usually community projects built by groups of unemployed men and designed by committee, thus they will rarely be eligible under Criteria B, association with a person. These dams are well documented and were relatively recently built, thus they are not anticipated to have information potential under Criterion D.

Under the developed context Federal Relief Dams can be considered for eligibility to the NRHP under criteria A and C in the following cases:

- 1) The dam was built during the period of significance using a plan created by the Minnesota Department of Conservation, Division of Waters and approved by a Federal granting organization, usually the WPA.
- 2) The dam was funded with federal monies using local labor and materials.
- 3) The dam was or is useful to a local community, and ideally is sited in a visible and accessible location. Conservation dams help to maintain water levels that contribute to recreation, tourism, or harvesting of fish or wild rice.
- 4) The essential features of the dam as described in the WPA dam construction methods section have not been removed or modified.

Integrity Requirements: WPA dams

For a WPA Type “C” dam property to be eligible all of the following integrity elements must be met.

Design

The dam has the essential elements required to impound water as defined in the drawn plans. In particular, piers are intact and not sawn down, intact slots allow use of stop logs, the WPA plaque is retained, and the supports and railings for the catwalk are intact. Plans for all dams can be found in *Manual of Standard and Special Lake Level Control Dams, Showing Principal Dimensions and Elevations* (Frellsen 1941). The Skunk Creek Dam in Pierz is an example of a dam that retains all of the elements that make it appear and function as designed.

Setting

The original setting is similar. For example, a dam that was publically accessible is still reachable, the dam is not flooded, and is on a waterway or at a lake outlet. A dam/bridge supports an active roadway. The surrounding of the flowage are of a similar character to the historic setting. Again, the Type “C” dam in Pierz is an example of a dam that retains its original connection to a landscape designed as a WPA-funded city park and golf course where a small swimming area is still maintained.

Materials

The original materials are intact. Wooden stop logs and walkways may be replaced, but masonry is in good original condition. The WPA gave preference to projects that could make a significant contribution to both employment and a local community. Local materials were used in these situations because they were inexpensive for financially strapped local units of government to provide, but often required a maximum effort, and thus wages, to extract and integrate into a dam structure. The expression of local materials, usually stone masonry unique to the particular locale, is integrated into the dam's immediate surroundings.

Workmanship

Elements that express both the broad character of the WPA dam construction, such as chamfered corners of the poured concrete, as well as individual workmanship of stone masonry are intact. Likewise, workmanship in the placement and use of local materials is evident, even if it does not evidence great skill.

Association and Feeling

The WPA plaque or other cast concrete panels that indicate the dam's date and that it was built with State and Federal assistance communicate the association of dams to the historic context and are preserved.

Recommendations

All structures require some maintenance to prevent falling into ruin, but the action of water, ice and the atmosphere on a dam can be particularly damaging and upkeep is costly. Taking no action and allowing a dam to deteriorate is not a workable option, because failure can be dangerous or even catastrophic. Many historic dams in Minnesota are currently past their engineering lifespan and decisions will need to be made regarding their treatment.

In addition to the safety and cost issues, dams pose threats to the ecology of living rivers by trapping sediments and limiting fish migration. Even in the historic period, these were forceful concerns and the construction of dams was often opposed by fishing interests. For example, as early as 1838 the construction of the Housatonic River was rejected by the Legislature of Connecticut. “Only a low tumbling dam, however, was permitted to be built, a high one being forbidden on account of its preventing the passage of the shad — a higher value being then attached to the shad fisheries than to the manufacturing interest” (Leffel 1874 :63).

Dams and the area where they impound water historically sat at important intersections between rivers and developing towns and industrial centers. Dams themselves may be historically significant and removal has the potential to both destroy the water-impounding resource and affect the setting of historic properties and districts. For this reason, a proactive consultation process should be undertaken to balance historic preservation concerns with river renewal.³⁶

This document will assist the process of dam inventory, evaluation, and documentation. Integrating sections developed for this project into Multiple Property Documentation Forms (MPDFs) approved by the Minnesota SHPO and the National Park Service could formalize evaluation guidelines. The existing logging MPDF could be supplemented with the additional dam information and evaluation criteria. Likewise, the WPA dam section could be made into a stand-alone document or amended to the Federal Relief MPDF.

Rather than individually evaluating dams, assessing effects and planning to mitigate effects on an individual, case-by-case basis a Procedural Programmatic Agreement (PA) could streamline the review and compliance process. Programmatic agreements are most useful for common undertakings and resources types and can establish standard treatments that serve the missions of both historic and environmental conservation. One advantage is that the overall resource type, in this case historic dams, can be more easily managed by looking at the resource from a statewide perspective. In addition, criteria outside the 106 process can be considered to create a hierarchy of interests. A

³⁶ The document *Dam Removal and Historic Preservation: Reconciling Dual Objectives* presents important information on this process http://www.dnr.state.md.us/fisheries/bloededam/image/FINAL_BOOK_LAYOUT.pdf

programmatic agreement would be made between the lead agencies and the SHPO with input from consultation with interested and informed parties.

Inventory of dams can be improved by using consistent language to describe the resources and consistently classifying and inventorying resources. Logging dams are currently inventoried as archaeological sites with numbers, un-numbered Alfa archaeological sites, and as structures, causing confusion in the evaluation and management process. Consistent inventory as archaeological sites and recordation of the entire resource, not just in-stream elements is recommended. Site names should derive from the location, logging company, or other significant source and should include the words “logging dam.” Similar treatment of mill dams is recommended depending on the resource type.

This team was able to visit two historic dams that have been removed in Sandstone (PN-SST-006) and Cannon Falls (GD-CFC-032). In Sandstone the dam abutments are still in place and parts of the wooden sill are still pinned to the streambed. As well as conveying a sense of the historic dam area, the remaining structure preserves information about historic dam building techniques. By removing most, but not all of the dam, the building methods are not submerged or covered and can be inspected. In contrast, the complete removal of any evidence of the dam in Cannon Falls does not allow for any interpretation of the historic relationship or importance of the dam to the existing town. This ahistoric feeling of landscape erasure is compounded by the fact that the dam is shown on local maps of the riverfront, there is a Mill Street, and yet there is no interpretive signage about the dam at the restored rapids. In cases such as these where a dam sits within or next to a historic district, notching the dam or leaving abutments greatly improves a sense of the past use and historic treatment of the river.

This team also found that recording dams that are in use, especially using photography and laser scanning, is greatly complicated by impounded water. States such as Maine have trained dam removal teams to document dams before and during removal to streamline the process of documentation and gather as much information as possible about the non-renewable historic resource.

Dams served an important function in the historical development of Minnesota. Many once important water-impounding properties are currently into disuse or disrepair and there is an increasing understanding of their role in the viability of our rivers. Streamlining the historic inventory and evaluation process through the use of this and other historic preservation documents are a first step in managing these important cultural resources. Proactive consultation between historic preservation and natural resources managers will allow the legacy of Minnesota’s historic dams to be effectively preserved.

end

Sources

Anderson, Rolf

1991 *Minnesota State Park CCC/WPA/Rustic Style Historic Resources, Multiple Property Documentation Form*. National Register of Historic Places, United States Department of the Interior, National Park Service.

1993 *Federal Relief Construction in Minnesota, Multiple Property Documentation Form*. National Register of Historic Places, United States Department of the Interior, National Park Service.

Anfinson, John O.

2003 *The River We Wrought. A History of the Upper Mississippi*. Minneapolis: University of Minnesota Press.

Anfinson, John O., et al.

2003 *River of History. A Resources Study of the Mississippi National River and Recreation Area*. A cooperative report by the National Park Service and the St. Paul District Corps of Engineers.

Anfinson, Scott

1989 Archaeology of the Central Minneapolis Riverfront, Part 1 Historical Overview and Archaeological Potentials. *The Minnesota Archaeologist* 48(1-2).

Anonymous

1894 Untitled article on wild fires. *Princeton Union Newspaper*, 6 September 1894.

1895 "The Dam Blowed." *Princeton Union Newspaper*, 20 June 1895.

1903 "She Had Nerve and a Big Gun." *Minneapolis Journal*, 24 April 1903.

Arnott, Sigrid, Geoffrey Jones, and David Maki

2013a *National Register of Historic Places Nomination Form for Indian Mounds Park, St. Paul, Minnesota*. United States Department of the Interior, National Park Service, Washington DC.

Arnott, Sigrid, Scott Brosowske and David Maki

2013b *National Register of Historic Places Nomination Form for Fort Juelson, Otter Tail County, Minnesota*. United States Department of the Interior, National Park Service, Washington D.C.

Artz, Joe Alan, Emilia L. D. Bristow, and William E. Whittaker

2013 *Mapping Precontact Burial Mounds in Sixteen Minnesota Counties using Light Detection and Ranging (LiDAR)*. Contract Completion Report 1776. Office of the State Archaeologist, University of Iowa, Iowa City.

- Bacig, Tom and Fred Thompson
1982 *Tall Timber*. Voyageur Press, Stillwater, MN.
- Baraga, Bishop Frederic
1966 *A Dictionary of the Otchipwe Language, Explained in English*. Reprint. Minneapolis: Ross and Haines.
- Bennett, Rebecca, Kate Wilhelm, Ross A Hill, and Andrew Ford
2012 A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data. *Archaeological Prospection*. Volume 19, p. 41-48.
- Bassell, Burr C.E.
1904 *Earth Dams: A Study*. The Engineering News Publishing Company. New York, NY. Accessed on Nov. 5, 2013 at< <https://archive.org/details/cu31924090409289>>
- Bell, Mary T.
1999 *Cutting Across Time: Logging Rafting and Milling the Forests of Lake Superior*. The Schroeder Area Historical Society, Schroeder, MN.
- Benchley, Elizabeth
1997 Nineteenth Century Logging along the Indian River in the Upper Peninsula of Michigan. In *The Michigan Archaeologist*, 43(2-3):153-174.
- Bigfork Commercial Club et al.
1956 *On the Banks of the Bigfork. The Story of the Bigfork River Valley*. Bigfork Minnesota.
- Billington David P., Donald C. Jackson, Martin V. Melosi
2005 *The History of Large Federal Dams: Planning, Design, and Construction in the Era of Big Dams*. Government Printing Office. accessed on November 5, 2013 at http://books.google.com/books?id=Q0Kc1MDUvZ4C&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false
- Birk, Douglas A.
1988 "A Preliminary Historical and Archaeological Survey of the 'Old Chengwatana' Locale, Pine County, Minnesota." *Institute for Minnesota Archaeology Report of Investigations*, Number 34. Minneapolis.
- 1997a Outta the Woods and Onto the Mills: Shifting Timber-Harvest Strategies on Minnesota's Early Lumbering Frontiers. *The Michigan Archaeologist*, 43(2-3):51-86. See also: <<http://www.fromsitetostory.org/sources/papers/mnlogging/mnlogging2.asp>>
- 1997b The Procurement Aspects of the Commercial Pine-Logging Industry in Minnesota (1837-1930s). *National Register of Historic Places, Multiple Property Documentation Form*. National register of Historic Places, Copy on file at the Minnesota State Historic Preservation Office, St. Paul.
- 1997c Stanchfield's Logging Camp. *National Register of Historic Places Registration Form*. Copy on file at the Minnesota State Historic Preservation Office, St. Paul.

- 1997d The Definition and Evaluation of Log Procurement Properties in Minnesota. *Institute for Minnesota Archaeology Reports of Investigations*, Number 451. Minneapolis.
- Blegen, Theodore C.
1963 *Minnesota. A History of the State*. Minneapolis: University of Minnesota Press.
- Brown, Nelson C.
1936 *Logging Transportation: The Principles and Methods of Log Transportation in the United States and Canada*. Wiley and Sons, New York.
- Bryant, Ralph C.
1923 *Logging. The Principles and General Methods of Operation in the United States*. Second edition. John Wiley & Sons, New York.
- Capp, Edward H.
1904 *The Story of...Baw-a-ting being the Annals of Sault Sainte Marie*. Sault Ste. Marie: Sault Star Presses.
- Carlson, Bruce M.
2007 *Beneath the Surface. A Natural History of a Fisherman's Lake*. St. Paul: Minnesota Historical Society Press.
- Carroll, Jane Lamm
1990 Dams and Damages. The Ojibway, The United States, and the Mississippi Headwaters Reservoirs. *Minnesota History* 52(1):2-15.
- Carstens, Patrick R. and Timothy L. Sanford
2011 *Searching for the Forgotten War-1812*. Xlibris Corporation.
- Challis, Keith, Paolo Forlin, and Mark Kinsey
2011 A Generic Toolkit for the Visualization of Archaeological Features on Airborne LiDAR Elevation Data. *Archaeological Prospection*. Volume 18, p. 279-289.
- Conservation Commission [CC]
1932 *First Biennial Report of the Commission on Conservation*. State of Minnesota, St. Paul, MN
- Coy, Fred. Jr., Tom Fuller, Larry G. Meadows, Don Fig
1992 Splash Dam Construction in Eastern Kentucky's Red River Drainage Area. *Forest & Conservation History* 6(4):179-184.
- Craik, David
1877 *The Practical American Millwright and Miller*. Carey Baird & Company. accessed on November 5, 2013 at <https://play.google.com/store/books/details?id=sG0JAAAAIAAJ>
- Creager, William Pitcher
1917 *Engineering for Masonry Dams*. J. Wiley & Sons, Inc accessed on November 5, 2013 <https://play.google.com/store/books/details?id=rI46AAAAMAAJ>

Curtiss-Wedge, Franklyn ed.

1911 *The History of Mower County*. H.C. Cooper and Co., Chicago IL.

Dennis, Michelle

1998 *Federal Relief Construction in South Dakota, 1929-1941*. Prepared for the South Dakota State Historic Preservation Office, Pierre, South Dakota accessed on August 8, 2013 at: <<http://history.sd.gov/preservation/OtherServices/SDFedRelief.pdf>>

Department of Conservation, Division of Drainage and Waters

1948-1951 Department of Conservation, Division of Waters Memos and Letters in the "Dam Modifications" Folder. Conservation Department Water Division Records in the collection of the Minnesota State Archives of the Minnesota Historical Society.

Department of Conservation, Division of Drainage and Waters

1939 Typical Lake Control Dam, Type "C" Blueprints on file in the Conservation Department Water Division Records in the collection of the Minnesota State Archives of the Minnesota Historical Society.

Dickmann, Donald, and Larry Leefers

2003 *The Forests of Michigan*. University of Michigan Press.

Dinsdale, Evelyn M.

1965 "Spatial Patterns of Technological Change: The Lumber Industry of Northern New York." *Economic Geography* 41(3):252-274.

Douet, James (editor)

2012 *Industrial Heritage Re-tooled. The TICCIH Guide to Industrial Heritage Conservation*. Carnegie House, Chatsworth Road, Lancaster, England: Carnegie Publishing.

Dunn, James T.

1966 "The St. Croix: Midwest Border River." *Rivers of America Series*. Carl Carmer, editor. New York: Holt, Rinehart and Winston.

Dunwiddie, Foster W.

1975 The Six Flouring Mills on Minnehaha Creek. *Minnesota History* 44(5):162-174.

Durant, Capt. Edward W.

1905 "Lumbering and Steamboating on the St. Croix River." *Collections of the Minnesota Historical Society* 10(2):645-675.

Elazar, Daniel

1989 Model of Moral Government. *Minnesota in a Century of Change: The State and its People Since 1900*. Minnesota Historical Society Press, St. Paul, MN:329-360.

Elverum, Kim A., and Tim Smalley

2012 The Drowning Machine. A Boat and Water Safety Pamphlet on Low Head Dams. St. Paul:Minnesota Department of Natural Resources accessed 10/5/13 at <http://files.dnr.state.mn.us/education_safety/safety/boatwater/drowningmachine.pdf>

- Evans, Oliver, Cadwallader Evans and Thomas Ellicot
 1848 *The Young Millwright and Miller's Guide*. Lea and Blanchard, Philadelphia, PA, accessed 10/5/13 at <<https://play.google.com/store/books/details?id=UEW7-CQPFoUC>>
- Folsom, W. H. C.
 1888 *Fifty Years in the Northwest*. Pioneer Press Company.
- 1901 "History of Lumbering in the St. Croix Valley, with Biographic Sketches." *Minnesota Historical Society Collections*, 9:291-324.
- Forester, Jeff
 2004 *The Forest for the Trees: How Humans Shaped the North Woods*. St. Paul: Minnesota Historical Society.
- Frame, Robert M., III
 1977 *Millers to the World. Minnesota's Nineteenth Century Water Power Flour Mills*. St. Paul: Minnesota Historical Society, Division of Field Services, Historic Sites, and Archaeology.
- 1980 *The Progressive Millers: A Cultural and Intellectual History of the Flour Milling Industry, 1870-1930 Focusing on Minneapolis, Minnesota*. Thesis submitted to the Faculty of the Graduate School of the University of Minnesota.
- 2013 Unpublished database of Minnesota Flour Mills.
- Fossum, Paul R.
 1930 Early Milling in the Cannon River Valley. *Minnesota History* 11(03):271-282.
- Frear, Dana W.
 1963 Early Sawmills of Hennepin County. *Hennepin County History*, Fall 1963: 3-5.
- Frellsen, Sidney A.
 1941 *Manual of Standard and Special Lake Level Control Dams, Showing Principal Dimensions and Elevations*. Division of Water resources and Engineering, Department of Conservation, State of Minnesota.
- Fries, Robert F.
 1989 *Empire in Pine: Lumbering in Wisconsin 1830-1900*. Wm Caxton Ltd. Sister Bay, WI (reprint of 1951).
- 1948 The Mississippi River Logging Company and the Struggle for the Free Navigation of Logs, 1865-1900. *The Mississippi Valley Historical Review*. 35(3):429-448.
- Frizzel, Joseph and Charles Allen
 1879 Examination of the Sources of the Mississippi, Saint Croix, Chippewa, and Wisconsin Rivers to Determine the Practicability and Cost of Creating and Maintaining Reservoirs upon the Headwaters of said Rivers, with a view to Improving Navigation of the Same. *Annual Report Chief of Engineers to the Secretary of War for the Year 1879, Appendixes to the Report of the Chief of Engineers*. accessed April 28, 2013 at: <https://play.google.com/books/reader?printsec=frontcover&output=reader&id=ri9RAAAAYAAJ&pg=GBS.PA941>

- Fuller, Clara K.
1915 *History of Morrison and Todd Counties, Minnesota*. 2 volumes. Indianapolis: B.F. Bowen.
- Gallagher, Julie and Richard Josephs
2008 Using LiDAR to Detect Cultural Resources in a Forested Environment: an Example from Isle Royale National Park, Michigan, USA. *Archaeological Prospection*. Volume 15, p. 187-206.
- Gardner, Denis
2004 *Minnesota Treasures: Stories Behind the State's Historic Places*. Minnesota Historical Press, St. Paul, MN.
- GISL (Geographic Information Sciences Lab)
2012 Multi-Hazard Mitigation Plan. Lake County, Minnesota. Report prepared by the Geographic Information Sciences Lab, University of Minnesota Duluth. See: http://www.co.lake.mn.us/vertical/sites/%7BA88D6CA0-192C-4EBE-8698-70C44B114E79%7D/uploads/LakeMHMP_2012.pdf
- Gould, Edward Sherman
1897 *High Masonry Dams*. D. Van Nostrand accessed on November 5, 2013 at <https://play.google.com/store/books/details?id=rJA6AAAAMAAJ>
- Greenleaf, James L. C.E.
1887 The Water-power of the Mississippi River and some of its Tributaries. *Reports on the Water-power of the United States, Part II*. Department of the Interior Census Office, Tenth census 1880.
- Granger, Susan, and Scott Kelly
2005 *Historic Context Study of Minnesota Farms, 1820-1960, Volume 2*. Report prepared by Gemini Research for the Minnesota Department of Transportation. Available online at: http://www.dot.state.mn.us/culturalresources/pdf_files/crunit/vol2.pdf
- Halsey, John R, Eric A. McDonald, and Rose Lockwood Moore
1997 The East Branch Big Creek Logging Dam and Sluiceway (200D25), Oscoda County, Michigan. In *The Michigan Archaeologist*, 43(2-3):115-126.
- Hart, Irving H.
1927 The Old Savanna Portage. *Minnesota History*, 8(2):117-139.
- Hohman-Caine, Christy A. and Grant E. Goltz
2005 "Evaluation of Itasca Logging Company Hatch/Turtle Lake Logging Dam, Itasca County, Minnesota." Unpublished report prepared for the Itasca County Highway Department.
- Hollenstein, Gene H.
1962 Power Development in Minnesota. *Minnesota Conservation Department, Division of Waters, Bulletin 20*. St. Paul.

- Holmquist, June D., and Jean A. Brookins
 1972 *Minnesota's Major Historic Sites. A Guide*. Revised second edition. St. Paul: Minnesota Historical Society.
- Hess, Jeffrey
 1989 *Minnesota Hydroelectric Generating Facilities, 1881-1928 Multiple Property Documentation Form* National Register of Historic Places, Washington, DC. on file at the Minnesota State Historic Preservation Office.
- Hesse, Ralph
 2010 LiDAR-derived Local Relief Models – a new tool for archaeological prospection. *Archaeological Prospection*. Volume 17, p. 67-72.
- Howell, Charles
 1976 Colonial Water wheels in the Wooden Age. in *America's Wooden Age: Aspects of Early Technology*, Brooke Hindle ed. Sleepy Hollow Press, Tarrytown Press, NY.
- Hughes, William Carter
 1862 *The American Miller, and Millwright's Assistant*. H.C. Baird. accessed on November 5, 2013 at <<https://play.google.com/store/books/details?id=bzxIAAAAIAAJ>>
- Hunn, Karene A. Motivans, and Walter A. Okstad,
 1983 "Logging Industry Thematic Study," Cultural Resource Management on the Superior National Forest, *1982 Annual Report, Cultural Resource Report No. 1* (Duluth, Minn.: U.S.D.A. Forest Service, 1983.
- Hunter, Louis C.
 1979 *A History of Industrial Power in the United States, 1780-1930. Volume One: Waterpower in the Century of the Steam Engine*. Charleston: University Press of Virginia.
- 1976 Waterpower in the Century of the Steam Engine. In *America's Wooden Age: Aspects of Early Technology*, Brooke Hindle ed. Sleepy Hollow Press, Tarrytown Press, NY.
- Johnson, Nathan
 2009 Pine City. *Images of America Series*. Charleston, South Carolina: Arcadia Publishing.
- Kane, Lucile M.
 1987 *The Falls of St. Anthony. The Waterfall That Built Minneapolis*. Reprint. St. Paul: Minnesota Historical Society Press.
- Kellogg, Louise Phelps (editor)
 1953 *Early Narratives of the Northwest, 1634-1699*. Reprint. New York: Barnes and Nobles.
- Larson, Agnes
 1949 *The White Pine Industry in Minnesota*. University of Minnesota Press, Minneapolis.
- Larson, Willard
 2011 *Early Sawmills of Minnesota*. Private printing limited to 100 copies.

Lass, William E.

1977 *Minnesota. A Bicentennial History*. New York: W. W. Norton and Company.

Leffel, James

1868 Illustrated Catalogue and Price List of Leffel's American Double Turbine Water Wheel. Springfield, James Leffel and Co. Springfield, OH accessed on November 5, 2013 at <<https://play.google.com/store/books/details?id=zyQyAQAAMAAJ>>

1874 *The Construction of Mill Dams*. Springfield, James Leffel and Co. Springfield, OH accessed on November 5, 2013 at <<https://play.google.com/store/books/details?id=7A4uAAAAIAAJ>>

1881 *Leffel's Construction of Mill Dams and Bookwalter's Millwright and Mechanic*. James Leffel and Co.

McClelland, Linda Flint, et al.

n.d. *Guidelines for Evaluating and Documenting Rural Historic Landscapes, National Register Bulletin 30*. U.S. Department of the Interior, National Park Service.

McClure, E.W

1888 *Township map of the St. Croix River and Tributaries: showing locations of dams / by., surveyor, Stillwater, Minn.* <http://collections.mnhs.org/cms/display.php?&irn=10643477>

McClurken, James M. (compiler)

2000 *Fish in the Lakes, Wild Rice, and Game in Abundance. Testimony on Behalf of Mille Lacs Ojibwe Hunting and Fishing Rights*. East Lansing: Michigan State University Press.

McDermott, John Francis

1941 *A Glossary of Mississippi Valley French, 1673-1850. Washington University Studies, New Series, Language and Literature*, 12. St. Louis.

McMahon, Eileen M. and Theodore J. Karamanski.

2009 *North Woods River: The St. Croix River in Upper Midwest History*. University of Wisconsin Press, Madison.

Merritt, Raymond H.

1979 *Creativity, Conflict & Controversy: A History of the St. Paul District U. S. Army Corps of Engineers*. Washington: U. S. Government Printing Office.

Minnesota Department of Natural Resources

n.d. Lake Outlet Dams. pdf accessed on August 10, 2013 at <http://files.dnr.state.mn.us/publications/waters/lake_outlet_dams.pdf> and <http://files.dnr.state.mn.us/waters/publications/lakeoutlet.pdf>

Minnesota State Historic Preservation Office

1993 *Preserving Minnesota: Planning for Historic Preservation into a New Century. A Comprehensive Preservation Planning Process. A Summary of Historic Contexts. Tier I: Broad Statewide Contexts*. Manuscript on file at the Minnesota State Historic Preservation Office.

Minnesota State Drainage Board

1912 *Report of the Water Resources Investigation of Minnesota, 1911-1912*. St. Paul: McGill-Warner.

Minnesota Territorial Legislature

1849 “An Act granting a charter to Elam Greely, his heirs, &c. to construct and maintain a dam across Snake river near the outlet of Cross Lake.” *Laws of Minnesota*, Chapter 31, October 20, 1849.

Moffat, Charles R., Mark Bruhy, Sean Dunham, and Kathryn C. Egan-Bruhy,

2011 *Historic Logging Industry Sites in the Chequamegon-Nicolet National Forest, Multiple Property Documentation Form* National Register of Historic Places, Washington, DC. on file at the Wisconsin State Historic Preservation Office.

Moon, Frederick and Nelson C. Brown,

1915 *Elements of Forestry*, Wiley and Sons, London
<https://play.google.com/store/books/details?id=Y1spAAAAYAAJ>

Nelligan, John Emmett

1929 “The Life of a Lumberman.” *The Wisconsin Magazine of History* 13(2):131-185.

Oliphant, Laurence

1855 *Minnesota and the Far West*. Edinburgh: William Blackwood and Sons.

Olsen, Walter. S.

1934 Division of Drainage and Waters. Department of Conservation, Conservation Commission Third Biennial Report. State of Minnesota: 38-72.

1936 Division of Drainage and Waters. Department of Conservation, Conservation Commission Third Biennial Report: 48-74.

1940 Location Maps for Lake Level Control Dams. Division of Drainage and Waters, Vol I. Department of Conservation, State of Minnesota.

Pine River Journal

Sept. 3, 1936 “Dam Started at Mayo Lake in Cass”

January 23, 1936 “Lake Levels to be Raised in Cass”

accessed on August 10, 2013 at Minnesota Reflections newspaper collection

<<http://reflections.mndigital.org/cdm/search/collection/p16022coll2/searchterm/The%20Pine%20River%20Journal/field/title/mode/all/conn/and/order/nosort>>

Poole and Hunt

1883 *Illustrated Descriptive Pamphlet and Price List of the Poole & Hunt Leffel Turbine Water-wheel: Manufactured by Poole & Hunt, Engineers & Machinists, Baltimore, Md., U.S.A.*

Accessed on Nov. 5, 2012 at

<<https://play.google.com/store/books/details?id=KicxAQAAMAAJ>>

Quaife, Milo Milton (editor)

1916 Extracts from Capt. McKay's Journal and Others. *Proceedings of Sixty-Third Annual Meeting*, 186-210. Madison: The State Historical Society of Wisconsin.

Ralph, George A., Chief Engineer

1910 *Report of the Water Resources Investigation of Minnesota 1909-1910*, State Drainage Commission, McGill-Warner Co, St. Paul, MN.

Ralph, George A., Chief Engineer

1912 *Report of the Water Resources Investigation of Minnesota 1911-1912*, State Drainage Commission in Cooperation with the United States Geological Survey, McGill-Warner Co, St. Paul, MN.

Roberson, John and Clayton Crowe

1993 *Engineering Fluid Mechanics*. Houghton Mifflin Co. International.

Rajala, Benhart

1991 *Tim-BERRR! Pine Logging in the Big Fork River Country*. St. Cloud: North Star Press.

Rajala, Jack

1998 *Bringing Back the White Pine*. Private printing. Duluth: Pro Print.

Elizabeth C. Reetz

2012 *Multiple Property Evaluation of In-Stream Historic Properties in the Lake Superior Basin of the Superior National Forest*. Under the Auspices of the Great Lakes Restoration Initiative.

Rector, William G.

1949 From Woods to Sawmill: Transportation Problems in Logging. *Agricultural History*, Vol. 23 (4):239-244 accessed at <<http://www.jstor.org/stable/3740583>>

1953 *Log Transportation in the Lake States Lumber Industry 1840-1918*. Arthur H. Clark Co. Glendale CA.

Riley, Melanie, Joe Alan Artz, William Whittaker, Robin Lillie, and Andrew C. Sorensen

2010 *Archaeological Prospection for Precontact Burial Mounds Using Light Detection and Ranging (LiDAR) in Scott and Crow Wing Counties, Minnesota*. Contract Completion Report 1768. Office of the State Archaeologist, University of Iowa, Iowa City.

Riggs, Stephen R.

1992 *A Dakota-English Dictionary*. Reprint. St. Paul: Minnesota Historical Society Press.

Roberson, John A and Clayton Crowe

1993 *Engineering Fluid Mechanics*. Fifth Edition, Houghton Mifflin Company, Princeton, New Jersey.

- Romain, William F., and Jarrod Burks
 2008 LiDAR Analyses of Prehistoric Earthworks in Ross County, Ohio. *Current Research in Ohio Archaeology* 2008,
http://www.ohioarchaeology.org/joomla/index.php?option=com_content&task=view&id=233&Itemid=32, accessed July 27th, 2013.
- LiDAR Assessment of the Newark Earthworks. *Current Research in Ohio Archaeology* 2008,
http://www.ohioarchaeology.org/joomla/index.php?option=com_content&task=view&id=232&Itemid=32, accessed August 10th, 2013.
- LiDAR Imaging of the Great Hopewell Road. *Current Research in Ohio Archaeology* 2008,
http://www.ohioarchaeology.org/joomla/index.php?option=com_content&task=view&id=231&Itemid=32, accessed August 11th, 2013.
- Ryan, J.C.
 1976 *Early Loggers in Minnesota*. Volume 2. Minnesota Timber Producers Association, Duluth MN
- Schoen, Christopher M.
 2004 *Phase II Archaeological Evaluation of the St. Croix Lumber Company Dam (21LA0g) and the Dunnigan Lake Civilian Conservation Corps Camp (21LA526) Along Trunk Highway 1, Lake County, Minnesota*. prepared by The Louis Berger Group, Inc. for MnDOT
 accessed April 28, 2013 at
 <<http://www.dot.state.mn.us/d1/projects/hwy1reconstruct/pdfs/archeologyreportphase2.htm>>
- Sedell, James R., Leone, F. N. and Duval, W. S.,
 1991 Water Transportation and Storage of Logs. *American Fisheries Society Special Publication* 19:325-368.
- Shrimpton
 1993 *How to Apply the National Register Criteria for Evaluation*, *National Register Bulletin 15*. U.S. Department of the Interior, National Park Service.
- Skaar, Kent,
 1997 *Minnesota Department of Natural Resources, Trails and Waterways Unit Cultural Resources, Annual report*, MNDNR and MHS.
- Smith, Chester W.
 1915 *Construction of Masonry Dams*. McGraw-Hill Book Company, accessed on November 5, 2013 at
 <https://play.google.com/store/books/details/Chester_Wason_Smith_Construction_of_Masonry_Dams?id=V09DAAAIAAJ>
- Stanchfield, Daniel
 1901 "History of Pioneer Lumbering on the Upper Mississippi and Its Tributaries, with Biographic Sketches." *Collections of the Minnesota Historical Society* 9:325-362.

State of Minnesota

1859 *Public Statutes of the State of Minnesota. (1849-1858)*. St. Paul: Pioneer Printing Company.

Stearns, Alton

2003 *Pine, Timber and the Otter Tail River*. Becker County Historical Society, Detroit Lakes, MN.

Stuntz, George R.

1884 "Evidences of Early Man in Northeastern Minnesota." *Minnesota Academy of Natural Sciences Bulletin*, 3:76-84.

1885 "The Mound Builders in Northeastern Minnesota; Their Occupations and Routes of Travel." *Minnesota Academy of Natural Sciences Bulletin*, 3:84-88.

Townsend, Jan, John H. Sprinkle, Jr., and John Knoerl

1993 *Guidelines for Evaluating and Registering Historical Archaeological Sites and Districts*. *National Register Bulletin* 36, National Park Service, USDI.

Upham, Warren

1888a "The Geology of Chisago, Isanti, and Anoka Counties." *The Geological and Natural History Survey of Minnesota, Final Report*, 2:399-425. N. H. Winchell, editor. St. Paul: Pioneer Press Company.

1888b "The Geology of Crow Wing and Morrison Counties." *The Geological and Natural History Survey of Minnesota, Final Report*, 2:580-611. N. H. Winchell, editor. St. Paul: Pioneer Press Company.

1888c "The Geology of Mille Lacs and Kanabec County." *The Geological and Natural History Survey of Minnesota, Final Report*, 2:612-628. N. H. Winchell, editor. St. Paul: Pioneer Press Company.

1888d "The Geology of Pine County." *The Geological and Natural History Survey of Minnesota, Final Report*, 2:629-645. N. H. Winchell, editor. St. Paul: Pioneer Press Company.

1899 "The Geology of Cass County and of the part of Crow Wing County northwest of the Mississippi river." *The Geological and Natural History Survey of Minnesota, Final Report*, 4:55-81. N. H. Winchell, editor. St. Paul: Pioneer Press Company.

1969 *Minnesota Geographic Names. Their Origin and Historic Significance*. Reprint. St. Paul: Minnesota Historical Society.

U. S. Army Corps of Engineers, St. Paul District, Mississippi Valley Division

2003 *Section 524 Inventory and Assessment Report: WPA Dams in Minnesota*. PDF provided to author by USACOE.

USACOE

2012 *A History Tour: Upper Mississippi Headwater Reservoirs Dam sites*. (CEMVP 25-42 | REV.07.12). U.S. Army Corps of Engineers, St. Paul District.

- Vaaja, Matti, Juha Hyyppä , Antero Kukko, Harri Kaartinen, Hannu Hyyppä, and Petteri Alho.
2011 Mapping Topography Changes and Elevation Accuracies Using a Mobile Laser Scanner. *Remote Sensing* 3(3), 587-600.
- Vandersluis, Charles, et al.
1974 *Mainly Logging*. Minneota, Minnesota: Minneota Clinic.
- Vogel, John N.
1983 "The Round Lake Logging Dam: A Survivor of Wisconsin's Log-driving Days." *Wisconsin Magazine of History* 66(3): 171-191.
- Washburn, F. L.
1886 "Notes of a Trip up the Thief River and at Lake Mille Lacs." *The Geological and Natural History Survey of Minnesota, Fourteenth Annual Report for the year 1885*, 338-342. St. Paul: J.W. Cunningham.
- Waters, Thomas F.
1977 *The Streams and Rivers of Minnesota*. Minneapolis: University of Minnesota Press.
- Wegmann, Edward
1888 and 1899
The Design and Construction of Dams: Including Masonry, Earth, Rock-fill, and Timber Structures: Also the Principal Types of Movable Dams John Wiley and Sons, NY.
- West, Jessie C. and Alvin H. Wilcox
1907 *A Pioneer History of Becker County, Minnesota*. St. Paul: Pioneer Press Company.
- Williamson, John P.
1992 *An English-Dakota Dictionary*. Reprint edition. St. Paul: Minnesota Historical Society Press.
- Wilson, Herbert M,
1893 *Manual of Irrigation Engineering*. John Wiley and Sons, New York, NY. accessed at: https://play.google.com/store/books/details/Herbert_Michael_Wilson_Manual_of_Irrigation_Engine?id=lxtCAAAAMAAJ on October 15, 2013.
- Winchell, Newton H. (editor)
1911 *The Aborigines of Minnesota*. St. Paul: Minnesota Historical Society.
- Winchell, Newton H.
1888 "The Geology of Washington County." *The Geological and Natural History Survey of Minnesota, Final Report*, 2:375-398. N. H. Winchell, editor. St. Paul: Pioneer Press Company.

Zellie, Carole

1988 *Upper Mississippi River Headwaters Reservoirs Damsites: Cultural Resources Investigation, Lake Winnebigoshish, Leech Lake, Pokegama Lake, Sandy Lake, Pine River and Gull Lake Reservoirs*. Prepared for the Army Corps of Engineers, St. Paul District, St. Paul, MN.

Ziegler, Frank

1977 *"Ken-Â-Big" The Story of Kanabec County*. Robert H. Beck, editor. Mora, Minnesota: B&W Printers.