The Streams of Time: The History of Channelization in Dane County's Riparian Systems and the Hope for Healing

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Geography Undergraduate Colloquium
December 16, 2017

Abstract:
Water is, and likely will always be, both a celebrated and fervently contested natural resource. Rivers have been both a basis for development of civilization and a victim of that development. Dane County, Wisconsin is no different, with streams both near cities and in the midst of farmlands whose natural bends and meanders have been forced off their natural course by the pressures imposed by urbanization and irrigation. This study defines the timeline of channelization in and the threats this poses to the ecological health of Dane County's stream systems from 1836 to 2013. The 10 streams that were investigated all faced varying levels of channelization, despite their different lengths and settings within the county, exemplifying that waterway alterations have known no bounds in the past. However, actions taken by several organizations and government officials indicate that there is hope for the healing of these damaged systems.

Introduction

In a country where nature has been so lavish and where we have been so spendthrift of indigenous beauty, to set aside a few rivers in their natural state should be considered an obligation.

Frank Church, U.S. Senate sponsor of the Wild and Scenic Rivers Act

Whether for recreation, transportation, or irrigation, it is always the hope of people settling in a new area that a reliable water source is near by. Streams are an abundantly useful resource, given that they can aptly meet each of these needs. However, growing cities and agricultural operations have impinged on these natural waterways on many occasions, sometimes forcing them off of their natural courses. Too often, these impacts are not considered or realized until a project is already complete, further fueling the contentious nature of any kind of development project involving water.

Channelization is a method of transforming a naturally meandering, or curving, river into a more straight and uniform one (Brooker 1985, 63-64). This can happen due to the natural water flow of a stream, although this is typically on a small scale and is generally a rare occurrence. Our project will focus more on the concept of man-made channels, which happen on a much larger scale. Historically meandering waterways that flow naturally with the curves of the landscape become straight or otherwise physically altered through the processes of dredging, tiling, or ditching (Luthin 2004, 36, 43). While channelization often makes building new roads or creating irrigation channels more efficient, it also drastically alters the flow of the stream. This can lead to problems related to increased water flow velocity, such as flooding downstream, and decreased capacity for the river's curves to act as a filter for sediments and pollutants.

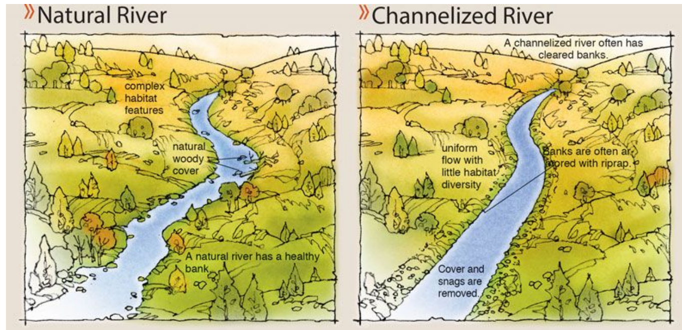

Figure 1. Naturally meandering streams are characterized by rich biodiversity within the riparian buffer zone and a geometry that flows naturally with the landscape. Channelized rivers tend to be straighter and deeper and in many cases have lost some of their riparian buffer zone. Downstream flooding becomes more prevalent due to increased flow velocity. *(Image source: geocaching.com)*

Wisconsin has a long history of management of and a complicated relationship with its water resources. Dane County is home to a variety of streams and creeks, with many in either the Yahara or Rock River watersheds. With Madison at its center, waterways in Dane County have faced channelization for well over a century as the capital city and its suburbs grew and evolved. Through the analysis of aerial photography and historical maps focusing on ten different streams, we will examine the history of channelization and the attitudes toward these water resources in Dane County.

This project aims to answer the following questions: 1) What historical patterns characterize the channelization of urban and rural streams in Dane County, Wisconsin? 2) Does urban or agricultural development play a greater role in the channelization of these streams? 3) How does the channelization of Dane County waterways embody the evolution of America's relationship with water resources, and more broadly, the natural environment?

We will create GIS shapefiles that identify where channelized streams are and where ecological restoration projects have taken place and use these to perform analyses on physical changes over time. While this will not include every stream in Dane County, we will examine streams in various locations throughout the county in order to demonstrate the pervasive nature of channelization throughout both urban and rural environments.

Literature Review

Historical Background

Sometimes a statement can be so oft repeated that the many breaths used to speak the old idiom wear out all its meaning, like the fast water of a stream smoothes out a stone. One such expression now devoid of significant meaning thanks to frequently careless retelling is the cliché "Water is Life". One can immediately see how little meaning remains in these three words, which still are tossed about like snowballs. When a speaker or writer falls back on reminding his audience that "water is life", what is it that he means? Maybe the orator means instead that to possess water is to possess life. This is a more nuanced statement, but still owes more to the wisdom of Hallmark than to any philosopher.

Water did not merely shape human civilization; it defined it, supported it, and propelled it onward. The mastery of water resources fueled Europe's rise to global ascendancy. New technologies to drain waterlogged wetlands resulted in agricultural booms, which provided the incentive for a market revolution and the means to support a rising population (Solomon 2010, 162). Trade and a strong maritime culture sprang up in Europe, beginning with the Vikings and progressing to the far sailing whalers and fishermen of the Basque, English, and Nordic peoples. As European maritime technology developed and European sailors adopted technologies from China and the Middle East, the possibility of voyages westward became possible (Solomon 2010, pg. 179). These voyages stumbled upon a continent unknown to civilizations of Europe, Africa, and Asia, opening a new world of opportunity for wealth and power, which had European nations tripping over each other to get a piece of the pie. While the Spanish were focusing on raiding, conquering, and ruling, the existing native empires of Central and South America- burgeoning maritime empires like Great Britain, France, and the Netherlands- set about planting agricultural colonies in North America (McHenry 1972, 27). The establishment of these colonies birthed a distinctly American culture, which was christened by adventures in the so-called 'wild frontier,' and later confirmed by a War of Independence against its colonial metropole. How these Americans, born in the shadow of a seemingly intractable wilderness, acted towards the streams and rivers of this country defined the calamity American waterways have suffered in the roughly two and a half centuries of westward expansion.

Alexis de Tocqueville, the famous French observer and commentator on American culture in the early days of the republic, describes the American attitude towards the natural beauty of the wilderness they strode out to tame: "…they may be said not to perceive the mighty forests that surround them till they fall beneath the hatchet. Their eyes are fixed upon another site: the American people views its own march across these wilds, **draining swamps, turning the course of rivers**, peopling solitudes, and subduing nature [emphasis added]" (McHenry 1972, 119). From the beginning, Americans have viewed the water as simply another aspect of the wild to be tamed and utilized for the people of the new nation. While commenting on the cultural and geographic unity of the growing nation in 1853, the writer Jesup W. Scott remarks:

> For commercial and social purposes, it [the central United States] is more the whole because of its lakes and rivers. By these channels are our people bound together. Even if steam [railroads] had not begun its race on the land, its triumphs on our interior waters [steamboats] in cementing the bonds of union among its various parts, would have been complete. From the remotest regions, men and the products of their labor are transported by steam to the central marts of trade. In short, steam, working on our waters, has made our commerce one and our people a brotherhood (McHenry 1972, pg. 121).

Clearly, to the pioneers and their descendents, rivers and streams served primarily as arteries of transportation for people and materials. Towards that end, local, state, and federal governments instituted river "improvement" projects that sought to "enhance" the commercial value of these important transportation routes, often by deepening the river channel, digging new canals, or by straightening the river's path.

Wisconsin Laws

These "improvement" projects proved popular with many Americans, including the citizens of the young states of Wisconsin, Michigan, and Minnesota. Delegates from these three states met at a convention held in Prairie du Chien in 1868 and issued a resolution strongly requesting the federal government to begin a navigation project connecting the Mississippi River to Lake Michigan by means of the Wisconsin and Fox Rivers (*Resolutions of the Convention Held in Prairie du Chien, Wisconsin* 1868). The petitioners outlined several familiar reasons for the project: commerce, defense, and unity between states. Navigation projects had long been etched into the consciousness of Old Northwest. In 1868, John H. Henry speculated on the economic impacts of these improvement projects:

> When all our vast railroads, canals, and telegraph lines are completed, and rivers improved, with our thousands of steam horses, steam and canal boats, moving every second of the day, who can calculate the immense extension which our internal trade will assume, and what will be the result in regard to the price of all the comforts of life… By improving rivers, canals, and building railroads, we have already surpassed all the nations of the earth… [All] that is needed to make us the most prosperous and strongest nation of the globe is to… **place strong bridles on our wild water-horses which eat up so much of our wealth, annually swallowing millions of acres of our choicest land as their food** [Emphasis added] (McHenry 1972, 125-126).

While water managers did not consider many of the streams in Dane County fit for navigation projects, Henry hints on another historic objective of river channelization: land "reclamation". To both the local farmers and the central planners in Washington or Madison, many "wasteful" wetlands thwarted farmers' access to new agricultural lands. To open previously undeveloped areas of the country to settlement and profitable economic growth, local, state, and federal authorities implemented drainage projects, the scars and effects of which can still be seen on Wisconsin landscapes. A pamphlet published in 1909 outlining drainage legislation in Wisconsin listed eighteen separate bills concerning proposed drainage projects (Kearney 1909, 7-11). Planners often carved new drainage ditches or deepened existing streams to drain wetland areas for farmers. These practices found their legal foundation and political blessing in the so-called Swamp Land Act (Kearney 1909, 4).

National Laws

The Supreme Court determined that, "[The Swamp Land Act] declares a public policy on the part of the government to aid the States in reclaiming swamp and overflowed lands unfit for cultivation in their natural state, and is a recognition of the right and duty of the respective States, in consideration of such grants, to make and maintain the necessary improvements" (Kearney 1909, 4). Wisconsin quickly latched on to this decision and rapidly pushed ahead for land reclamation programs. The pamphlet states that "In no other State of the Union is the subject [of wetland drainage] under consideration of more importance than in Wisconsin. Our favorable location, our nearness to the principal markets of the country, and the abundant richness of our soil,, all impel us to be active in the work of reclaiming our wet lands and thereby adding immensely to the wealth and comfort of a growing population" (Kearney 1909, 6). And so the war against Wisconsin's wetlands continued.

Closely related to land reclamation was two other related objectives: flood and erosion prevention. Following the near complete clearing of forested land in the Mississippi River value and other regions of the central United States, flooding increased dramatically (McHenry 1971, 183-186). The Congressional Subcommittee on Conservation and Natural Resources noted during a public hearing on stream channelization in 1971 that "the dredging, channelization, and modification of rivers and streams undoubtedly may serve or increase available water storage, **provide flood protection to bottom land** which is then developed for residences and crops, decreases mosquito populations and increase land value [Emphasis added] (House Government Operations Committee 1971, 2). In effect, flood prevention had become the central objective of government channelization projects. A bill proposed in 1935 from the House Committee on Flood Control listed twenty six individual "river improvement projects" to prevent flooding and improve navigability (*Public Works Projects for Controlling Floods, Improving Navigation, Regulating the Flow of Certain Streams, Etc*. 1938). These proposed ventures included dam, canal, and artificial embankment creation and restoration projects costing billions of dollars (*Public Works…* 1938). The truly remarkable aspect of this bill is how unremarkable it is; this piece of flood control legislation is simply one bill, proposed during one congressional session, from a committee that probably proposed hundreds of such programs.

Erosion prevention shares a similar pattern to federal navigation and flood control projects. In a statement to the Subcommittee on Conservation and Natural Resources, Charles H. Callison of the National Audubon Society comments on how the U.S. Soil Conservation Service

(SCS) “set out to show and teach the farmers of America how to keep their topsoil from washing and blowing away, how to keep the rainfall from rushing destructively down the hillsides, how to hold more precious water in the uplands, how to use the land wisely according to its natural characteristics…” (House Committee… 1971, 9). Callison contrasts the service with the approach of the U.S. Army Corps of Engineers whose “method was to try to capture and control the runoff by building big dams on the main stems of river systems. And when the dams turned out usually inadequate to hold all the floodwaters, the corps would straighten the channels below the dams and contain them with higher and higher levees, thus to hasten the discharge of waters to the sea” (House Committee… 1971, 9). Callison then states that the work of the SCS began to adopt many of the practices of the Army Corps of Engineers, turning “meandering rivers into straight and tidy ditches” (House Committee… 1971, 10). Callison further charges that these changes and projects only benefited a few landowners along the river who gained a few acres more of farm land (House Committee… 1971, 10).

Conservation

Thankfully, momentum began to build against channelization and other forms of degradation. The torch of conservation, passed by spoken and written word from Muir and Roosevelt to Leopold, Carson, and Nelson. Americans finally awakened to the warnings conservation organizations like the National Audubon Society, the Sierra Club, and The Wilderness Society, and set about to right the wrongs of the past. Environmental and conservation organizations testified at the hearing before the Subcommittee on Conservation and Natural Resources, explaining the damage federal flood prevention and land reclamation programs had on wildlife. The Committee itself outlined these charges, stating that previous river improvements projects may have: destroyed trout and game species habitat; polluted downstream reservoirs and lakes; destroyed swamps and other natural water purification sites; encouraged farmers to drain their own lands through lateral ditches; increased erosion upstream and flooding downstream; destroyed vast areas of wildlife habitat through the cumulative effects of individual projects; frustrated the ability of ground water to naturally recharge during rainy seasons; and encouraged further development and degradation of floodplains (House Committee… 1971, 3-4). The feedback during this public hearing strongly indicted the management practices of these federal bureaucracies, and stated unequivocally that soil and water conservation of the type practiced by the Army Corps of Engineers and the SCS was not conservation at all.

The disasters of the drainage programs were well-known in Wisconsin: Aldo Leopold chronicled the disastrous draining of the extensive marshes of the "sand counties" of central Wisconsin. He writes that speculators and farmers assumed the deep peat soil left when the marsh was drained would provide excellent crop land (Leopold 1949, pg.106). Instead, this peat, so rich in organic material accumulated over thousands of years, began to decompose as soon as it dried (pg. 106). Then it burned. After the fires extinguished, all that was left of the much vaunted soil was inhospitable sand. The Horicon Marsh found it's savior in Louis Radke, who recognized the potential in the land and fought to acquire it as public land to restore it from the drained wasteland it had become (Kahl 2011, 14). After a seven year campaign educating the public, Radke saw his long awaited goal come to life as the Horicon Marsh Wildlife Refuge Bill passed in 1927 (Kahl 2011, 37). The state of Wisconsin had appointed Otto Zeasman, a soil-drainage expert with the University of Wisconsin Extension to oversee this project, and in his professional memoirs Zeasman recounted his deep disappointment with the fiasco. Zeasman recalls how farmers from the prairie states had been lured to purchase the drained land by land speculators who organized the drainage project (Zeasman 1972, 8). The victims of these shady sales often sold their moderately sized prairie farms for large tracts of drainage land (Zeasman 1972, 8). Soon, many of these farms were abandoned. An important biodiversity hotspot in central Wisconsin had been sacrificed, and not a penny was made on the bargain.

Zeasman, in his memoirs, comments on a bill that was under debate in the Wisconsin legislature in 1971 that sought to curtail future drainage projects (Zeasman 1971, 10). And while the old campaigner in the war against wetlands believed the legislation to be folly, stating that the outside regions “do not appear to be suffering for want of wet land”, the existence of such a bill suggests that the attitude of Wisconsinites towards their water resources had begun to change (Zeasman 1971, 10-11).

And attitudes did begin to change. Channelization projects slowed, and local, state, and federal agencies took more care to protect existing streams and rivers. But then, in the 1990’s and 2000’s, stream restoration projects began. Building on efforts trout fishing organizations experimented with in earlier years, Wisconsin community members and non-profits began to heal their rivers. Stream restoration efforts on Black Earth Creek in western Dane County had paid off well, as the stream quickly became recognized as one of the premier trout streams in the United States (Wisconsin State Journal 1991, 51). In 1998, a dam removal project on Token Creek in Dane County restored another section of stream (WSJ 1998, 9). Members of the Dane County chapter of Trout Unlimited implemented another stream restoration project on Deer Creek, also in Dane County, which yielded similar results to the Black Earth Creek restoration, creating another choice trout stream (Madison Capitol Times 1999, 5B). After eighteen years of informal existence, the Token Creek Watershed Association applied for non-profit status in 1999, shortly after the Wisconsin Department of Natural Resources unveiled a long-term, multi-million dollar restoration project for Token Creek (WSJ 1999, 7). Following the dawn of the new millennia, numerous restoration projects have been proposed and completed, restoring and truly improving hundreds of miles of stream in Wisconsin. Thankfully, the current has turned, and the future of stream restoration has never been brighter.

Many of the streams of Dane County, Wisconsin, shared in this fate. And while the timing of the channelization project or the agencies that executed them have not yet been uncovered by this project, a simple logical exercise suggests that the majority of streams were degraded for the sake of land reclamation and flood control. The channels of interest to this project simply lack the depth, width, or convenience to be used for any more navigation than canoeing. With the exception of Wingra and Starkweather Creeks, and the canal created to connect Lake Mendota and Monona, these creeks do not connect any urban areas, or even flow through urban areas. The majority of channelization occurs in rural areas, or in "natural" areas composed from abandoned drainage projects.

Ecological Background

Geomorphology

Streams are aquatic systems characterized by unidirectional flow and they typically have three zones: benthic zone, hyporheic zone, and the riparian zone. Looking at the hydrology of rivers and streams, stream flow is the master variable for ecological conditions in streams.

Stream flow is typically measured by discharge, the volume of water passing through a channel cross section per unit time. Different streams have different flow regimes - which is characterized by the discharge pattern over time - determined by magnitude, frequency, duration, timing, and rate of change of the discharge. Differences in discharge reflect geology, regional climate, and human alteration.

Typically rivers and streams do not have thermal stratification due to their being very well mixed, however, they have greater thermal variation compared to that of lakes. The smaller volume of water and shallower basin allows for more rapid thermal changes. Amount of light reaching the river depends on two controls, surrounding conditions and water characteristics, which can aid the changes in temperature and variety of habitats within streams (Kuglerova 2016, 2). Trees, canyons, and banks can all be light blocking features found on landscapes, while depth and particulate matter can be river characteristics that affect amount of lights. Spatial patterns of streams also lead to differing amounts of light. Small streams can have high or low amounts of light, depending on the geography, tree cover, and the season. Larger rivers typically receive high amounts of light due to the open canopy, yet the light rarely reaches river bottom, partially due to depth and partially due to turbid waters absorbing the light (Knox 1977, 324). These variances in stream environments provide complex fish and habitat structures, allow for higher species abundance.

Flow regimes are often used to assess extent of human alterations and to identify determinants of stream community composition. The human alterations can be measured by looking at the change in flow regime over time, typically caused by channelization for agriculture, navigation, or to reduce local flooding. Channelized or straightened streams tend to have faster water flow, which causes deepening and widening of the channel, along with increases in erosion and flooding (Brooker 1985, 63-64). By removing natural meanders, the higher velocity of water leads to difficulty recharging ground water, increasing probability of downstream flooding, and increasing erosion (Wisconsin Department of Natural Resources 2015, 29).

In Wisconsin, erosion caused by channelization can cause high nitrate levels in groundwater, which can get into our drinking water and cause health issues at high levels (Wisconsin Department of Natural Resources 2015). The high volume of channelized waterways in agricultural lands of Wisconsin is characterized by removal of the riparian buffer zone along the water (Knox 1977, 341-342). Without the riparian buffer zone, the sediment deposits into the stream are increasing and surface runoff isn't being slowed or lessened by vegetation absorption. This runoff is especially important to take note of in Wisconsin due to the rolling terrain, which can help transform the channels and increase downstream floods and sedimentation (Knox 1977, 328-329). These ideas back the research that shows stream quality and abundance of agricultural/urban lands have a negative correlation (Wang 2011, 9).

Natural streams with meanders help maintain the quality of the environment by allowing for greater species abundance and acting as barriers to slow water flow, helping reduce drainage of wetlands and erosion (Prellwitz 1976, 2). Without meanders, natural vegetation cover, and other natural features of streams and rivers, habitat degradation is able to act on the ecosystem.

Biologic Communities

Stream community composition can be determined by harsh regimes or mesic groundwater regimes, which is the difference between very strong biotic interactions due to constant feed of water or very drastic changes due to high water changes (Nakamura 2014, 544 - 545). Channelized water systems tend to have harsh regimes due to the increased water flow and flooding, leading to ecological effects which affect the aquatic organisms in the system. The biggest driver for evolution in biota in lotic systems is the adaption to flowing water in order to maintain position in the water, survive the extreme changes in water levels, and forage for food (Clark 2017, 544). These conditions vary by water system, and changes to river characteristics such as light and temperature affect the species within and around the streams they've adapted to.

Many species of fish are sensitive to changes in characteristics of streams, such as water temperature, increased inflow of sediments or depth, allowing them to be indicator species (Brooker 1985, 63-64). Channelizing streams reduces habitat variation, leading to decreases in species richness within the system (Nakamura 2014, 545). Changes in stream characteristics are typically caused by the removal of bankside trees, leading to increases in temperature and depth of the water, which furthers losses of vegetation. Typically sediment inputs, channel slope, and river hydrology come together to create a balanced river system, but any changes to the system leads to shifting geomorphology, creating issues for the species who depend on the streams (Knox 1977, 340-341).

Restoration

Despite drastic changes historically to rivers all across Wisconsin, studies show that after a few decades, river geomorphology may stabilize and create a new equilibrium (Fitzpatrick 2005, 88). This may lead to challenges with restoration efforts, due to the species now adapted to the ecosystem would need to cope with another large disturbance (Knox 1977, 341). Despite the chance for harm on the current species, restoration will promote increasing species diversity both in and around the river. Allowing for high frequency small floods allows for maintenance of habitats to host species adapted to the different disturbances (Nakamura 2014, 552).

These restoration challenges build on the idea that restoration projects must vary by stream, because some projects may not be feasible in certain areas. Factors such as sediments resulting from the project, change from historical to current water flow, or proximity to agricultural runoff sites are all to be considered when planning for restoration (Luthin 2004, 43,46). Changes in morphology of the streams due to restoration is one criticism, such disturbances to an ecosystem could be detrimental to the species and oppose the restoration goal of increasing biodiversity and improving stream quality (Clark 2017, 546).

While there may be negative impacts on agriculture and stress on species by removing channelized waterways, stream remeandering provides benefits to the ecosystem such as reduced flooding, decreased erosion, reduction of water temperature by reintroducing forests, and increased biodiversity (Prellwitz 1976, 1-2). While remeandering helps restore previously channelized streams, there are some effects from channelization which cannot be restored when comparing channelized streams to restored or untouched streams. For example, retention efficiency and aquatic mosses are both lower in restored streams compared to natural streams (Muotka 2002, 153-154). For the channelized streams that cannot have large projects to restore them, a simple solution to help is to place boulders in streams to reverse depletion of organic matter due to increased water flow (Lepori 2005, 231).

Methods

Our primary data sources include maps from 1836, 1861, 1899, and 1913, as well as aerial imagery from 1937, 1976, and 2013. We examined physical changes over time within ten of Dane County's streams: Badfish Creek, Black Earth Creek, Door Creek, Dunlap Creek, Koshkonong Creek, Maunesha River, Nine Springs Creek, Starkweather Creek, Token Creek, and Wingra Creek. We chose to research these particular streams based on a cursory overview through modern aerial photographs of water bodies in Dane County, selecting those which showed evidence of physical flow alteration. These streams are found in urban, suburban, and rural areas of Dane County, providing us the opportunity to examine the effects of both urban development and agricultural development on stream channelization.

After acquiring the maps and aerial imagery required from repositories such as the Wisconsin Historical Society, the Robinson Map Library at the University of Wisconsin, and the Wisconsin Historical Aerial Imagery Finder, we began the process of georeferencing our maps. This was necessary for all imagery with the exception of the 2013 orthophotograph. We used a standard five control points for georeferencing.

Following the rectification of our georeferenced maps and imagery, the line tool in ArcMap was used to trace the full path of each creek in our study from every year for which we had maps or imagery. These shapefiles were then compiled based on year and based on stream, so that both the full picture of Dane County's channelization history could be compared year-by-year, as well as stream-by-stream.

Finally, the sinuosity of each stream was measured using the Stream Gradient and Sinuosity Toolbox in ArcHydro. Determining the sinuosity allowed for quantitative analysis of how straight a given stream is based on how much it deviates from the shortest line between two points. A lower sinuosity indicates a straighter stream, whereas a higher value indicates a more sinuous or meandering stream. A hallmark of channelized streams is that they tend to be more linear than naturally meandering streams, so in most cases we can assume that sections of streams that have a lower sinuosity value than their historical counterpart have been physically altered.

This sinuosity tool measures sinuosity by dividing the total length of the feature by the straight length, or valley length, of the feature. The tool was developed for use with rivers that are found in more pronounced valleys than those in Dane County, and thus the values it produced for the streams we studied were inaccurate. We came to conclusion that the straight length of our streams needed to be measured manually within ArcGIS. Once this was completed, the calculation for sinuosity was done by hand in order to find the final sinuosity values.

Data Analysis

Sinuosity Analysis

The sinuosity analysis revealed the pattern that we expected to see in terms of the timeline of channelization. Many of the creeks saw a peak in sinuosity in 1861. The streams were likely not more sinuous than they were in 1836; however the 1836 map did not contain very much detail as far as the meanders of each creek, although the general paths appeared to be relatively accurate.

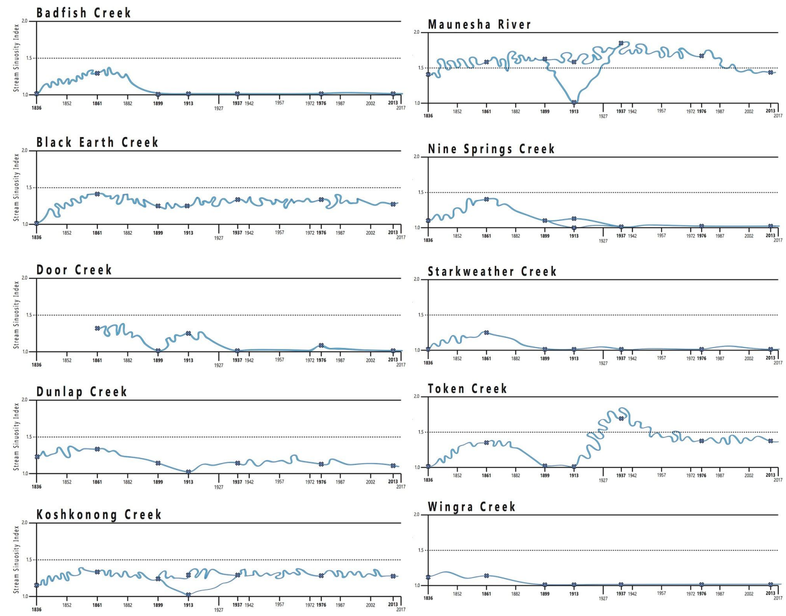

Figure 2. Each point in the above charts represents a measured sinuosity value correlating to a year for which a map or aerial image was available for each particular stream. A larger values indicates a meandering stream, whereas a smaller value indicates a straighter stream. The change from a high value to a low value over time could be indicative of channelization. The curves in the lines connecting the point are the cartographer's artistic choice to represent the transition from meandering to channelized, or lack thereof, over time. If a stream's chart contains two lines, the second, shorter line represents a drainage system that was constructed.

Several creeks suffered a sharp decline in sinuosity by 1937. This likely correlates with the population growth the city of Madison saw at the turn of the century, as the creeks that suffered this channelization were mostly within the Yahara Watershed close to the center of Dane County. The longer creeks, such as Koshkonong and Black Earth, have remained close to constant in sinuosity since 1937. These longer streams on the rural edges of the county seemed to be immune to the effects of channelization over time; while some parts of them were indeed channelized at some point, their sheer length allowed them to retain much of their original shape, if not reclaim some lost territory. The shorter creeks, such as Dunlap, Badfish, and Nine Springs had some of the lowest sinuosity values of the creeks we studied, nearly flatlining near a value of 1 by 1937 at the latest.

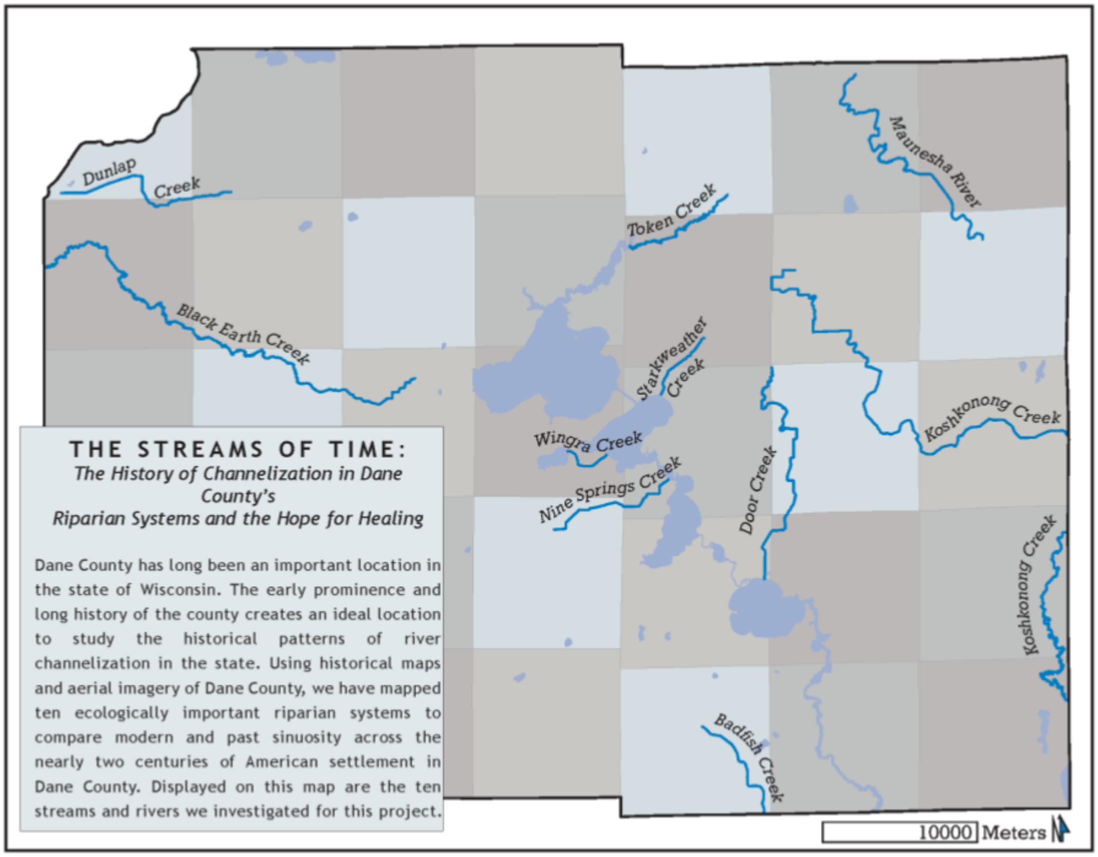

Figure 3. The creeks examined for evidence of channelization are Badfish Creek, Black Earth Creek, Door Creek, Dunlap Creek, Koshkonong Creek, Maunesha River, Nine Springs Creek, Starkweather Creek, Token Creek, and Wingra Creek. This map depicts the locations of these creeks throughout Dane County, based on the streams as they were in 2013.

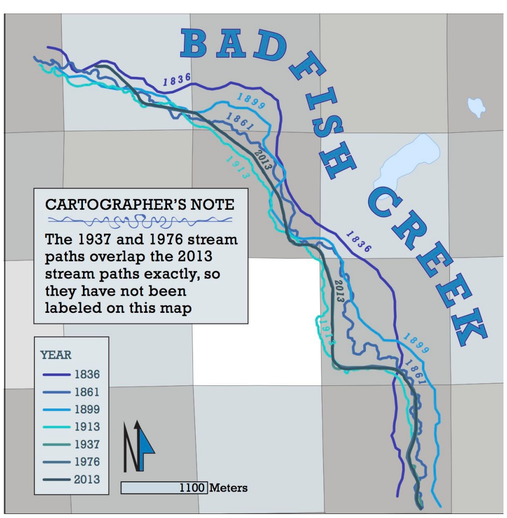

Figure 4.

Badfish Creek is located in southeastern Dane County, directly south of Lake Kegonsa at the end of the Yahara Lakes Chain. According to the Dane County State of the Waters Report in 2008, there is hardly any section of the creek that has not been channelized through ditching, straightening, and widening efforts. This transition can be seen in the sharp contrast between the easy meanders of 1913 and the sharp, 90 degree angles of 2013's stream.

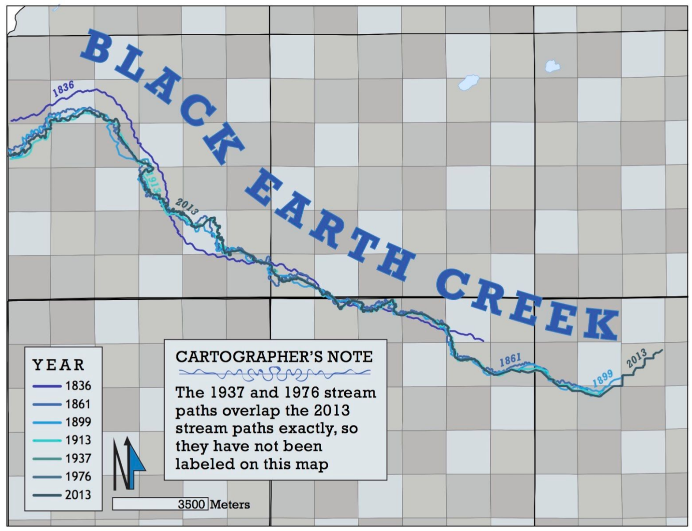

Figure 5.

Black Earth Creek flows across the west side of Dane County, stopping just short of Middleton. It is clear that much of the development within Black Earth Creek's path happened inside of the creeks meanders. Although its headwaters are mainly the section of the creek that has been channelized, the significant residential development have been the main cause of concerns for the health of the creek in terms of water quality (State of the Waters 2008).

Door Creek flows into Lake Kegonsa, running north-south along the east side of the Yahara Lakes chain. It has been heavily channelized and ditched, especially due to a drainage system project that began in 1919. Despite this extensive channelization, it flows very slowly and has proved to be a poor habitat for aquatic wildlife (State of the Waters 2008). Door Creek is perhaps one of the most dramatic examples of channelization in a longer creek observed in this project.

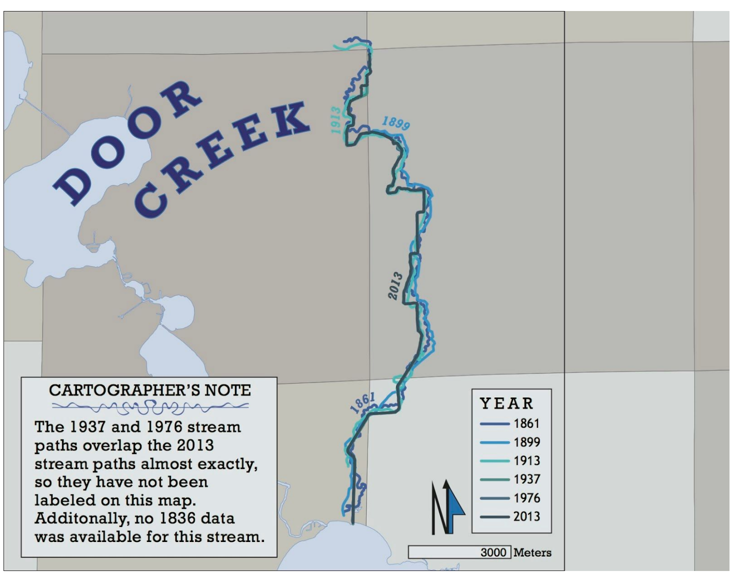

Figure 6.

As of 1913, **Dunlap Creek** was showing strong evidence of channelization. Located the northwest Dane County near the Wisconsin River, the creek had once meandered along in an L-shape, but by 1913 the stream had a predominantly East-West directionality as opposed to its

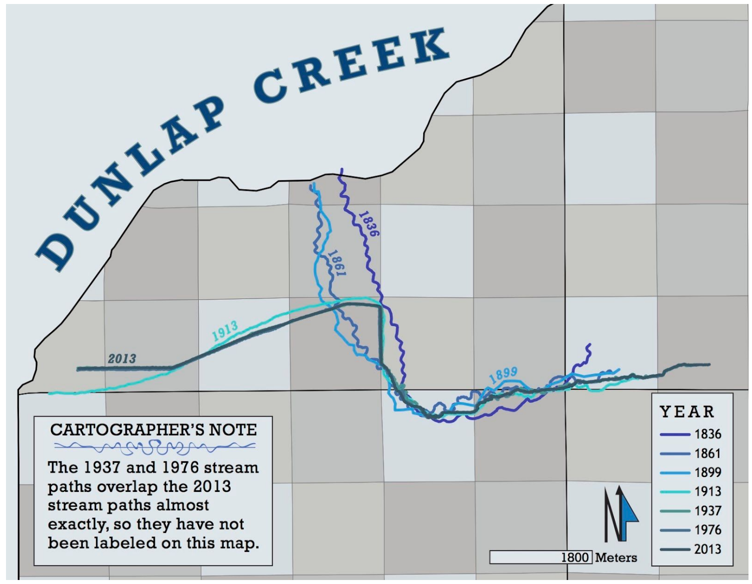

Figure 7.

original North-South. It is unclear whether this was due to errors on the early cartographers' part as to what was actually a part of Dunlap Creek, or whether the course of the creek really was altered this dramatically between 1899 and 1913. In 1991, there was a small restoration effort made in order to prevent streambed erosion that was occurring in the creek (State of the Waters 2008).

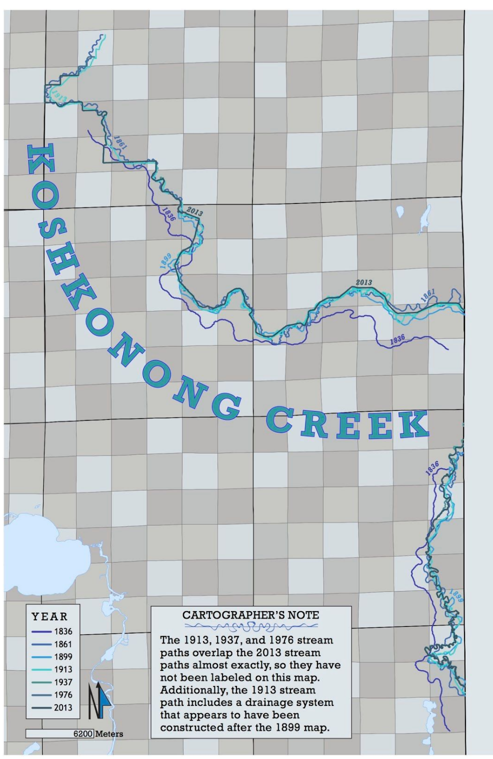

Figure 8.

Koshkonong Creek was the longest creek examined in this project. It appears discontinuous in Figure 8 due to the fact that it curves out of the eastern border of Dane County, in again, and then finally exits for good in the southeast corner of the county. Koshkonong's watershed has had much of its wetlands drained due to the heavily agricultural land use in the area. Lower Koshkonong creek is far less channelized than its northern counterpart, and the Rockdale Dam was removed from the creek in 2001 (State of the Waters 2008). Like Black Earth Creek, although some sections of Koshkonong Creek have been obviously channelized, the sinuosity analysis shows that as a whole, the creek was relatively immune to the effects of channelization due to its significant length.

Dams, ditching, and drainage of wetlands all contributed to portions of the **Maunesha River** earning a spot on the DNR's Impaired Waterways list (State of the Waters 2008). This creek is also a good example of the fact that while early cartographers generally had a good idea of the pathway of the streams and rivers in Dane County, their placement was not entirely accurate, as can be seen with the difference between the placement of the 1836 stream path versus all subsequent years.

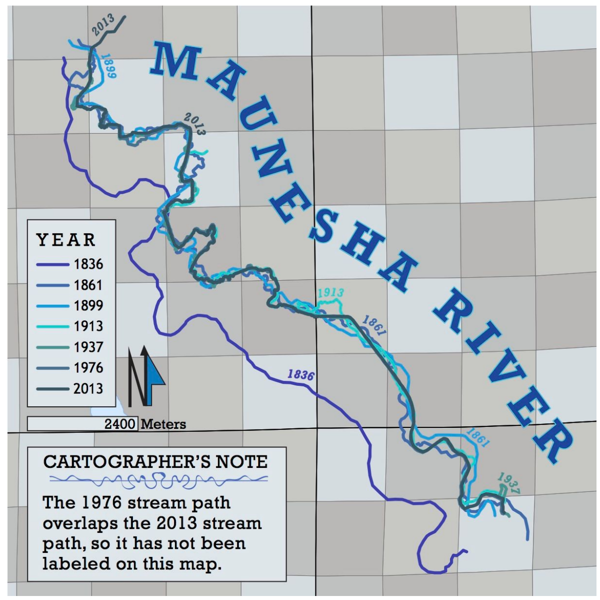

Figure 9.

Nine Springs Creek lies just south of Lake Monona and Lake Wingra. Urban runoff is problematic due to its proximity to the large cities in the center of the county, and the creek has been dramatically ditched and straightened over time (State of the Waters 2008).

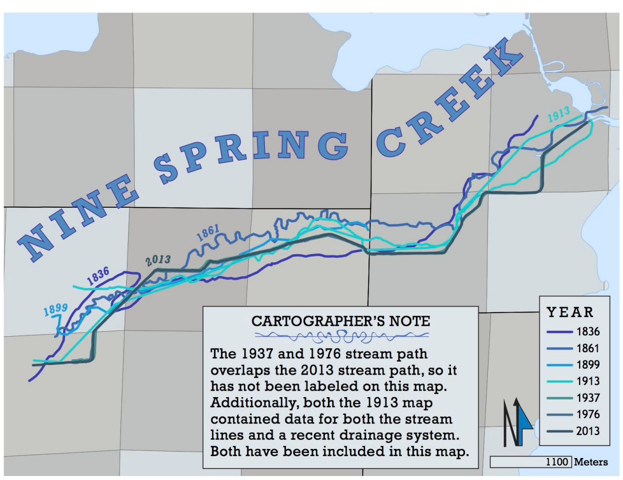

Figure 10.

Starkweather Creek flows into Lake Monona. Its location adjacent to the city of Madison and the Dane County Regional Airport have caused severe contamination of the creek with toxic chemicals in the past (State of the Waters 2008), and as is evidenced in Figure 11, the creek has been straightened within its original pathway to the channelized creek that it is today. Starkweather Creek has also earned a spot on the DNR Impaired Waterways list.

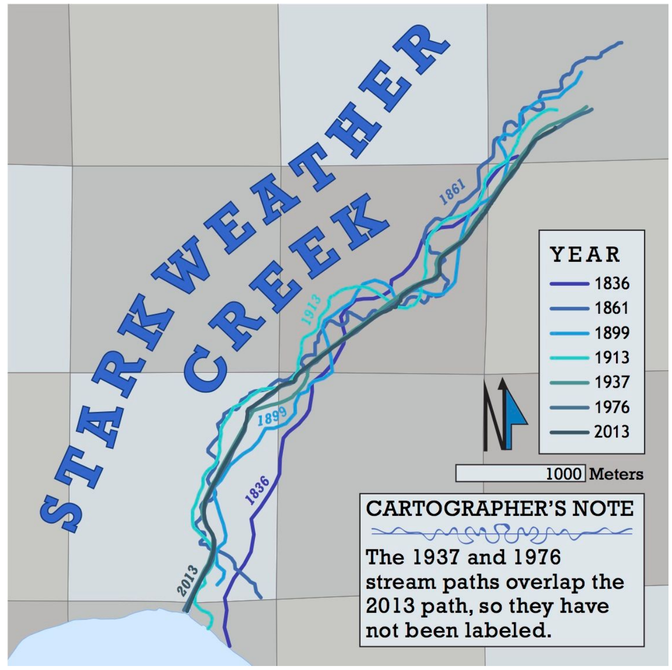

Figure 11.

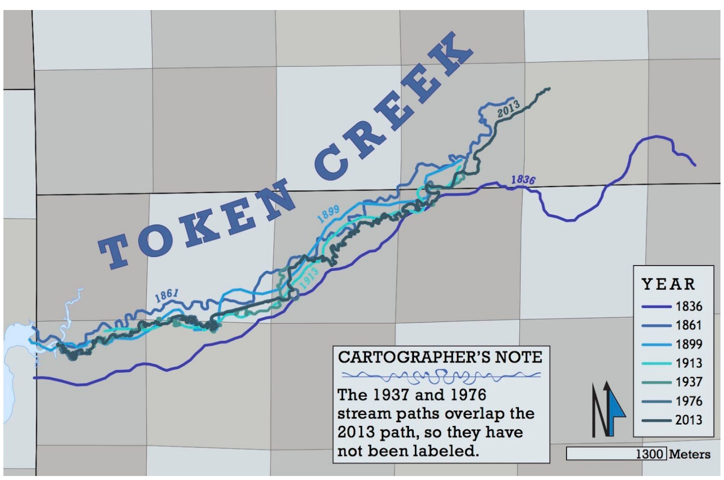

Figure 12.

Token Creek lies just northeast of Lake Mendota at the head of the Yahara Lakes chain and is a tributary to the Yahara River. Token Creek has remarkably retained much of its natural geometry throughout the years, with only a dam, which was removed in 1995, causing a significant change in the hydrology of the creek (State of the Waters 2008).

Located in the heart of Madison, **Wingra Creek** faced the forces of channelization early on. Aside from the 1899 map, which depicts a path much different than the other maps and aerial imagery, one can observe a marked change in the course of the stream between 1861 and 1913.

Channelization of Wingra Creek began in 1905, and the water quality is extremely poor due to runoff (State of the Waters 2008). The housing developments in the area and the creation of the University of Wisconsin Arboretum likely contributed to some of the stream path seen in Figure 13.

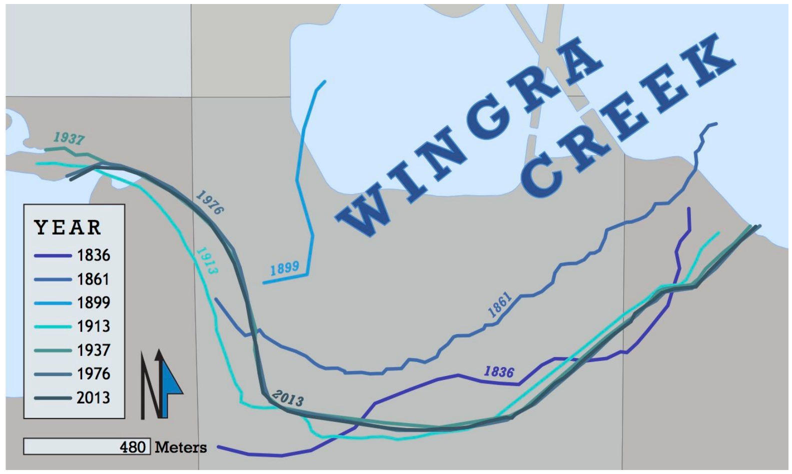

Figure 13.

Discussion

Research Problems

We are finding throughout the course of our research that the maps we have access to are not as accurate as other maps or the aerial imagery. The maps from years prior to 1900 unfortunately lack detail, so many streams that we hypothesized to meander quite dramatically are mapped relatively straight. While we still assume them to meander more than their modern counterparts, we have no way of knowing this for sure, and thus it is difficult to determine when exactly channelization began to occur.

The map from 1899 has the lowest accuracy amongst the four maps we have data from due to misaligned streams and lack of detail of meanders.

The aerial imagery from 1937 and 1967 is also problematic because some images are significantly distorted, making it nearly impossible to accurately georeference them. As a result, there were difficulties creating lines following the stream pathways, since the pathway was not necessarily continuous from one image to another due to the distortions. Many of the rural imagery lacks landmarks to georeference to, and many of today's urban areas have so many changes to the landscape finding matches between the imagery is difficult. Although we carefully georeferenced each image to ensure accuracy, we recognize that there are some distortions that we did not completely resolve and our shapefiles may not be as accurate as desired.

The aerial imagery from 1937 and 1967 does not have high image quality. Near the border of each image, the image is typically darker and less clear. The grayscale nature of the photographs makes it difficult to distinguish between land, water, or roads in some instances, depending on the exposure of the particular photograph. Tree clusters bordering the streams make it difficult to ascertain where the stream lay within a patch of forest.

Future Research

If we have more time to complete this research, we would like to use far more control points for georeferencing the aerial imagery and maps in order to make the spatial data as accurate as possible. Researching more than ten streams and finding a more comprehensive sample of streams to give us a better picture of the history of stream channelization in Dane County would be ideal. With more information, we could provide a better analysis of where future restoration projects may be possible. It also would be interesting to speak with city planners throughout the county, the Dane County Office of Lakes and Watersheds, and the Wisconsin Department of Natural Resources to get a more complete history of the policies, official or unofficial, relating to stream channelization in Dane County and how this is changing with a better understanding of the impacts of channelization on soil and water quality.

Conclusion

Stream channelization has certainly left its mark on Dane County. These alterations to riparian systems are powerful, and it can be difficult to return the damaged rivers to their original state. Many smaller creeks throughout the county have seen significant, if not total, channelization, and even the larger streams are not immune to the perils of ditching and straightening. Each creek we examined, whether it was long or short, urban or rural, is marked by some variety of channelization.

Channelization is not the only factor harming Wisconsin's rivers, though. Phosphorus contamination is another major threat to Dane County's streams, especially within the Yahara Watershed (Wisconsin DNR). Furthermore, channelized streams provide an even faster route for contaminants to travel along, leading to the quicker delivery of troubles like severe algal blooms.

However, change is possible with the help of ecosystem restoration projects. The DNR's Impaired Waterways list identifies rivers and creeks across Wisconsin that are damaged, whether that be physically or chemically, based on the Clean Waters Act. A waterway's status on the DNR's list is not dependent on whether it is channelized or not; however, given the dramatic ecological impacts channelization can have, channelization can be a good indicator that a stream is not at peak health (Wisconsin DNR Impaired Waters List). Additionally, Dane County executives recognize the importance of river health and are working towards a $12 million project remove thousands of pounds of sediment containing phosphorus from the bottom of creeks in the Yahara River watershed, including Nine Springs, Door, Dorn, and Token creeks (River Alliance of Wisconsin 2016).

Without this kind of initiative to repair and restore channelized and otherwise damaged waterways, these streams would face a much darker future. While flippant attitudes towards water resources used to be the norm, more and more citizens, government leaders, and non-profit organizations are stepping up to the task of reclaiming responsibility for the state of Wisconsin's streams. Understanding the history of a stream is crucial to understanding its future, and Dane County is taking those steps to ensure a better future for its water systems.

Acknowledgements

We would like to thank Dr. William Gartner for helping guide us in establishing the direction of our project and instructing us in the workings of ArcHydro. Dr. Joseph Mason aided us in determining the scope of our project and gave us a better understanding of the place of stream channelization in Dane County's history. Jaime Martindale, the Map and Geospatial Data Librarian at the Robinson Map Library, and Lisa Marine, a staff member at the Wisconsin Historical Society, gave us invaluable assistance in acquiring all the historical maps and aerial imagery that we needed to complete our project. We are also immensely grateful for the data, historical information, and imagery that was available to us from the Dane County State of the Waters Report, the Wisconsin Department of Natural Resources, and the United States Department of Agriculture.

Bibliography

Brooker, M.P. 1985. The ecological effects of channelization. *The Geographical Journal* 151 (1): 63-69.

Clark, J. M., J. J. Montemarano. 2017. Short-term impacts of remeandering restoration efforts on fish community structure on a fourth-order stream. *Water* 9 (7): 546-561.

Fitzpatrick, F. A., M. W. Diebel, M. A. Harris, T. L. Arnold, M. A. Lutz, and K. D. Richards. 2005. Effects of Urbanization on the Geomorphology, Habitat, Hydrology, and Fish Index of Biotic Integrity of Streams in the Chicago Area, Illinois and Wisconsin. *American Fisheries Society Symposium* 47:87–115.

Jones, J. J. 2004. Civilization – the basis for water science. *The Basis of Civilization – Water Science?* ed. J. C. Rodda and L. Ubertini. Rome: International Association of Hydrological Science. pg. 277.

Kahl, E. A. 2011. The design and formative evaluation of "The Wisconsin Conservation success stories" documentary in the Wisconsin Conservation Hall of Fame Museum at the Schmeeckle Reserve Visitor Center. *College of Natural Resources University of Wisconsin - Stevens Point* 1-133.

Kearney, M. T. 1909. *Drainage Legislation in Wisconsin*. Madison, WI: Wisconsin Legislature.

Knox, J. Human impacts on Wisconsin streams channels. *Annals of the Association of American Geographers* 67 (3): 323-342.

Kuglerova, L., K. Botkova, R. Jansson. 2016. Responses of riparian plants to habitat changes following restoration of channelized streams. *Ecohydrology* 10:1 1-13.

Leopold, A. 1949. *A Sand County Almanac*. New York: Ballantine Books.

Lepori, F., D. Palm, and B. Malmqvist. 2005. Effects of stream restoration on ecosystem functioning: detritus retentiveness and decomposition. *Journal of Applied Ecology* 42 (2): 228-238.

Luthin, C. S. and Thompson, A. L. 2004. Chapter 4: Planning Your Wetland Restoration, from the *Wetland Restoration Handbook for Wisconsin Landowners*. Bureau of Science Services, Wisconsin Department of Natural Resources.

Muotka, T, P. Laasonen. 2002. Ecosystem recovery in restored headwater streams: the role of enhanced leaf retention. *Journal of Applied Ecology* 39(1): 145-156.

Nakamura, F., N. Ishiyama, M. Sueyoshi, J. N. Negishi, T. Akasaka. 2014. The significance of meander restoration for hydrogeomorphology and recovery for wetland organisms in the Kushiro River, a lowland river in Japan. *Restoration Ecology* 22:4 544-554.

Prellwitz, D. M. 1976. Effects of stream channelization on terrestrial wildlife and their habitats in the Buena Vista Marsh, Wisconsin. *Wisconsin Cooperative Fishery Research Unit, College of Natural Resources, University of Wisconsin—Stevens Point.*

River Alliance of Wisconsin. 2016. Dane County to Pursue "Legacy" Phosphorus Removal Project. *River Alliance of Wisconsin.*

Solomon, S. 2010. *Water: The Epic Struggle for Wealth, Power, and Civilization*. New York: HarperCollins.

Various authors. 1971. *A Documentary History of Conservation in America*. ed. R. McHenry and C. van Doren. New York: Praeger Publishers.

Various authors. 2008. *Dane County State of the Waters Report.* Dane County Office of Lakes and Watersheds.

Wang, L., J. Lyons, P. Kanehl, and R. Getti. 2011. Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. *Fisheries* 22 (6): 6-12.

Wisconsin Department of Natural Resources. 2015. Chapter 4: Changes and trends in ecosystems and landscape features, from *The ecological landscapes of Wisconsin: an assessment of ecological resources and a guide to planning the sustainable management*. Wisconsin Department of Natural Resources.

Wisconsin Department of Natural Resources. 2015. Lower Rock River basinwide issues. *Wisconsin Department of Natural Resources.* Retrieved from http://dnr.wi.gov/topic/watersheds/basins/Lowerrock/basinissues.html.

Wisconsin Department of Natural Resources. 2016. Wisconsin's 2016 Impaired Waters List. *Wisconsin Department of Natural Resources.* Retrieved from http://dnr.wi.gov/topic/impairedwaters/2016ir_iwlist.html.

Zeasman, O. 1972. *Land Drainage and Soil Conservation in Retrospect*. Madison, WI: University of Wisconsin, University Archives Oral History Project.

Data Sources

Cantwell Printing Company. Standard Historical Atlas of Dane County, Wisconsin containing Maps of Villages, Cities, and Townships: Together with Replats of the County and of the United States and World. 1911. 2 inches to 1 mile. "Wisconsin Historical Society: Standard Historical Atlas of Dane County, Wisconsin containing Maps of Villages, Cities, and Townships: Together with Replats of the County and of the United States and World." Electronically published 2016. Accessed 14 October 2017. <http://content.wisconsinhistory.org/cdm/compoundobject/collection/maps/id/16849/rec/136>

Cram, Thomas Jefferson. Map of the 4 lakes and their outlet into Rock River: to accompany the report of Thos. J. Cram Capt. T.E. on the reconnaissance thereof. 1839. 1:17,500. "Wisconsin Historical Society: Map of the 4 lakes and their outlet into Rock River: to accompany the report of Thos. J. Cram Capt. T.E. on the reconnaissance thereof". Electronically published 2010. Accessed 14 October 2017. <http://content.wisconsinhistory.org/cdm/singleitem/collection/maps/id/78/rec/20>

Gay, Leonard W; Anson, O; Stone, M B. New Atlas of Dane County, Wisconsin. 1899. 1:31,680. "Wisconsin Historical Society: New Atlas of Dane County, Wisconsin." Electronically published 2016. Accessed 14 October 2017.
<http://content.wisconsinhistory.org/cdm/compoundobject/collection/maps/id/18701/rec/92>

Geib, Warren Jacob. Soil map, Wisconsin, Dane County sheet. 1913. 1:62,500. "Wisconsin Historical Society: Soil map, Wisconsin, Dane County sheet / U.S. Department of Agriculture, Bureau of Soils ; State of Wisconsin Geological and Natural History Survey ; College of Agriculture, University of Wisconsin." Electronically published 2013. Accessed 14 October 2017. <http://content.wisconsinhistory.org/cdm/singleitem/collection/maps/id/1840/rec/142>

Ligowski, A. Map of Dane County, Wisconsin [map]. 1861. "Wisconsin Historical Society: Map of Dane County, Wisconsin / compiled from the latest records & actual surveys by A. Ligowski ; engraved, printed, colored, & mounted by Edw. Mendel." Accessed 14 October 2017. Electronically Published 2013. <http://content.wisconsinhistory.org/cdm/singleitem/collection/maps/id/1839/rec/32>

Suydam, John. Maps of the Four Lake Country, Taken from the Township Maps in the U.S. Land Office [map]. 1836. 1:126,720. “Wisconsin Historical Society: Maps of the Four Lake Country, Taken from the Township Maps in the U.S. Land Office by John V. Suydam. Electronically published 2013. Accessed 9 October 2017. <http://content.wisconsinhistory.org/cdm/singleitem/collection/maps/id/1835/rec/16>

USDA. *Dane County* (aerial photo). 1:20,000. 1937.

USDA. *Dane County* (aerial photo). 1:40,000. 1976.

Vanderpoel, Aaron. Four Lakes Region, Wisconsin [map]. 1836. 1:86,215. “Wisconsin Historical Society Maps Collection: Four Lakes Region, Wisconsin.” Electronically published 2013. Accessed 9 October 2017. <http://content.wisconsinhistory.org/cdm/compoundobject/collection/maps/id/5444/rec/9>

Wisconsin Historical Society. Map of Dane County, Wisconsin [map]. Between 1835-1840. “Wisconsin Historical Society Maps Collection: Map of Dane County, Wisconsin.” Electronically published 2012. Accessed 9 October 2017. <http://content.wisconsinhistory.org/cdm/singleitem/collection/maps/id/1644/rec/6>

WisconsinView. 2013 NAIP DOQQs [Ortho map]. 2013. WisconsinView NAIP Digital Ortho Quarter Quads. Accessed 21 October 2017. <http://relief.ersc.wisc.edu/wisconsinview/session3.php>

Appendix

Sinuosity Measurements

OBJECT ID	Stream Name	Length (m)	Sinuosity	Year	Straight length (m)	Shape length (m)	Quality
1	Badfish	8185.416	1.017	2013	8047.470	8319.347	IMP
2	Badfish	8167.237	1.012	1976	8071.070	8300.869	IMP
3	Badfish	8205.488	1.017	1937	8071.610	8339.746	IMP
4	Badfish	8645.595	1.099	1913	7867.440	8787.140	IMP
5	Badfish	9304.523	1.070	1899	8696.070	9456.757	IMP
6	Badfish	11112.158	1.285	1861	8648.890	11294.007	IMP
7	Badfish	9151.645	1.070	1836	8556.540	9301.399	IMP
8	Black_Earth	35538.097	1.237	1899	28739.660	36145.356	OUT
9	Black_Earth	40993.242	1.415	1861	28961.920	41693.440	OUT
10	Black_Earth	33490.171	1.246	1913	26884.150	34062.111	OUT
11	Black_Earth	42016.742	1.302	1976	32265.700	42734.000	OUT
12	Black_Earth	23685.627	1.097	1836	21599.400	24091.234	OUT
13	Black_Earth	42219.357	1.278	2013	33036.690	42940.032	OUT
14	Black_Earth	42737.051	1.308	1937	32665.930	43466.507	OUT
15	Door	10580.847	1.028	2013	10289.300	10752.234	IMP
16	Door	10850.641	1.024	1976	10593.740	11026.373	IMP
17	Door	6196.641	1.010	1937	6135.120	6297.243	IMP
18	Door	10300.025	1.235	1913	8340.300	10466.775	IMP
19	Door	12813.904	1.062	1899	12065.160	13021.152	IMP
20	Door	17972.432	1.325	1861	13566.190	18263.038	IMP
21	Dunlap	9434.906	1.224	1836	7706.680	9596.285	OUT

22	Dunlap	10719.580	1.361	1861	7875.700	10902.999	OUT
23	Dunlap	12922.789	1.093	1913	11818.080	13144.325	OUT
24	Dunlap	14738.134	1.190	1937	12381.240	14990.502	OUT
25	Dunlap	14034.451	1.130	1976	12415.910	14274.792	OUT
26	Dunlap	13844.853	1.108	2013	12495.840	14081.929	OUT
27	Dunlap	9512.748	1.156	1899	8225.980	9675.531	OUT
28	Maunesha	24370.346	1.485	2013	16411.980	24758.112	IMP
29	Maunesha	21433.839	1.609	1976	13323.620	21774.689	IMP
30	Maunesha	25946.187	1.893	1937	13706.560	26358.993	IMP
31	Maunesha	18411.352	1.550	1913	11877.200	18703.944	IMP
32	Maunesha Drainage	3064.214	1.010	1913	3034.320	3112.848	IMP
33	Maunesha	21971.351	1.580	1899	13902.930	22320.917	IMP
34	Maunesha	24812.938	1.580	1861	15707.930	25207.584	IMP
35	Maunesha	20275.447	1.394	1836	14544.170	20598.387	IMP
36	Nine Springs	9630.386	1.031	2013	9339.270	9630.386	IMP
37	Nine Springs	9171.896	1.035	1976	8860.280	9171.896	IMP
38	Nine Springs	8997.559	1.030	1937	8733.470	8997.559	IMP
39	Nine Springs Drainage	9027.054	1.043	1913	8654.690	9027.054	IMP
40	Nine Springs	8688.816	1.107	1913	7846.380	8688.816	IMP
41	Nine Springs	5372.275	1.145	1899	4690.610	5372.275	IMP
42	Nine Springs	12511.253	1.454	1861	8606.760	12511.253	IMP
43	Nine Springs	10165.130	1.108	1836	9172.160	10165.130	IMP
44	Wingra	3465.852	1.079	2013	3212.120	3523.046	IMP
45	Wingra	3496.473	1.074	1976	3255.960	3554.172	IMP

46	Wingra	3539.639	1.032	1937	3430.040	3598.054	IMP
47	Wingra	3481.874	1.068	1913	3259.090	3539.343	IMP
48	Wingra	929.826	1.032	1899	901.280	945.176	IMP
49	Wingra	2520.394	1.115	1861	2260.990	2561.966	IMP
50	Wingra	2307.887	1.104	1836	2090.430	2345.955	IMP
51	Starkweather	5064.150	0.955	2013	5301.220	5146.819	IMP
52	Starkweather	5347.199	1.016	1976	5261.460	5434.473	IMP
53	Starkweather	5259.546	1.018	1937	5168.560	5345.388	IMP
54	Starkweather	6000.697	1.076	1913	5578.960	6098.665	IMP
55	Starkweather	6041.242	1.083	1899	5578.510	6139.817	IMP
56	Starkweather	7643.422	1.238	1861	6174.290	7768.140	IMP
57	Starkweather	4825.245	1.049	1836	4601.930	4904.023	IMP
58	Token	12982.192	1.490	2013	8713.140	13193.545	IMP
59	Token	8557.773	1.427	1976	5996.300	8697.114	IMP
60	Token	12608.081	1.728	1937	7297.370	12813.499	IMP
61	Token	5724.712	1.073	1913	5336.300	5817.926	IMP
62	Token	7467.105	1.075	1899	6948.390	7588.806	IMP
63	Token	10364.817	1.380	1861	7511.340	10533.599	IMP
64	Token	10592.184	1.065	1836	9949.510	10764.369	IMP
65	Koshkonong	45133.908	1.115	1836	40478.130	45852.964	IMP
66	Koshkonong	68217.320	1.380	1861	49421.090	69304.806	IMP
67	Koshkonong	62292.526	1.293	1913	48189.640	63285.491	IMP
68	Koshkonong	14959.589	1.010	1913	14814.390	15197.336	IMP
69	Koshkonong	63030.613	1.271	1937	49580.020	64034.965	IMP
70	Koshkonong	62257.123	1.272	1976	48950.110	63249.288	IMP

71	Koshkonong	60964.571	1.250	2013	48768.940	61935.849	IMP
72	Koshkonong	41703.425	1.223	1899	34111.330	42366.060	IMP