Exploring Barriers & Opportunities for Co-Benefits of Climate Adaptation in the St. Joseph River Basin

University of Notre Dame & Dublin City University
Joint Summer Research Project

By Maggie Barrett, Leo Carroll, & Daniel Ringrose

1. Introduction

1.1. Climate Change in the Agricultural Midwest

Any modern discussions of politics, economics, and development seem incomplete when they fail to account for the increasing effects of climate change on all aspects of human life. While coastlines and drought-ridden areas often capture the majority of media attention, areas such as the Midwestern United States are not exempt from feeling the effects of rising temperatures and repeated extreme weather events. Since 1850, the Midwest has seen drastic changes in land use as forests and wetlands were razed and drained for increased agricultural production.[17] These changes reduced the carbon sequestration and water retention abilities of the land, resulting in increased flood risks, erosion, and water quality degradation from sediment and nutrient runoff. Agricultural runoff from much of the Midwest drains into the Mississippi River, ultimately creating nutrient overload issues in the Gulf of Mexico.[45][21] Likewise, waterways in the upper Midwest drain into the freshwater Great Lakes and are beginning to create similar problems, putting one of the world's greatest freshwater resources at risk.[37][38]

Today, the 127 million acres of agricultural land in the Midwest create one of the most intense areas of agricultural production in the world, supplying $86 billion in agricultural exports in 2009 – more than 87% of the total national agricultural exports.[48] The agricultural production is focused primarily on corn and soybeans, accounting for 75% of farmable Midwestern land use and one-third of the world's annual corn and soybean production.[46] With this reliance on monocultural production, the Midwest is particularly vulnerable to the effects of climate change, specifically increases in temperature and variable levels of precipitation. While increasing temperatures may temporarily increase the length of the growing season and favor production, warmer winters allow for the survival of insect pests and can contribute to the northern expansion of new pests and pathogens into the Midwestern states.[33][34] Additionally, increased spring precipitation heightens the risk of erosion and early crop loss, later accentuated by warmer, drier summers that place the remaining crops at a higher risk of failure.[34] Fighting the area's natural state as a wetland, farmers must work harder to drain their land in response to increasing precipitation events, thus placing downstream areas at a higher risk of flooding.

1.2. St. Joseph River Basin

The St. Joseph River Basin (SJRB) is a prime example of Midwestern land at risk of intense climate effects, particularly flooding and water quality issues. The St. Joseph River Basin drains 4,682 square miles across Northern Indiana and Southwest Michigan.[28] Stretching across 15 counties and home to over 1.5 million people, the mainstem of the river begins in Michigan, crosses the Indiana-Michigan border twice, and eventually culminates as the third-largest watershed to drain into Lake Michigan. While 70% of the land in the watershed is used for agriculture, several cities lie along the mainstem and throughout the basin, including South Bend, Elkhart, Goshen, and Angola in Indiana, as well as Coldwater, Dowagiac, Three

Rivers, and St. Joseph in Michigan. Even though the majority of agricultural land use is located outside of these cities' boundaries, accounting for this land use is important for local government bodies as they evaluate water quality and downstream flooding within their communities.

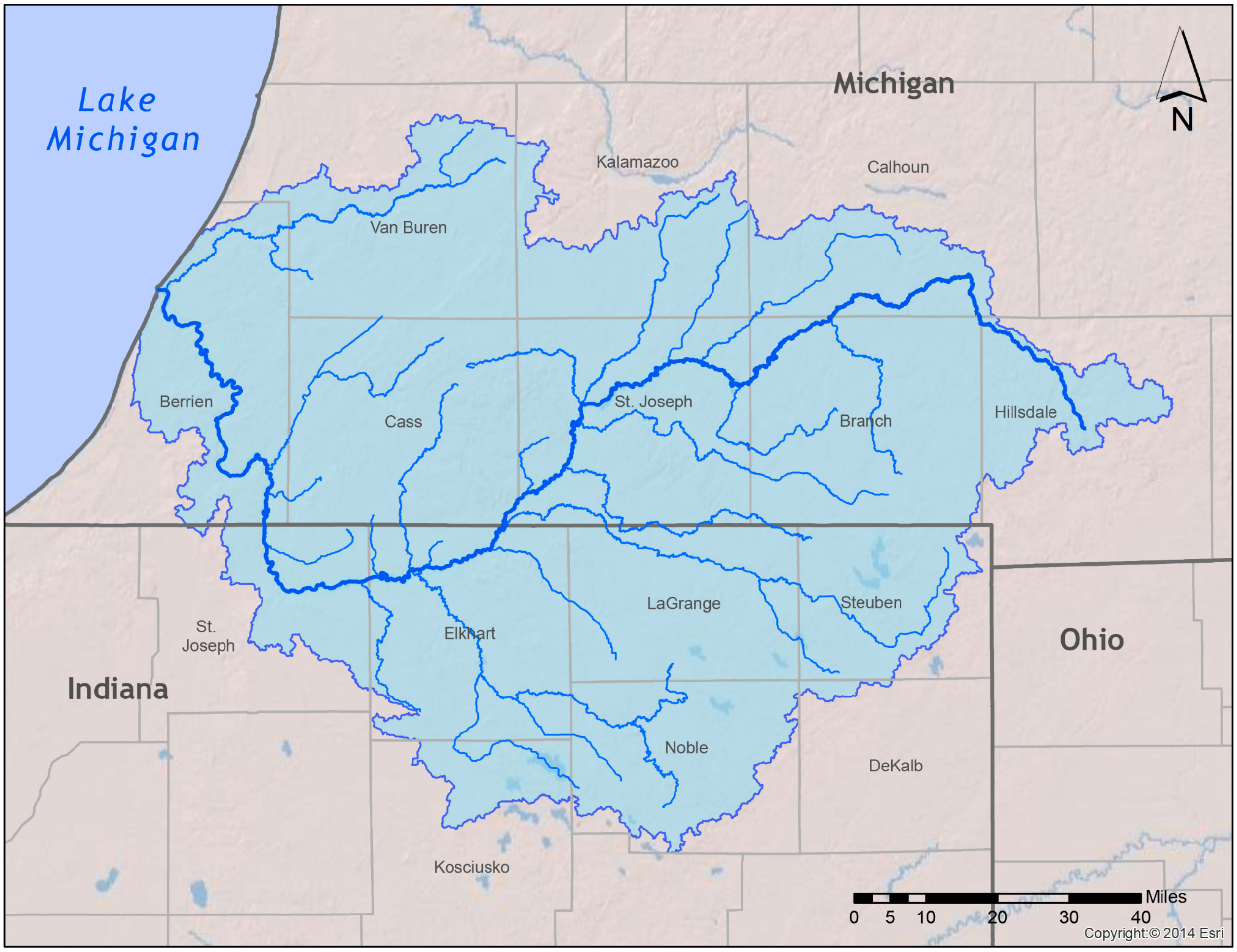

Figure 1: Map of St. Joseph River Basin
Source: St. Joseph River Basin Commission

While industrial activity throughout the 20th century led to concerns about water quality issues in the St. Joseph, the regulation of pollutants being dumped into the river and the development of general waste treatment plans have predominantly addressed those concerns. Now, local concerns regarding the issue are primarily focused on mitigative measures for flooding, particularly after two notable flooding events in 2016 and 2018.[4] Human interference on the river's path and the drainage flows of tributaries have shrunk riparian zones and lowered the retention capacity of nearby land. This has also resulted in increases of both sediment and nutrient runoff entering the waterways, which then has implications for the water quality of not only the St. Joseph River, but also Lake Michigan.

Figure 2: Impact of 500-Year Flood in South Bend (2016)
Source: Santiago Flores, South Bend Tribune

Figure 3: 2400-Year Flood Along St. Joseph River (2018)
Source: Robert Franklin, South Bend Tribune

As a watershed comprising both rural agricultural lands as well as urban and industrial areas, the St. Joseph River Basin serves as a comprehensive example of the varying effects of climate change in the Midwest as well as a potential hotbed for policy development and experimentation. *This report will serve to emphasize the basin's importance in the larger Great Lakes region, the challenges to effective management in our current policy landscape, and opportunities for improvement through a comprehensive case study and analysis.*

2. Methodology

2.1. Case selection/Focus area (partnership with SJRBC)

The illustrative case area was selected through a collaboration between the St. Joseph River Basin Commission (SJRBC) and the University of Notre Dame's Environmental Change Initiative (ECI). The report serves as an early exploration of one proposed site of interest for the National Science Foundation (NSF) Civic Innovation Challenge, which calls for projects that "pilot community-driven, innovative, and actionable research-centered strategies for adaptation, mitigation, and resilience in community systems, services, and economic drivers that are vulnerable in the face of a changing climate."[24] The St. Joseph River Basin sits in a unique area of the country that can be categorized as both the Midwest and the Great Lakes region, meaning that issues of water resources and agriculture production are interconnected and require careful policy formulation and implementation. Within the SJRB, the SJRBC has identified Phillips Ditch, a man-made drainage ditch, as an area of concern due to both poor water quality and increasing flood risk. By focusing on Phillips Ditch, our report hopes to highlight potential challenges and solutions that can be replicated and extended to address similar problems within the larger St. Joseph River Basin and Great Lakes region.

2.2. Conceptual framing

Given the SJRBC's interest in increasing opportunities for climate adaptive practices that would both reduce flooding and improve water quality, we drew from recent literature providing a conceptual framing for adaptive capacity.[7] Adaptive capacity refers to the human ability to adapt to change, which is especially important in the context of climate change.[7] As communities face increasing threats to wellbeing, investments in adaptive capacity by local governments, development agencies, and community groups become vital. This framing, shown in Figure 4, identifies five core domains of adaptive capacity: (1) assets to utilize in times of need; (2) flexibility to change strategies when necessary; (3) collective organization and action; (4) learning to recognize and respond to opportunities of and for change; and (5) the agency to decide whether to change or not.

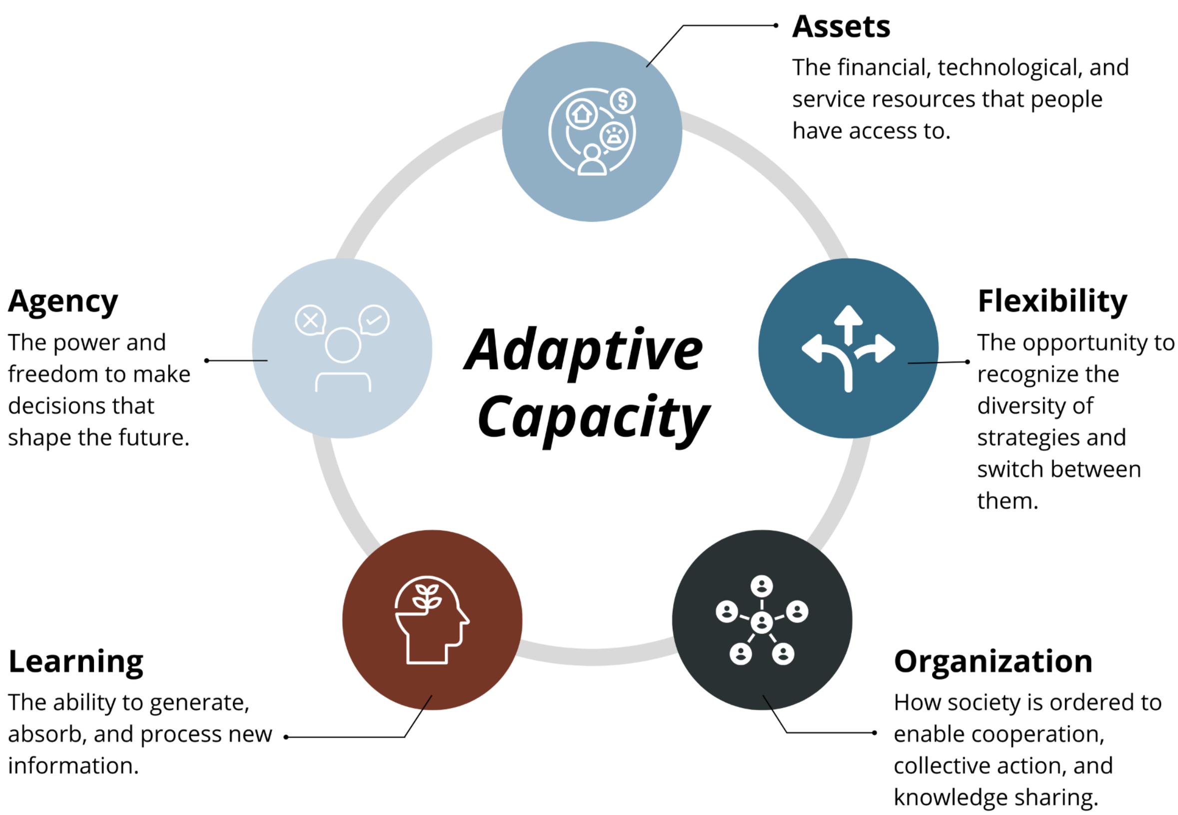

Figure 4: Domains of Adaptive Capacity
Adapted from Cinner, J.E., Adger, W.N., Allison, E.H. et al.

2.3. Assessment Process

Using the adaptive capacity framework as outlined in Figure 4, we examined the illustrative case and its policy and programming context to identify important investment areas within the assets, organization, and learning categories. To do this, we provided an initial analysis of Phillips Ditch using *Geographic Information System* (GIS) software and we reviewed additional documents addressing community organization to maximize co-benefits.

2.3.1. Policies and Programming

While exploring options and opportunities for policy planning, we focused primarily on addressing concerns of flooding and water quality, as these are the main issues in the SJRB and the Midwest at large. However, there is room for tremendous co-benefits associated with reduced flooding and improved water quality, including increased biodiversity, improved carbon sequestration, heat stress reduction, air quality improvements, and more. For example, traditional flood management strategies, known as “gray” infrastructure, may include pipes or water treatment plants that hope to reroute surface water and prevent pollution from entering waterways through physical and chemical processes.[12] Conversely, green and blue infrastructure utilize the ecosystem services offered by natural systems, such as water bodies and green or open spaces.[20] While traditional gray infrastructure methods may seem the most cost-effective way to achieve flood damage reductions, current literature suggests that utilizing a combination of green, blue, and gray infrastructure provides the best flood protection, while also maximizing the resulting co-benefits.[1]

In our exploration of nature-based solutions, we focused primarily on investments in green and blue infrastructure through wetland restoration and the implementation of cover crops and two-stage ditches. Due to the historical abundance of wetlands in the St. Joseph River Basin, the restoration of such ecosystems feels like a natural next step. The Phillips Ditch area is particularly suited for a combination of cover crops and two-stage ditches, as the drainage of water in agricultural areas upstream is a leading cause of flooding issues downstream.

2.3.2. ArcGIS & SWAT analysis

To best assess policy options within the watershed, data inputs were combined in the form of a hydrological model using Geographic Information System (GIS) software. Many GIS softwares exist to examine the properties of a watershed, but the one that is used extensively in the illustrative case study is the ArcGIS add-on of Texas A&M's Soil and Water Assessment Tool (SWAT). This software add-on, also referred to as ArcSWAT, is incredibly useful due to its ability to easily integrate parameters from a wide array of databases. Because ArcGIS is a well-established GIS service that incorporates several other softwares (ArcMap, ArcView, etc.), much of the data taken from online databases is readily compatible with the software, meaning that ArcSWAT provides hydrological modeling capabilities while incorporating the ease of traditional ArcGIS interfaces. Furthermore, ArcSWAT provides a wide range of results to interpret from both imported and simulated data regarding how the watershed is impacted by changes.

To perform analysis through the use of ArcSWAT, a minimum of three parameters are required. The first parameter, and one that is used extensively throughout the process, is topographic elevation data in the form of a Digital Elevation Model (DEM). DEM files consist of topographic data divided into rasters, or square units, of varying sizes that can be read and interpreted by GIS softwares. The topographic data is the parameter that defines the boundaries of the watershed being considered, using elevation data to create basin parameters early on in the modeling process. The next type of data considered is land use data. This data can be taken from several different databases, but the one that is most compatible with ArcSWAT is data taken from the National Land Cover Database (NLCD), as it assigns numerical values that can be easily read by ArcSWAT. Finally, soil data is taken in the form of either STATSGO or SSURGO data. The STATSGO, or State Soil Geographic database consists of data at a 1:250,000 scale in the continental U.S., and this type of data is advised for use in multi-state projects.[41] The SSURGO database, in contrast, consists of

National Cooperative Soil Survey data ranging in scale from 1:12,000 to 1:63,360, making it much more suitable for county or city usage due to the smaller sized raster units.[42]

The modeling process begins with delineating the watershed in ArcSWAT, which is done by importing the DEM and selecting the watershed's outlet. The delineation process creates several shapefiles, specifically the overall basin, subbasins, the watershed reaches, and the longest flow path in each subbasin. Next, using the DEM, soil, and land use data rasters, ArcSWAT generated data outputs known as Hydrological Response Units (HRUs). These HRUs are units of data that combine the three data parameters into areas of land that respond to weather events differently, altering the movement of water within the watershed. The sensitivity of HRUs can be adjusted as well, specifically in regards to how much of a role the input data plays in water interaction. Once HRUs are defined, the weather conditions must be defined as well. ArcSWAT contains a vast database of simulated weather conditions that can be readily imported, though weather data can also be imported from external databases to integrate historical data. The weather data that is used by ArcSWAT consists of precipitation, temperature, solar radiation, relative humidity, wind speed, and the selection of a weather generator dataset. These weather parameters, whether they are taken from a historical database or simulated, can then be used to generate input tables. After creating these input tables, an analysis was performed by selecting the timeframe for weather data simulation, allowing the HRU data to generate results accordingly. The analysis process creates several output tables, and these results can be further validated through a process known as manual calibration. A typical calibration process requires additional data that is measured in the field, such as runoff, to adjust parameter sensitivity such that the model's output matches the observed values.[3] Depending on the availability of measured data, calibration may either be limited or impossible for certain watersheds, meaning that a model's accuracy is limited to existing field data.

3. Policy, Planning, and Programming Context

Any decisions made regarding adaptive measures in the St. Joseph River Basin fit into a broader landscape of federal, state, and local authority, laws, and programs. Across each level of government are several agencies and departments tasked with addressing components of environmental protection (described in Figure 3). While departments within the federal government usually have the most reliable funding and can therefore offer reliable financial incentives for action, these incentives are often distributed and facilitated by state and local actors. This requires agency by the subnational government entities, particularly when more localized programming can highlight the solutions best suited to address specific needs of the river basin. Building synergies through coordination of these organizations is vital for adaptive capacity growth in the region.

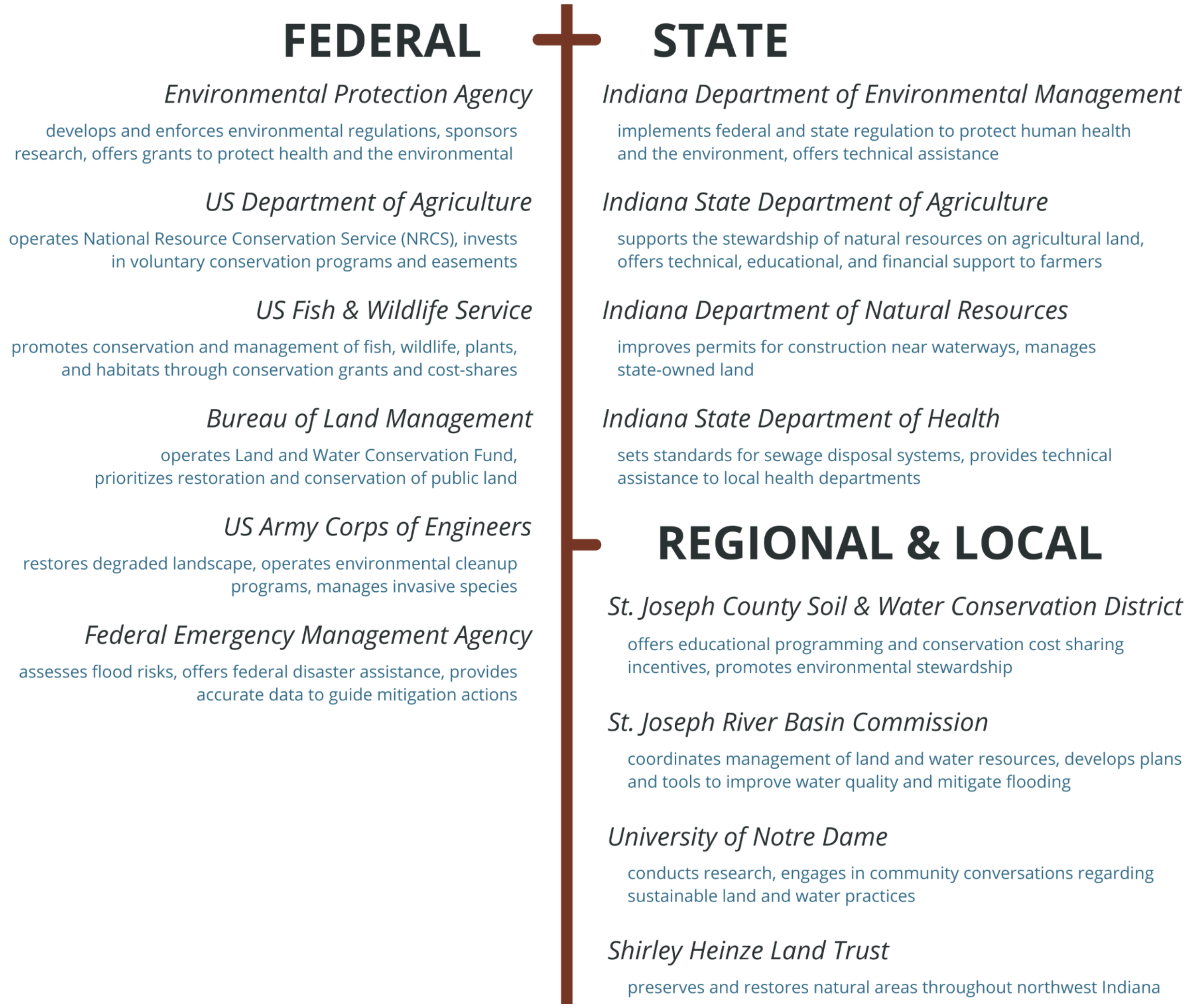

Figure 5: SJRB Policy Organization

3.1. Federal Policy, Planning, and Programming

Federal environmental policy primarily addresses large issue areas affecting public health, such as air and water quality, which are enforced by federal agencies fairly uniformly across the varying regions of the country. Relevant federal agencies in the United States include the Environmental Protection Agency (EPA), the Bureau of Land Management (BLM), the US Fish and Wildlife Service (FWS), and the Department of Agriculture (USDA). Within these agencies, departments such as the USDA's Natural Resources Conservation Service (NRCS) provide more specific services, including working with state authorities to sponsor conservation incentives through easements, financial, and technical assistance.[44] Additionally, the Federal Emergency Management Agency (FEMA), under the US Department of Homeland Security, responds to crises in the aftermath of natural disasters and extreme weather events.

Federal environmental laws are traditionally passed by Congress and then enforced by the relevant agency, such as the Clean Air Act, Clean Water Act, and Safe Drinking Water Act, which are overseen by the EPA, and the Endangered Species Act, overseen by the FWS. These agencies must then carry out the law by overseeing its implementation within individual states.

Through the NRCS, the Environmental Quality Incentives Program (EQIP) provides financial and technical assistance for voluntary conservation practices by agricultural producers.[43] The goal of the program is to demonstrate the compatibility of agricultural production and environmental quality by supporting practices such as wildlife enhancement, pastureland improvement, soil health practices, water quality practices, and forestry management. National priorities of the program are the following: to reduce nonpoint source pollution and the contamination of surface and groundwater; to conserve ground & surface water resources; to reduce emissions; to reduce soil erosion and sedimentation; to promote at-risk species habitat conservation; to conserve energy; and finally, the promotion of biological carbon storage and sequestration.

The NRCS's Agricultural Conservation Easement Program, or ACEP, offers financial and technical assistance to help conserve agricultural lands and wetlands, preserving their related co-benefits.[39] This assistance comes through Agricultural Land Easements and Wetland Reserve Easements. Within ACEP's Wetland Reserve Easements, the Wetland Reserve Enhancement Partnership seeks to promote partner contributions to these conservation easement projects.

3.2. State Policy, Planning, and Programming

In the United States, all powers that are not delegated to the federal government are retained by the states. For many functions, therefore, each individual state is managed by its own set of laws and regulations that often vary considerably based on the culture and resources of each state; this results in a breadth of environmental and natural resources management strategies. This can create difficulty with planning and management across state boundaries for land and water resources that don't cleanly stop at a state border, such as the St. Joseph River.

In Indiana, water policy falls under riparian law, meaning that water is a public good that is included as a part of the land on which it falls upon or travels on. This suggests that those with land bordering a body of water, such as a stream or drainage ditch, have joint rights over it – unless the water is navigable and qualifies as waters of the United States[35]. Indiana traditionally holds the common enemy doctrine, which states that "surface water which does not flow in defined channels is a common enemy and…each landowner may deal with it in such manner as best suits his own convenience."[25] This means that landowners may limit ground water absorption or change the grade of their own property without regard to the impacts it may have on their neighbors. Without the ability to directly control the movement of water on private land, this means the state must rely on incentive-based approaches to flood control.

Ultimately, measures such as the common enemy doctrine stand to benefit farmers the most, as they traditionally drain the largest areas of land. The lack of regulation on land draining was accentuated by the passage of Indiana Senate Bill 389, passed in 2021, which reduced protections for certain wetland types and ephemeral streams. Perhaps the biggest change resulting from the bill was the declassification of Class 1 wetlands, which have been disturbed by human activity and do not support a large array of biodiversity. Although these regions lack an abundance of animal and plant life, they play an important role in the storage of water, assisting in reducing runoff speed, preventing flooding events, and filtering nutrients before they enter into water systems. These wetlands also account for nearly 60% of wetland area in Indiana, therefore the destruction or draining of such landscapes may lead to even greater problems with flood and water quality.[30]

3.3. Local Policy, Planning, and Programming

While Indiana law ensures that the majority of control over natural resources and environmental issues is kept by the state, municipalities hold the power to dictate matters that exist on a small scale or a specific case-by-case level unique to that region. Unfortunately, due to the independent nature of the local governmental sector, the level of importance and stringency accompanying some of these environmental regulations can vary wildly from one area to another. One municipality may place a much higher emphasis on environmental protection and natural preservation as opposed to another.

The St. Joseph County Soil and Water Conservation District (SWCD) provides support for those interested in applying for certain NRCS grants and programs, including EQIP and the Conservation Stewardship Program. Additionally, the SWCD provides its own financial incentives for land management practices shown to improve soil health and water quality, such as no-till, cover crops, and filter strips.[19]

Local drainage boards may find success by leveraging ditch taxes to incentivize better land management practices. Through ditch taxes, farmers and landowners could pay for their role in impediments to natural ecosystem services – in the SJRB, this is seen through drainage ditches that move water downstream for the benefit of those upstream.[29] Ditch taxes are traditionally set by static factors such as acreage or proximity to the ditch, but moving towards dynamic factors such as land use and management practices can create a weighted fee structure that is better suited to address the modern landscape. Use of this more equitable proportionment structure has been successful in Van Buren County in Michigan and LaGrange County in Indiana, leading to significant reductions in sediment load.[13]

3.3.1. Community Planning at an Urban-Rural Fringe

Using the “Community Planning for Agriculture and Natural Resources: A Guide for Local Government”, produced by Purdue Extension and the Indiana State Department of Agriculture, we can create a foundational map for building resilient communities, particularly ones that contain both urban and rural areas. This foundation becomes especially relevant in St. Joseph County, as the County updates its Comprehensive Plan for the first time since 2002. Purdue’s Community Planning Guide emphasizes three main goals for land use-related planning and development: first, to support the landscape through natural land conservation and working-land visibility; second, to help existing places thrive by maintaining existing infrastructure and investments in downtown areas; and finally, to create great new places that encourage people to stay in areas long-term. While all three of these goals are essential for comprehensive planning strategies, the first goal is particularly relevant in conversations of climate adaptation and resilience. To explore more deeply this goal of supporting the natural landscape and integrating urban-rural points of connection, the objective can be broken down into four subsections.

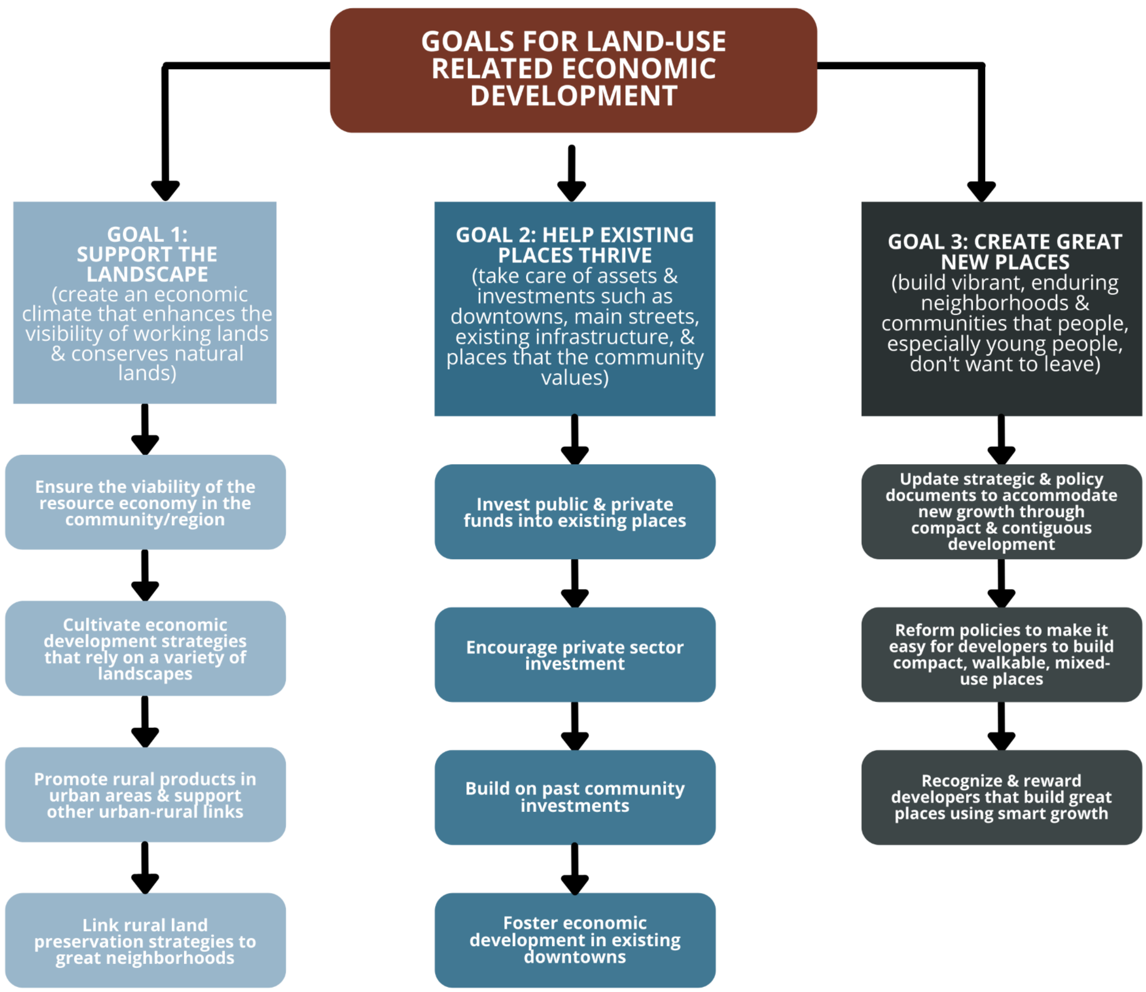

Figure 6: Land Use and Economic Development
Adapted from “Community Planning for Agriculture and Natural Resources”

The first subsection seeks to ensure the viability of the resource economy in the community, meaning that natural resources are protected and existing farmers are able to continue in their livelihoods. Certain tools and policies to protect such viability include market use-in-value taxation, where the value of property is determined by the utility received from it, rather than a traditional appraisal that would include development value. This can support farmers by keeping their taxes lower so they can keep their farmland as farmland, rather than being pressured by rising taxes to sell to developers. Another policy could be offering credits for conservation, similarly allowing farmers to preserve farmland and protect it from future development. Additionally, putting into place right to farm policies can protect farmers from nuisance lawsuits that attempt to disrupt historical farming operations. For example, in Indiana, state code makes known that "it is the policy of the state to conserve, protect, and encourage the development and improvement of its agricultural land for the production of food and other agricultural products." As such, the state's agricultural production is threatened by the expansion of nonagricultural land into agricultural areas, particularly when these changes result in nuisance suits that threaten the operations of farms. Therefore, Indiana state law aims to limit the circumstances in which agricultural activity can be declared a nuisance and made to cease production.

While this serves as an additional example of agriculturally-dominant state policy, it protects from aggressive development into rural lands, protecting the livelihoods of generational farmers and ensuring longer-term survival of agricultural lands. Ideally, this policy would be supplemented with conservation policies that incentivize practices that improve water quality and reduce downstream flooding problems. Two other opportunities that support the survival of resource-based economies include supplemental development of renewable energy sources such as solar, wind, or biomass, as well as payments for ecosystem services such as water retention and purification.

The next subsection aims to create economic development strategies that rely on both urban and rural landscapes. This may include the purchase of development rights, which transfer the right to develop from one area, which remains undeveloped and protected, to another, such as an urban neighborhood looking to increase development density. Conservation easements can also serve to protect natural lands from any future development, and are often supported through national programs like the NRCS ACEP program described above.[39] Finally, fee simple acquisition of land can aid in the purchase of open lands by a land trust, such as Shirley Heinze Land Trust, which operates across northwestern Indiana.

The third subsection seeks to promote rural products in urban areas & support other urban-rural links. This may offer slightly less tangible opportunities for urban-rural connections, such as direct marketing to consumers or "buy local" campaigns, but they also offer opportunities for community-building across geographical classifications. For example, opportunities to connect urban and rural community members may incentivize rural farmers to decrease the water they drain from their property, thus preventing downstream flooding in urban neighborhoods. Likewise, urban residents can better understand the benefits of local farms, offer financial support through the purchase of natural resources, and encourage the conservation of natural areas for recreational use.

Finally, the initial goal of supporting the local natural-resource landscape can be promoted by linking rural land preservation strategies to great neighborhoods. This may include the creation of priority funding areas, thereby promoting development in certain already-developed areas in order to relieve pressure on undeveloped land – or conservation easements that allow for recreational use of protected areas.

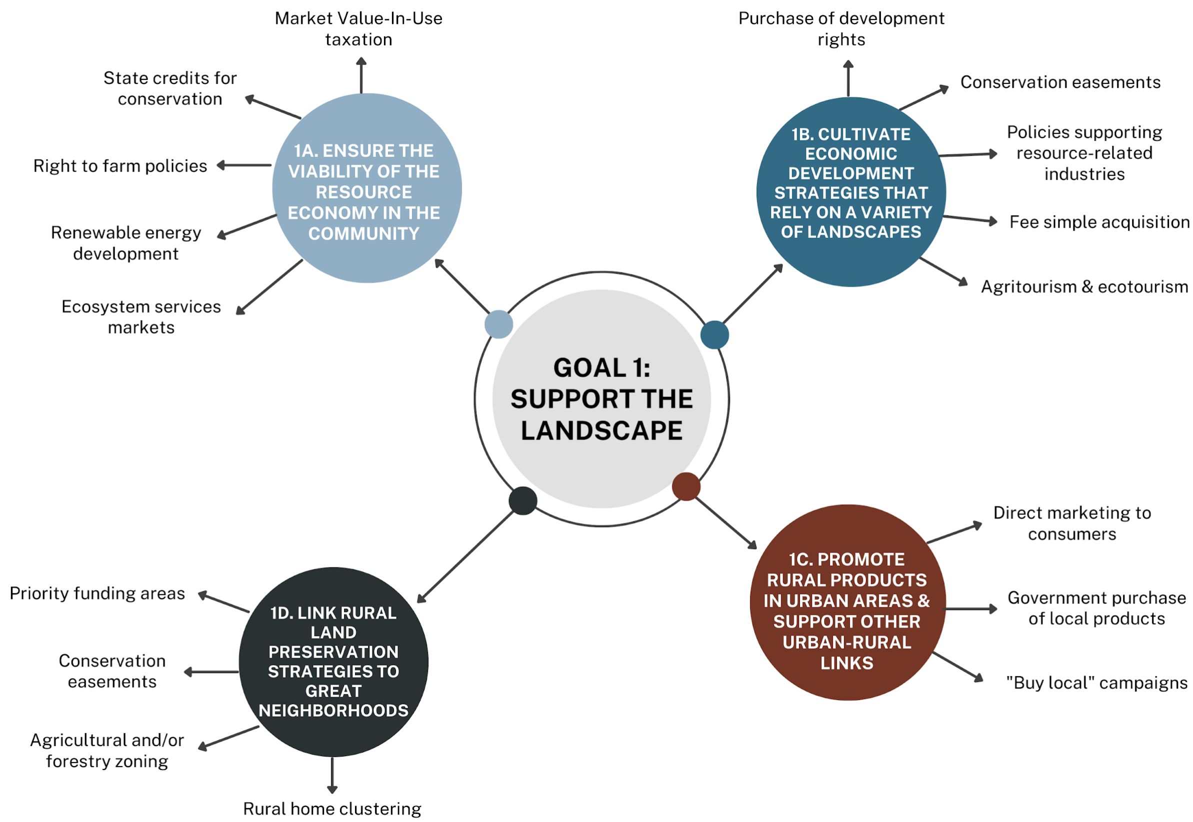

Figure 7: Supporting the Natural Landscape
Adapted from "Community Planning for Agriculture and Natural Resources"

These suggestions for improved community planning and development are especially relevant when exploring the St. Joseph River Basin, as the land-use along the river and watershed changes frequently from urban to rural and back again. It is important to create policy while recognizing its implications for the larger watershed. No single community lives in a vacuum; therefore, policies should be used to maximize the benefits for both urban and rural areas while acting to protect existing natural resources and plan for future extreme weather events. The relevant suggestions become even more important as we focus on a specific area of the SJRB – Phillips Ditch.

4. Illustrative Case: Phillips Ditch

At the southern edge of the City of South Bend, Phillips Ditch serves as a “fringe area” between upstream rural regions draining into downstream urban regions. This makes building adaptive capacity all the more vital in order to protect the quality of water running into the St. Joseph River and then Lake Michigan, reduce flooding from upstream drainage activities, and shape more integrative planning in an area that has already seen the implications of climate change firsthand.

4.1. Overview

While Phillips Ditch was initially a natural basin, it became a more pronounced ditch through man-made efforts that altered the historical course of the water using culverts and redirection efforts. In particular, there have been several changes around US Highways 20 and 31, both of which converge by the Jewel Woods neighborhood. Not only is Jewel Woods one of the furthest downstream neighborhoods in the watershed, it is also bounded by these two major controlled-access highways, meaning that the natural drainage basin has been altered heavily. As the land has become more heavily developed in this neighborhood, less natural drainage area is available, meaning that water accumulates more copiously. This is a result of increased residential development in the neighborhood, which is removing the natural permeability that the natural landscape had. The combination of less permeable surface and altered drainage routes means that storm events have disproportionate effects on the Jewel Woods area, such as the major 500-year and 2400-year flooding events in 2016 and 2018, respectively.[3]

The natural shape of the ditch’s channel has been altered over time to more effectively provide drainage to local agricultural producers. This has implications for the health of water systems downstream; as the ditch retains less water in the rural areas, and then brings both heavy flow of water, as well as pollution from fertilizer runoff, into urban communities. Shown in Figure 8 is a map of land use in the Phillips Ditch Basin, as of 2019.

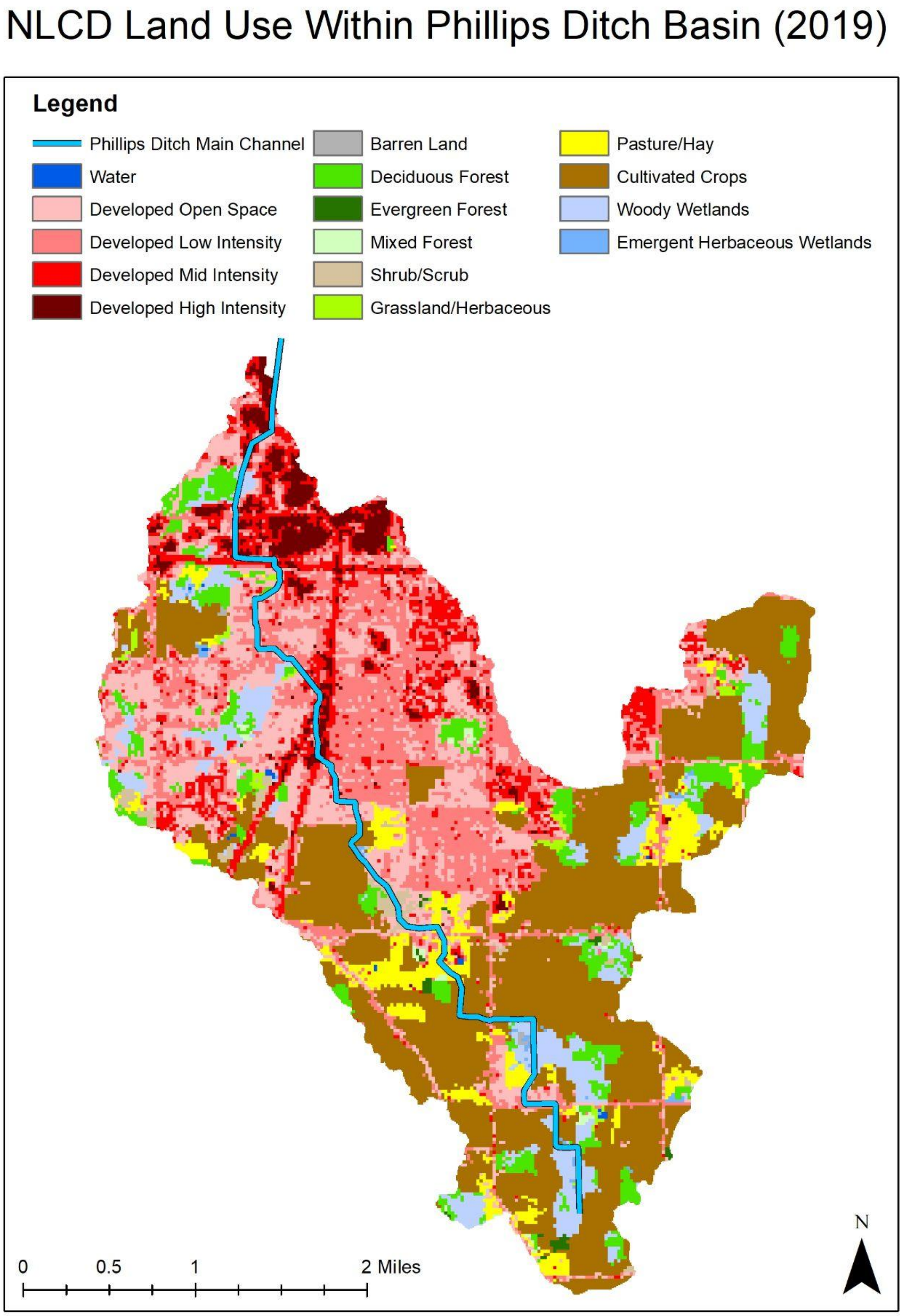

Figure 8: Map of Land Use in Phillips Ditch, 2019

4.2. Modeling

4.2.1. Modeling Procedure and Results

As described in the Methods Section, the primary tool used to analyze the Phillips Ditch watershed was ArcSWAT. In order to accurately assess the watershed, the proper data inputs mentioned in section 2.3.2: ArcGIS and SWAT analysis were used. For the basin that drains into Phillips Ditch, there are five major parameters used to generate a complete model in ArcSWAT: elevation data, soil types, land use, precipitation, and temperature readings. Elevation data was taken from the USDA's Natural Resources Conservation Service (NRCS), consisting of twenty separate raster files that were mosaicked and clipped to fit within St. Joseph county's boundaries. The elevation data is provided in terms of small rectangular raster files, which while easily accessible, require knowledge of ArcGIS's mosaicking tool to be made into a proper ArcSWAT input, adding some difficulty to the process. This digital elevation model (DEM) consists of a 10m resolution based on the available resolution options from NRCS. Soil type data was taken from the Web Soil Survey, a database created by the USDA to provide intricate soil data. The USDA data consisted of SSURGO soil assignments within a shapefile of the county. The SSURGO data was chosen as opposed to STATSGO data due to the fact that the watershed is confined only to one county, which meant a more detailed dataset would be necessary. This data consisted of a 1:12,000 resolution shapefile and was converted to a raster in order to be compatible with ArcSWAT, as shapefiles are vector-based data as opposed to the raster-based data that ArcSWAT requires. Similar to the mosaicking process, the conversion tool requires foundational GIS knowledge to use, meaning that even with accessible shapefile data, ArcSWAT analysis cannot be performed without baseline knowledge of the software. Land use data was taken from the 2019 version of the National Land Cover Database (NLCD) map of the US, which has a default resolution of 30m. This data was clipped to fit within the boundaries of St. Joseph county in a similar fashion to the other rasters. Finally, precipitation and temperature data were taken from the NOAA database reports, specifically weather data from the South Bend airport station. The other weather parameters (wind speed, solar radiation, and relative humidity) were simulated through ArcSWAT's own weather database. While these parameters are crucial for developing a model, there is a noticeable lack of hydrological data for the Phillips Ditch case, meaning that manual calibration for this model cannot be performed unless more data is available. Manual calibration incorporates existing data in order to "train" the model to create outputs that reflect real-world conditions. Because there are no public databases of hydrological gage data for Phillips Ditch, no real-world conditions could be found to properly calibrate this smaller watershed. Regardless of whether or not this calibration process can occur, comprehensive results can still be obtained from the use of these data inputs.

To validate the results, especially in regards to weather data, four separate cases were created in ArcSWAT and analyzed over the same time period. The first case consisted of using the NOAA weather data and an unaltered NLCD land use map, largely to test the efficacy of historical data. This contrasts the second case, in which all parameters (including the NLCD map) were held the same except for the weather data. For the second case, ArcSWAT's simulated weather data was used instead. The third and fourth cases follow a similar pattern, in which the third case uses the NOAA data while the fourth case uses simulated weather data. However, these latter cases both use an altered version of the NLCD land use map in which the original coverage over the Jewel Woods neighborhood was replaced with a woody wetlands designation to analyze the downstream changes that occur from altered land use. Woody wetlands were chosen to test the impacts of wetland restoration on hydrological outputs, such as runoff, groundwater exchange, and sediment yield to assess flood risk. Because of the lack of calibration available for the watershed, the efficacy of the model and potential land use changes depends on a direct comparison of the four cases. Shown below is a table of the four cases considered and what parameters are adjusted for each trial.

Table 1. Trial Cases for ArcSWAT Model

Case Number	Precipitation and Temperature Data Source	Land Raster Used
1	NOAA (South Bend Airport)	Unaltered NLCD 2019
2	ArcSWAT Simulation	Unaltered NLCD 2019
3	NOAA (South Bend Airport)	Altered NLCD 2019
4	ArcSWAT Simulation	Altered NLCD 2019

In addition, two additional figures are shown. The first figure shows the three raster datasets for Phillips ditch (DEM, land use, and soil) and their respective sources. The next figure shows a comparison between the two NLCD raster files. The raster on the left shows the original 2019 land use conditions of the watershed, whereas the raster on the right has an additional light blue area near the highway interchange. The added blue area represents the woody wetland designation assigned to the approximate area of the Jewell Woods neighborhood. Other than this, the two rasters are identical elsewhere.

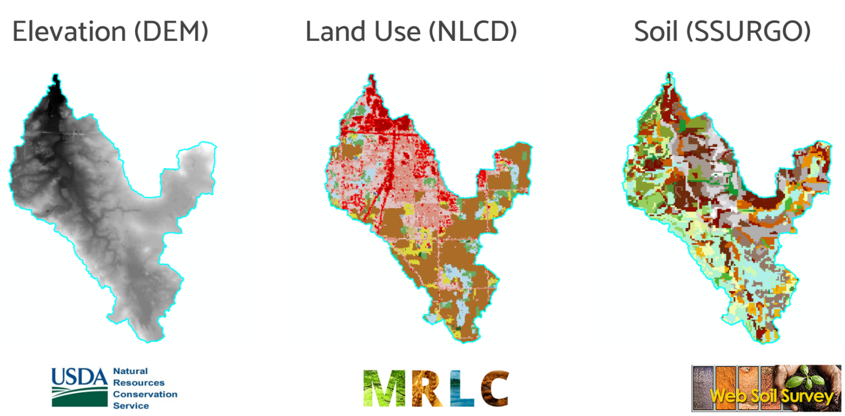

Figure 9: Required rasters within the bounds of the Phillips ditch watershed

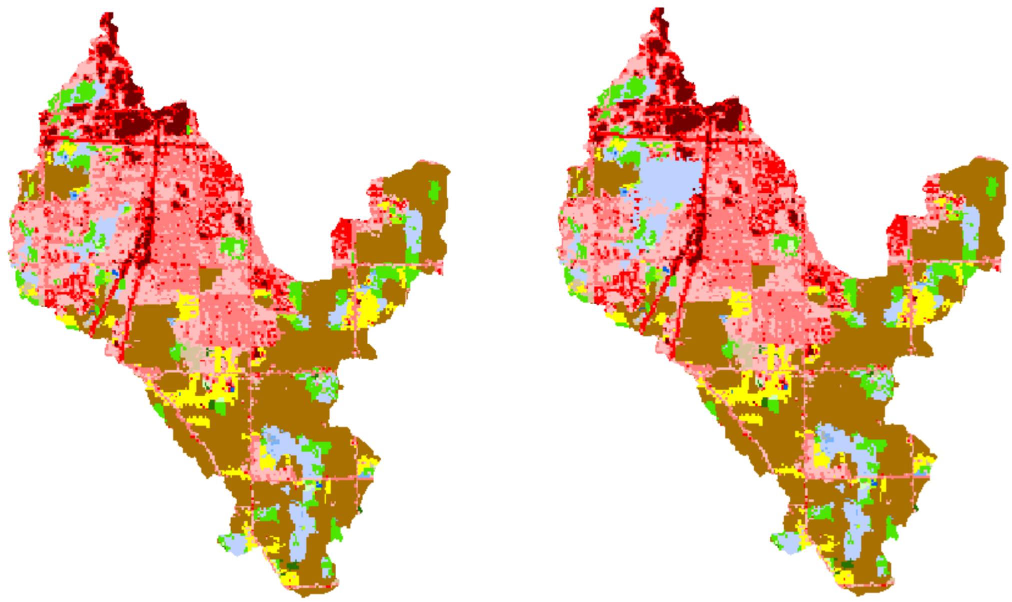

Figure 10: Unaltered vs Altered 2019 NLCD Land Use Rasters

The first step in developing the different models was to delineate the approximate watershed of Phillips Ditch by assigning an outlet point (where the ditch enters Bowman Creek) and elevation data from the county-wide DEM. Following the creation of the watershed, HRUs were then developed using the NLCD and SSURGO data taken from the external databases. The HRUs were generated with the highest sensitivity so that all categories of land use available would be accounted for, as the watershed is small enough to be confined to St. Joseph County. This procedure was performed identically for all four cases, with the exception of a different NLCD dataset for the latter two cases. For cases 1 and 3, weather data was defined using historical data from NOAA, whereas cases 2 and 4 were analyzed using simulated data. Following the development of the HRUs, the input tables were created for all four cases and then run under an eleven year time period. The eleven year time period contains one warm-up year and runs from the beginning of 2006 to the end of 2016 using daily intervals for increased accuracy. The one year warm-up period is an essential part of the modeling process that ensures the model has time to “train” before generating results. However, because there are a wide variety of output tables generated from the data, it is important to determine which outputs are the most useful in determining the effectiveness of the model.

ArcSWAT provides a dialogue window following the successful completion of running a model. This dialogue window can be used to check for errors in the model, but it also provides a series of easy to interpret results that provide a general overview of the watershed’s properties. The following are categories of data that are provided and checked by the error checker: hydrology, sediments, nitrogen and phosphorus cycles, plant growth, landscape nutrient loss, land use summary, instream processes, point sources, and reservoirs. While the error checker alone gives relatively limited data outputs, it helps users identify problems in the watershed. For example, if the error checker were to give a warning about excessive sediment yield, this could be an indicator of a river with an abnormally high sediment load. The model itself is an excellent tool to determine relevant field measurements to take into account, as a lack in calibration data indicates a body of water requires more intensive monitoring.These general values help provide context for proposing new approaches to adaptation, but they only do so on a broad scale. To determine the efficacy of the model, specific values are taken from these dialogue windows and compared with one another. In doing so, this will not only assess the accuracy of data, but it will help determine how much of an impact land use plays in mitigating watershed issues. Three distinct tables are shown that illustrate the contrasts in data output.

The first table focuses on the hydrology results of the four cases. The potential evapotranspiration (*PET*) represents water that can be taken from the watershed system in the form of evaporation and transpiration, which is larger than the model's actual evaporation and transpiration value. *Precipitation* represents water that enters the system through the atmosphere, while surface runoff represents water that ends up accumulating on the surface. *Lateral* and *Return flows* represent the movement of water in the root zone and shallow aquifer respectively into the exposed ditch. The *percolation* and *revap* values examine the intake and removal of water respectively from the shallow aquifer, while recharge to deep aquifer represents water being lost as it enters a deeper groundwater system. These values are all critical in determining general characteristics of the watershed, specifically determining where water is distributed as it moves through the basin. All of these values are tabulated for the four cases in Table 2.

Table 2. Hydrology Results from ArcSWAT Error Checker

Hydrology Results (All Units in mm)	Original Land Use, External Weather Data (Case #1)	Original Land Use, Simulated Weather Data (Case #2)	Updated Land Use, External Weather Data (Case #3)	Updated Land Use, Simulated Weather Data (Case #4)
PET	1045.2	1147.9	1045.2	1147.9
Evaporation and Transpiration	586.3	596.3	586.2	596.7
Precipitation	1033.3	923.1	1033.3	923.1
Surface Runoff	274.91	215.81	271.82	212.99
Lateral Flow	11.32	9.28	11.44	9.37
Return Flow	136.92	84.73	139.85	86.93
Percolation to Shallow Aquifer	163.61	108	166.71	110.34
Revap from Shallow Aquifer	20.88	22.91	20.88	22.91
Recharge to Deep Aquifer	8.18	5.4	8.34	5.52

For cases 1 and 3, the error checker gave a warning indicating that surface runoff may be excessive, pointing to a discrepancy between the simulated and measured weather conditions. Between simulated and measured weather conditions, it appears that higher precipitation, surface runoff, percolation and recharge indicate more water is entering and remaining in the system than what the simulated data predicts. The large difference between return flow values in simulated and measured cases shows that measured cases experience more groundwater feeding into the ditch than the simulated data indicates, which may play a role in the ditch's response to storm events. This finding shows that a further study of the groundwater is necessary in order to determine the role it plays in flooding events, especially if it deviates heavily from simulated data. Overall, PET and evaporation and transpiration remain similar between the two, indicating that atmospheric interactions are largely consistent as opposed to subsurface conditions. Between changes in land use (case 1 vs case 3 and case 2 vs case 4), it appears that surface runoff is reduced while groundwater feeding, such as lateral and return flow, increases. However, these values only differ by a few millimeters over an eleven-year period. This indicates that there are minimal changes in the watershed's hydrology upon altering land use, but it indicates that the land use change could be better suited on a different part of the watershed or on a larger scale.

The third table consists of sediment data, which is essential in determining the movement of sediment throughout the watershed. The maximum and average upland sediment yields show the highest observed and typical volumes of sediment moved throughout the watershed. In-stream sediment change indicates the change in sediment throughout the main course of water (in this case Phillips ditch). The sediment values are shown in Table 2 below.

Table 3. Sediment Results from ArcSWAT Error Checker

Sediment Results	Original Land Use, External Weather Data (Case #1)	Original Land Use, Simulated Weather Data (Case #2)	Updated Land Use, External Weather Data (Case #3)	Updated Land Use, Simulated Weather Data (Case #4)
Max Upland Sediment Yield (Mg/ha)	81.96	51.88	81.96	51.88
Average Upland Sediment Yield (Mg/ha)	3.84	2.98	3.94	3.04
In-Stream Sediment Change (Mg/ha)	-3.41	-2.72	-3.51	-2.77

The maximum upland sediment yield is significantly higher than the average upland sediment yield in all four cases. This value is so high that in all four cases the ArcSWAT error checker warns of excessive sediment yield. High maximum yields are an indication of land use issues within the model, specifically a low presence of biomass. Depending on the results that would be taken from calibration, this could be an indicator of abnormally low biomass that would encourage altering the upstream area of the ditch. Sediment change and yield is higher in measured cases as opposed to the simulated case, indicating that weather discrepancies may be leading to overestimated yield values. Similarly, the refined land use cases seem to provide a small increase in upland sediment yield and a greater sediment change, showing that the presence of these wetlands does not mitigate excessive sedimentation. As with the hydrology results, this is an indication that if land use changes were to be implemented for flood mitigation, they would not perform nearly as effectively. This opens up an opportunity to analyze land use changes along other portions of the watershed to determine if land use projects would work more effectively elsewhere.

The fourth and final table displays the total subbasin load, indicating how much of a certain material moves through the watershed. Flow is representative of the water movement, while sediment, nitrogen, and phosphorus represent the movement of these respective pollutants through the watershed. Shown in Table 4 below are the values affiliated with subbasin loading.

Table 4. Subbasin Results from ArcSWAT Error Checker

Total Subbasin Results	Original Land Use, External Weather Data	Original Land Use, Simulated Weather Data	Updated Land Use, External Weather Data	Updated Land Use, Simulated Weather Data
Flow (m^3/s)	0.34	0.25	0.34	0.25
Sediment (Mg/yr)	10237.09	7915.91	10448.27	8044.91
Nitrogen (kg/yr)	32892.73	29439.91	32937	29422.91
Phosphorus (kg/yr)	6727.19	5886.55	6759.86	5905.12

As expected based on the results of Table 3, sediment loading is larger in the altered land use scenario than in the original land use scenario, which is indicative of the need for a solution that goes beyond land use control. Pollutant values seem to shift dramatically between simulated and external weather data cases, which is an indicator of hydrology discrepancies that require calibration to resolve. While this may also be an indicator of precipitation conditions being higher than ArcSWAT expects, the answer cannot be determined without further field data. All three tables demonstrate essential findings in regards to the nature of the ditch and effectiveness of the model. The following conclusions can be drawn from the results of the four cases:

- Cases 1 and 3 (external weather data cases) give warnings of excessive surface runoff, indicating that more water is entering and remaining in the system than when simulated.
- The ditch appears to have much greater groundwater feeding when external weather data is used, indicating it is a heavily groundwater-fed ditch.
- Atmospheric conditions (evaporation, transpiration) remain consistent for all four cases, showing that discrepancies are attributed to how water is kept in the basin.
- Altered land use causes hydrology values to shift towards numbers indicating flood control, but they aren’t large enough to warrant land use change in Jewel Woods.
- All four cases generate warnings of excessive sediment yield, which is an indicator of low biomass in designated land use areas. This points to potential issues with land usage in the area and emphasizes a need for further studies of surrounding land.
- Woody wetlands in the altered land use map do not reduce sediment yield, but actually increase it, indicating that it does not control pollutant spread as anticipated.
- Pollutant yield between cases of simulated and external weather data indicate a large discrepancy in output, indicating further hydrological studies are needed to examine pollutants within the basin.

4.2.2. Modeling Discussion

In order to provide sufficient data to drive policy decisions, it is important to consider which parameters serve as inputs. The data itself can derive from a variety of fields, taking on forms such as hydrological studies or examples of prior policy in action. For many projects, the amount of available data is critical in driving implementation of policy. If there is a lack of measured gauge data in a watershed, for example, this is a clear indicator that more monitoring is required in that particular watershed. If a particular wetland restoration found success in one state, it is reasonable to try and analyze how a similar restoration method would work in a different state. Furthermore, paying attention to certain parameters and the roles they play in an analysis helps uncover which areas policymakers should focus on. Incentives themselves derive from a better understanding of data inputs. An example of this would be discovering a dramatic change in surface runoff upon experimenting with land use data in certain parcels. By revealing this piece of information, it provides a stronger incentive to steer policymakers in the direction of adjusting land use. In the context of the St. Joseph River Basin, data capacity plays a large role in directing policy choices for climate issues. From a technical standpoint, there are several important pieces of data in the public domain that are used as analysis inputs. By using certain technical inputs from this domain, models are generated from a small number of inputs that provide guidance for policy.

As the ditch reaches the more developed areas of the watershed, it appears to divert significantly from the natural path. Two areas where this diversion is especially prominent occur at the U.S. Highway 20 crossing and an upstream segment between Chippewa Road and Ireland Road. Due to the heavy development near these areas, Phillips Ditch has been heavily channelized with an underground system and culverts to carry flow to Bowman Creek. The following figure shows the natural path that accumulates from the basin as compared to the manmade course of the ditch.

Phillips Ditch Overlaying Natural Flow

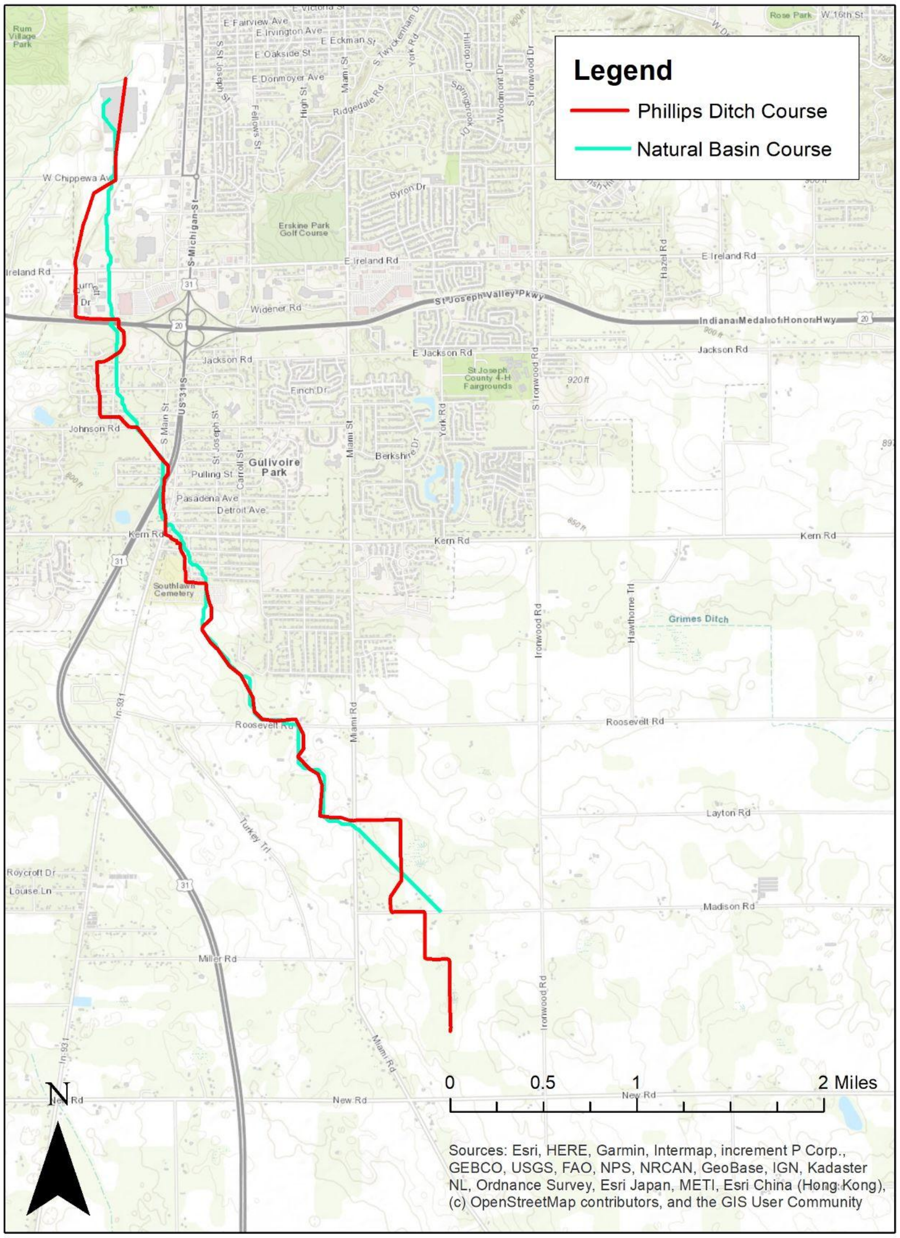

Figure 11: Map of Phillips Ditch Flow

In 2017, McCormick Engineering, LLC conducted a drainage study to assess the primary causes of the 2016 flooding events. The study consisted of examining old hydrological studies and calibrated a model to fit a 100-year storm event. Furthermore, the hydrological model had to account for new drainage paths that occurred as a result of a U.S.-31 realignment project. It is important to note this drainage study needed to use estimates of discharge due to a lack of gauge data. Both the Indiana Department of Natural Resources (IDNR) and the Indiana Department of Transportation (INDOT) have yet to perform a drainage study following the relocation of U.S.-31. The chosen calibration values of 650 and 750 cubic feet per second (cfs) were chosen just past the old U.S.-31 crossing and U.S.-20 crossing respectively based on historical data. These values were assigned for the manual calibration due to a lack of sufficient data, but they reflect expected values for the ditch during a storm event. A prior INDOT study, while not a comprehensive study, outlined a plan to develop 5 detention basins to control flooding, which were included in this study to examine their potential impacts. However, IDNR does not incorporate detention basins in their calculations that are not designated “flood control projects”, even if they have the ability to store water. As a result, the study finds several places along the watershed that have storage capacity but are not designated as such, meaning there is significant potential for improper calibration values. With INDOT’s ambitious flood control proposal and IDNR’s omission of existing basins, there appears to be contrasting ideas on how to measure values within the watershed. In turn, this also demonstrates poor coordination between potential land use options, which creates uncertainties in a hydrological model.[22]

The study also found that there were no precipitation gauges within the watershed, meaning that in a similar manner to the ArcSWAT study, data had to be taken from the airport’s gauges. Because the gauge is several miles northwest of the watershed, precipitation data from the airport is not indicative of precipitation data for the ditch and may not provide an accurate model. This issue is further touched upon in the study upon the analysis of the model in comparison to the calibration spots. In the area where the first calibration point was taken, the model generated a discharge of 648 cfs in comparison to the provided value of 650 cfs, which is within less than a percent within the intended value. However, the second calibration point generated a flow of 842 cfs in contrast to the predicted 750 cfs when modeled, which is a much larger contrast. The report explains that this difference can be attributed to the 750 cfs flow being taken from an exponential approximation, so a difference was to be expected, though it becomes indicative of potential flooding issues in the downstream area of the ditch. The study also finds that of the existing infrastructure that plays the largest role in reducing floods, it comes down to wetlands in the agricultural upstream of the watershed. Wetlands further downstream, such as that along Johnson Road in the Jewel Woods neighborhood, appear to have limited impacts on reducing flow. This aligns with the findings in the ArcSWAT model that demonstrate minimal hydrological changes in response to increased wetlands.

4.3. FEMA Buyouts

After the flood events of 2016 and 2018, St. Joseph County began discussions with FEMA regarding buyouts of houses in the flood prone areas of Jewel Woods. Ultimately, 16 properties were selected and purchased by the County with financial support from FEMA (see Figure 11).[27] Currently these properties sit fallow as the County plans their usage, which will be determined in conjunction with the results of a new hydrological study of Phillips Ditch within the Jewel Woods neighborhood that is currently underway.[26] The following figure shows the 2019 NLCD land use raster alongside the remaining houses that are part of the FEMA buyout at the time of this report.

NLCD Land Coverage and FEMA Buyout House Locations

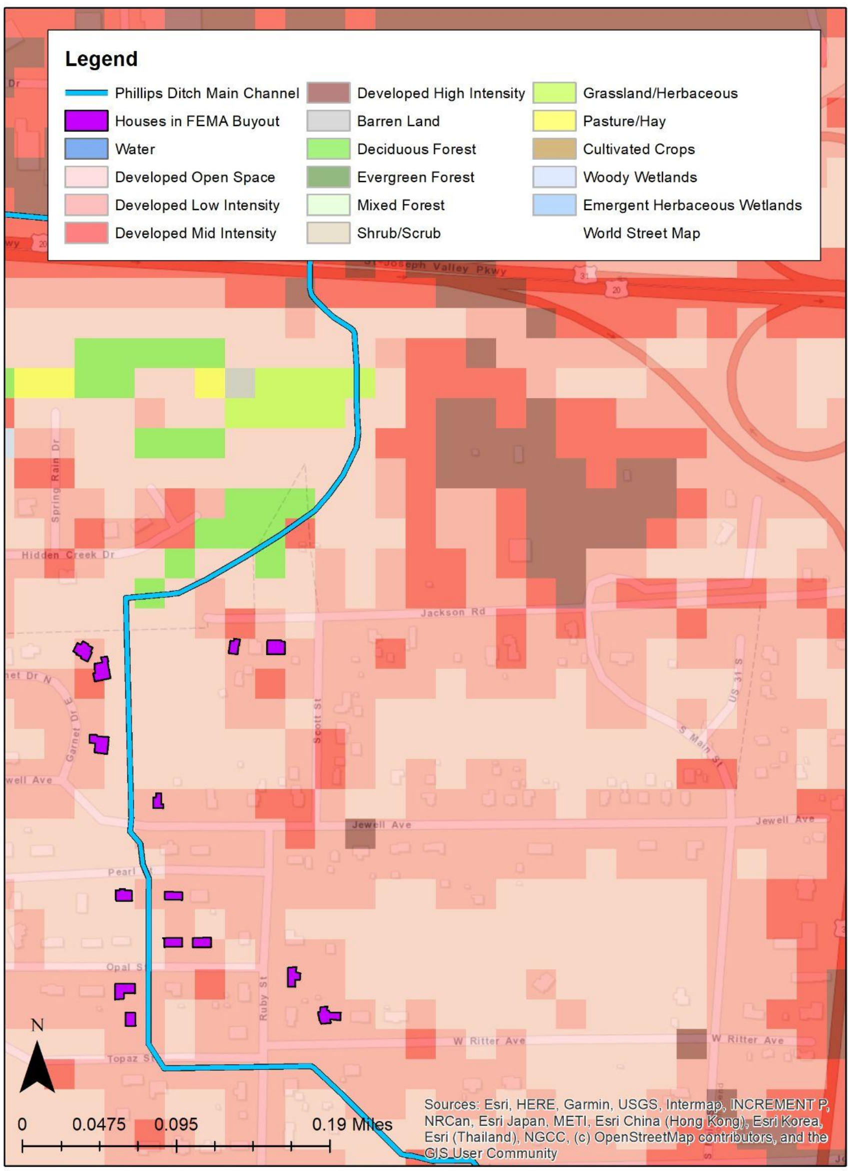

Figure 12: FEMA Buyouts in Jewel Woods Neighborhood Overlaying 2019 Land Use Map

Similar to the findings encountered in developing the ArcSWAT model and 2017 study, it was determined by the St. Joseph County engineer that more gauge data is needed in order to manually calibrate flow data with the model. However, a period of at least three years of gauge data is needed, meaning that until that point, there is no quantitative assessment sufficient enough to gauge which improvement method would be the most effective. Land management methods such as restored wetlands and two-stage ditches may be effective in theory, but the lack of a fully calibrated hydrological model means there is too much uncertainty to fully invest in a project yet.

While these gaps in hydrological data pose an issue for immediately choosing an approach, there are certain FEMA-imposed limitations on the Jewel Woods properties that provide guidance for a potential approach. In particular, there are two paragraphs in the deed that outline usage limitations.[14] The first paragraph (Paragraph 1.a: Compatible Uses) is as follows:

> The property shall be dedicated and maintained in perpetuity as open space for the conservation of natural floodplain functions. Such uses may include: parks for outdoor recreational activities, wetlands management, nature reserves, cultivation, grazing, camping (except where adequate warning time is not available to allow evacuation), unimproved, unpaved parking lots, buffer zones, and other uses consistent with FEMA guidance for open space acquisition.

In the next section, Paragraph 1.b: Structures, several potential structures that are permitted on the new site are listed. These structures are listed as follows:

- A public facility that is open on all sides and functionally related to a designated open space or recreational use;
- A public restroom; or
- A structure that is compatible with open space and conserves the natural function of the floodplain, including the uses described in Paragraph 1.a, above, and approved by the FEMA Administrator in writing before construction of the structure begins.

The structural requirements of the area ultimately mean that retention ponds and other methods of water storage are not permitted, adding another limitation to potential drainage alternatives. What this means is that the feasibility of a two-stage ditch is more realistic than other retention methods, as it aligns with the land use restrictions implemented. However, the feasibility of the two-stage ditch, like any other method, cannot be determined unless further studies are performed.

4.4. Nature-Based Solutions

The current landscape of Phillips Ditch is heavily constructed of gray infrastructure, including expansive culverts, underground retention areas, and road systems. The recent acquisitions of land along the ditch highlight the opportunity to expand green and blue infrastructure in the area, improving natural flood protection abilities and maximizing the co-benefits produced from such investments. Due to the heavily agricultural upstream areas, the area is well suited for two nature-based solutions (NBS) in particular: wetland restoration and the expansion to a two-stage ditch supplemented with winter cover crops.[15]

4.4.1. Wetland Restoration

Figure 13: Co-Benefits of Wetland Restoration

Looking towards wetland restoration practices, it is clear that when approached correctly there are a plethora of co-benefits to be gathered from the restoration of wetlands regions. Root systems from wetland vegetation aid in the filtration and trapping of sediment and pollutants that would otherwise be carried further into the watercourse.[36] Wetlands in St. Joseph County are historically woody wetlands. Consequently, much of this sediment management can be carried out by forest or shrubland vegetation, which aid in improving water quality and stabilizing water turbidity by slowing down the movement of passing water and allowing sediment to settle.[11] From an economic standpoint, there are many benefits to this improvement in water quality such as a boost in fishing and water sport driven tourism and a reduced cost in costly water filtration systems for sediment removal. The restoration of wetlands also leads to increases in the total water holding capacity of the land, as water is no longer restricted between the confines of riparian land and can flow outwards to store water within large expanses of land. These natural retention spaces hold surface runoff after heavy precipitation events before slowly releasing water; therefore reducing flooding impacts. As a result, the co-benefits of these ecological habitats result in decreased flood prevention investments and man-made water retention systems, especially when applied to upstream regions. The return of wetland species into established wetlands provides more stable and biodiverse systems to the landscape; the provision of native plants and animals adapted to this habitat likely results in improved efficiency for nutrient cycling.[23] Improved nutrient cycling leads to a drop in nutrient offloading into water systems, thereby reducing the cost of water treatment strategies and algal bloom mitigation efforts. A critical co-benefit is climate mitigation; woody wetlands aid in the sequestration of carbon within the tree biomass itself, as well as in vegetation growing inside the biome.[5] This boosts the carbon offsetting potential of such wetland regions so long as the levels of carbon stored are reliably calculated.

4.4.2. Cover Crops and Two-Stage Ditches

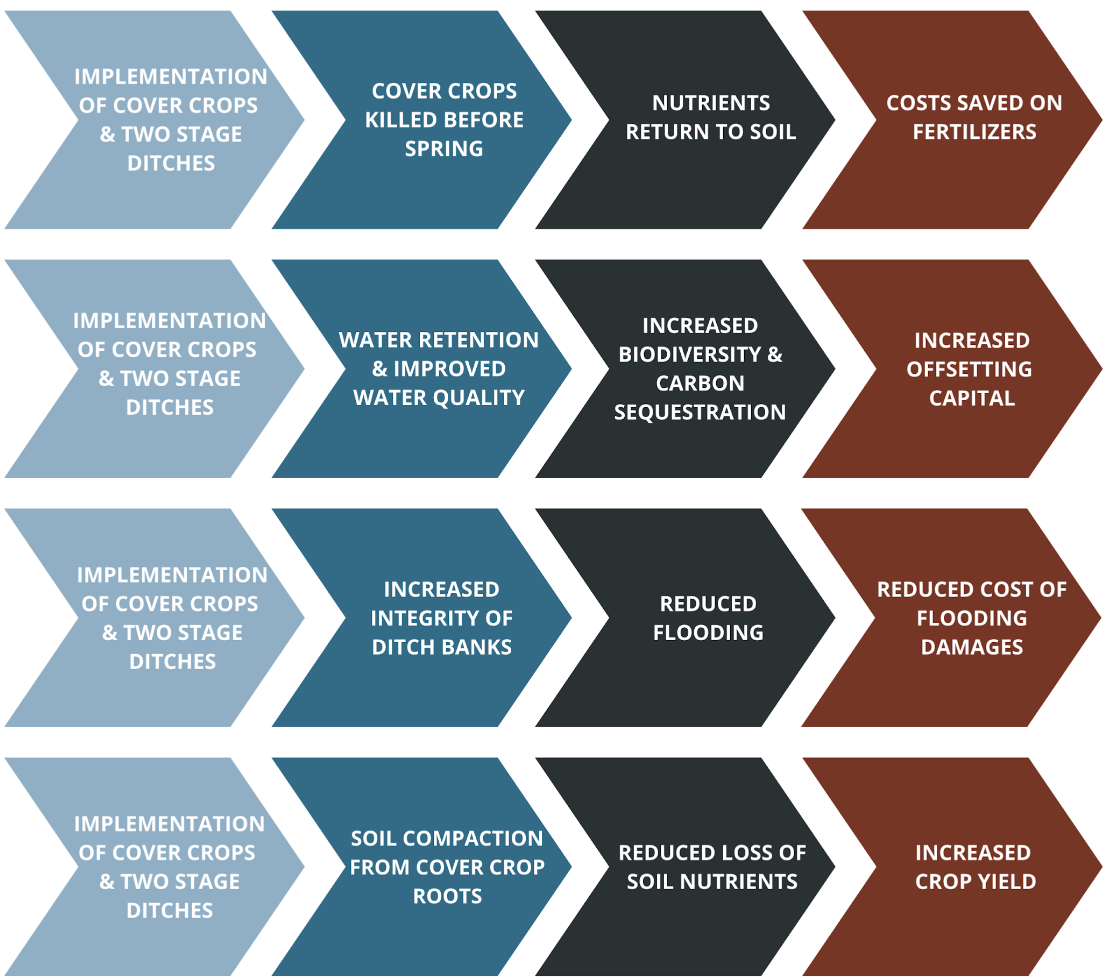

Figure 14: Co-Benefits of Cover Crops & Two-Stage Ditches

An important NBS for agricultural areas is cover crops and two-stage ditches, which can be applied in unison to maximize co-benefits. Two-stage ditches have been implemented and monitored within the context of the SJRB and other regions such as Upper Miami and Tippecanoe, showing significant reduction in sedimentation and nutrient loading. Similar cover crop studies have been carried out in the Kirkpatrick and Shatto Ditch watersheds respectively.[32]

Cover crops involve the planting of vegetation on farmland throughout the winter months to minimize nutrient-heavy surface water runoff that would otherwise flow into water systems downstream. The crops are killed off before the planting season in spring; providing an opportunity for nutrients to return to the soil. This not only prevents excess nutrients from leaching into the surrounding water, but has the co-benefit of reducing the cost spent on fertilizers as the soil remains fertile after a period of dormancy. The long root systems of the cover crops compact and hold soil together, reducing the loss of sediment and promoting increased crop yields from healthy soils.[8]

Two-stage ditches focus on increasing the width of the channel on ditches and promoting the natural flow of water downstream to allow for sediment offloading and natural biodegradation within the water channel. The original depth of the ditch is maintained, with a widening of the secondary layer of the stream to allow for a slower flow of water over these sections. The grass benches of the two-stage ditch help to stabilize the banks in times of heavy water flows, thereby reducing the likelihood of flooding along riparian land. This aids in water retention, as a combination of water stored within the root systems of cover crops and the expanded ditch assist in flood mitigation and carbon sequestration within the accumulated biomass of the ditch. According to a study involving ditches based in the SJRB, 300-1100 kilograms of Nitrogen are sequestered yearly from mature two-stage ditches.[31] This has the potential to connect agricultural land owners to the carbon offsetting market and familiarize them with the potential of adaptive capacity. With successful implementation of this NBS already evident in the SJRB, considerations can be made as to other sections of the river that could benefit from the practice, such as the Phillips ditch region which suffers from periodic flooding and further upstream to prevent flash floods on low lying relief.

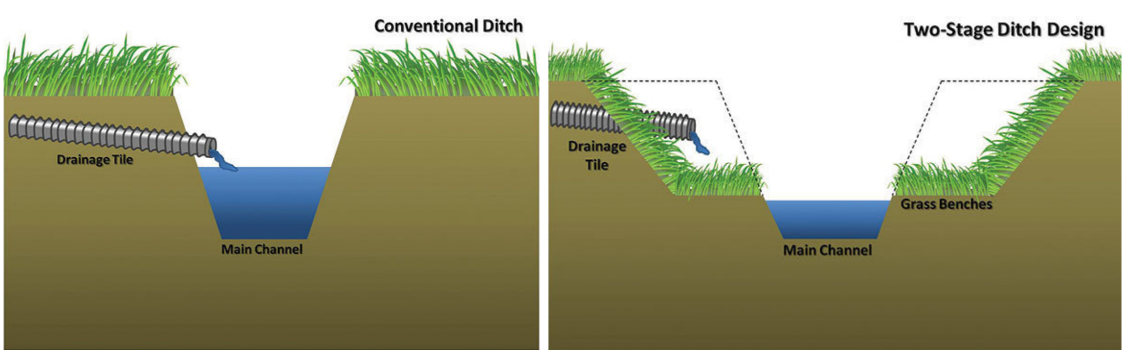

Figure 15: Conventional Versus Two-Stage Ditches
(environmentalchange.nd.edu 2015)

As an extension of the benefits of the two stage ditch, a less explored yet potentially effective NBS would incorporate wild rice. In Asia, paddy fields that employ native wildlife to purify water and break down organic waste. The beneficial effects of rice in water systems extends to the St. Joseph River Basin; as efforts are being made to grow wild rice along the main channel of the St. Joseph. Once an integral resource to the native tribes occupying the region, the channelization and pollution of the river throughout the early 20th century had a detrimental impact on the number of wild rice habitats along the various tributaries of the St. Joseph. The Nottawaseppi tribe of Southern Michigan have acquired drones through federal funding that have allowed them to properly manage and proliferate wild rice crops along the SJRB. This will not only aid in restoring harvesting traditions, but allow for the development of wetlands and increased biodiversity by slowing the movement of water; thereby increasing filtration efficiency. The wild rice crop itself requires high levels of phosphorus and nitrogen to grow, making for efficient sequestration sinks along the river channel, and allow sediments suspended in the water to settle.[10]These projects indicate that a link between organic filtration and carbon sequestration in water saturated regions is effective for amplifying environmental co-benefits.

5. Analysis and Discussion

5.1. Barriers & Gaps

Aside from the SJRBC, structures supporting organization for coordinated action in climate adaptation are generally weak. This applies across the various actors within the system - physical, financial, or policy/programming. Similarly, learning for better decision-making in climate adaption for flooding and water quality is hampered by data gaps. Although the persistence of flooding events in Phillips Ditch garnered media attention, there was a surprising lack of data concerning the history of the ditch - or a clear plan for the future management of the site. The use of ArcSWAT information was helpful in the compilation of data in the area as the models could detail land distribution patterns that would otherwise be unavailable. However, the lack of hydrological measurement data prevented a fully calibrated model from being implemented. While a current hydrological study is underway, not enough historical data exists to properly develop the model, reflecting a need to place more gauges in the stream and potentially to collect weather data. In doing so, future efforts to maintain the ditch and its surrounding area will be much easier to pursue. A recommendation for similar sub basins in the Great Lakes region is to prioritize hydrological studies, especially in sub basins that are prone to being “bad actors”.

Another gap was the lack of information on regulatory controls for water management coordination at the municipal level. It is unclear whether there is sufficient allocation of resources to ensure environmental monitoring and enforcement to regulate offenses to newly introduced ordinances. A lack of information was found detailing the number of groups overlooking such operations which made for difficulties in suggestions for new water management strategies and effective modeling of the site.

The lack of resource availability was a limiting factor for analyzing data and policy management in the Midwest. The existence of so many organizations acting solely or in unison with each other on separate objectives as opposed to following a set of clearly defined regulations and goals only adds to this incoherence. A visible outlier in the way environmental issues are tackled in the US is the state of California, which has developed an intricate system of environmental management and policy mapping in order to create cohesive management solutions for the development and maintenance of statewide environmental programs, an approach that would assist in compiling both Michigan and Indiana shared interest in the environmental management of the SJRB.[6]

5.2. Opportunities

5.2.1. Leveraging Assets

Looking at the adaptive capacity domain of assets, we have identified many of the financial, technological, and service resources that are available at the federal, state, and local levels. Where state and local funding is limited, national programs such as the NRCS's EQIP program can fill financial gaps while being supplemented with technical support from local experts. Employees at the county and city level bring a wealth of knowledge regarding certain geographical areas and specific environmental and political problems, although they may be constrained by time and budget restrictions.

Assets may be provided by private organizations, such as the University of Notre Dame, which offers not only information and research capabilities but also financial support for local projects. Partnerships with city officials can lead to projects with benefits both to the University and to the local community, such as the development of the Seitz Park hydroelectric plant[9]. Finally, non-profit organizations such as the Shirley Heinze Land Trust contribute experienced professionals, technical support, and financial backing through practices such as fee-simple acquisitions.

The urban-rural fringe areas provide opportunities for knowledge creation and learning between groups in the SJRB - highlighting the importance of the organization and learning components of adaptive capacity building.

5.2.2. Coordination for Co-Benefits

Improving the adaptive capacity of the SJRB will require strong investments in the organization and coordination of relevant groups. In order for the aforementioned assets to be fully utilized, emphasis must be placed on the continued development of partnerships between local agricultural representatives, city and county officials, neighborhood groups, non-profit organizations, and universities. This may require direct emphasis on such coordination in the forthcoming St. Joseph County Comprehensive Plan, as well as voluntary efforts to follow the integrative planning measures described in Section 3.3.1, Community Planning at an Urban-Rural Fringe.

As extreme weather events inevitably increase, strong bonds between these groups will provide a cohesive structure for individuals to look to for support and information. It becomes important, then, to ensure that efforts to better organize society include all members of society, rather than simply the wealthiest neighborhoods or areas of importance. The SJRB is not protected against the disproportionate effects of climate on the poorest and most vulnerable groups, and any attempts to build resilience must place these groups at the very center of adaptation efforts.

The St. Joseph River Basin presents a unique opportunity for local government and private organizations to coordinate for local development and decision-making, particularly when looking towards climate adaptation actions. Locally, with collaboration between the St. Joseph River Basin Commission, Shirley Heinze Land Trust, University of Notre Dame, City of South Bend, and St. Joseph County, important progress can be made to improve water quality, reduce flooding, and protect the lives and livelihoods of the community members most vulnerable to climate change.

6. Conclusions

In order to establish an effective means of adaptation within St. Joseph County and the broader St. Joseph River Basin, improvements will be required in both the data available for planning as well as coordination within the planning itself. As seen on a smaller scale within the Phillips Ditch area, a lack of background data can lead to difficulty in mapping out effective strategies for the mitigation of arising climate issues. Philips Ditch also serves to emphasize the importance of cohesive planning, as it shows how the detrimental impacts of flooding may not necessarily be seen by those making impactful choices upstream, but can have large implications for those downstream. The problems facing the SJRB are intrinsically systemic, meaning that action cannot be contained to simply one neighborhood or tributary, but will require comprehensive coordination between rural producers, urban neighborhoods, government bodies, and community organizations.

A more comprehensive analysis of the St. Joseph River System will be necessary in order to identify the areas best suited for adaptive measures, as they may not always be where problems are most easily identified. This will require collaboration across the Indiana-Michigan border, government and non-governmental groups, and urban and rural regions. The health of the Great Lakes is irrevocably connected to the health of the SJRB, and therefore requires full cooperation from the communities within the river basin as well as those who rely on the Great Lakes as a freshwater resource. By investing in nature-based solutions and reaping their inevitable co-benefits, effective adaptation efforts can have widespread positive impacts within the St. Joseph River Basin, and serve as a catalyst for further action across the Great Lakes and Midwest.

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