DOW SUSTAINABILITY FELLOWS
UNIVERSITY OF MICHIGAN

The Nature Conservancy

Soil Tax Incentives Project

Dow Sustainability Fellowship 2020

Team 2 Final Report

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Table of Contents

Executive Summary

Michigan is home to over 47,000 farms and nearly 9.8 million acres of farmland. In the Great Lakes region, two-thirds to three-fourths of all sedimentation that occurs is from agriculture, and this sedimentation has significant ecological, public health, and economic implications. The Nature Conservancy's Michigan Chapter (henceforth referred to as TNC) has worked on several initiatives to address these challenges. Most of their work to date has focused on partnering with farmers and other agricultural stakeholders to promote and incentivize the use of on-the-field techniques to reduce erosion and sedimentation, like reduced or no-till practices. Sedimentation has demonstrated impacts on water and ecosystem health, thereby affecting the quality of drinking water, recreation and tourism, infrastructure, and even property values. Based on these wide implications on the community's health and economy, TNC hypothesizes that there is a greater shared interest in reducing sedimentation that can be tied to financial incentives.

Our Dow Sustainability Fellows team was tasked with developing a model that could quantify these indirect costs to non-agricultural stakeholders. TNC aspires to then build this into a sustainable, revolving funding program for statewide soil conservation efforts. While they have made progress with on-the-field techniques, they hope this larger funding initiative can support implementation of more expensive edge-of-field practices, like riparian buffers or silt fences.

Our approach to this project consisted of:

- Conducting a literature review on existing sedimentation impacts and costs research
- Interviewing the program manager of the existing Gratiot Watershed Program (GWP), a successful pay-for-performance pilot, to assess lessons learned and best practices to scale statewide
- Analyzing existing geospatial datasets to identify regions within Michigan that are particularly vulnerable to sedimentation risks
- Developing a proof-of-concept cost model using water treatment costs and sediment load data for the 58 water treatment plants in Michigan that rely on surface water

The GWP demonstrated significant sediment reduction over the USDA Natural Resource Conservation Service's (NRCS) comparable program, the Regional Conservation Partnership Project (RCPP). The GWP follows a pay-for-performance approach, in which farmers are paid for meeting sediment reduction targets, whereas the NRCS pays farmers just to implement practices without measuring those results. As such, the GWP was able to reduce 9.6 pounds of sediment per program dollar, whereas the RCPP only averaged 2.2 pounds reduced per dollar spent. Given the effectiveness of the GWP, we center our report on scaling that program through three recommendations:

1. **Quantify the downstream economic benefits from sediment reduction.**
   TNC needs to quantify the direct and indirect costs of sedimentation to incentivize stakeholders to support this financing program. We recommend TNC prioritize stakeholders in water treatment, infrastructure, and recreation/tourism, particularly

municipalities and local governments. We developed an initial model to quantify downstream savings for water treatment plants and found the potential statewide cost savings range from $1,023,039.91 to $3,069,119.74. Our vulnerability analysis combined with the cost model helped identify ten water treatment plants to prioritize. Reducing sediment load by 30% at just these ten plants could result in $884,251.58 of cost savings. Our model provides a framework to begin quantifying costs in other industry areas, for which we also outline the initial cost estimation research in the report appendix. Quantifying these combined economic benefits is critical for securing public or private financing at the desired scale.

2. **Expand watershed modeling.**
   The GWP currently relies on modeling from the Michigan State University Great Lakes Watershed System to prioritize farms. TNC should expand this modeling so that it is available in all Michigan watersheds where agriculture is a major factor in sedimentation. In conjunction with building out the cross-sector cost model, this will provide a more accurate view of sediment reduction outcomes through more robust sediment load data and attributable stakeholders.

3. **Develop a new pricing strategy.**
   While GWP has demonstrated its effectiveness over RCPP in achieving sedimentation reduction, a major obstacle of the program is increasing farmer participation. This is mostly because pricing is currently set below the cost to farmers and below the payment available through RCPP. We recommend a new pricing strategy that consists of determining the lower and upper bound of payments based on the calculated economic costs and opportunity costs to farmers and incorporating additional considerations based on the cross-sector indirect cost modeling. This new pricing strategy will help the GWP compete with alternative revenue sources and ideally grow its participation rate to have a larger impact at scale.

Our recommendations lay out next steps for TNC to continuing scaling its pay-for-performance program first through our identified priority areas, and then statewide. By following our initial cost findings in other sectors and cost model methodology, TNC can continue partnering with The University of Michigan Dow Sustainability Fellows to quantify indirect costs from other industries, starting with infrastructure and tourism/recreation to build out the full revolving funding model. TNC can also apply our water treatment cost model to initiate conversations with municipalities to determine the appetite for these stakeholders to participate in such a program, which would not only provide economic benefits to the region through cost savings, but also improved ecosystem and community health.

Introduction: Scaling Pay-for-Performance Soil Conservation Statewide

According to the most recent Census of Agriculture, the market value of Michigan farm products sold in 2017 was over $8.2 billion[i]. Despite national and state declines in the industry, agriculture remains an essential part of Michigan's economy[ii]. However, agriculture is the nation's leading cause of water quality degradation[iii] through both sediment and nutrient pollution. Sedimentation is the process of soil detachment, transport, and deposition in a new location. This process can result in habitat degradation, loss of fertile topsoil, reduction in recreation value and use, increased flooding, and infrastructure damage, amongst others.

Many factors affect erosion and sedimentation rates in agricultural fields, such as vegetation type and cover, climate, land slope, soil characteristics, and importantly, land management practices. Unfortunately, conservation practices and policy tools aimed at reducing sedimentation from agriculture are underutilized in Michigan, as evidenced by the fact that 66-75% of sedimentation in the Great Lakes Region is from agriculture[iv]. Additionally, as climate change results in more frequent and severe weather, causing more erosion and sedimentation,[v] it will become increasingly important to address sedimentation to preserve land productivity, water quality, and public health.

While farmers may see more direct impacts from sedimentation, such as reduced cropland productivity, local governments and citizens also bear indirect costs. For example, sedimentation shortens water pump lifespan and reduces infiltration capabilities, affecting water treatment infrastructure and costs, driving up local budgets. Many studies also demonstrate the negative impacts of sedimentation on tourism through recreational fishing, ecosystem health, human health, and property values.

The Michigan Chapter of The Nature Conservancy (TNC) hypothesizes that there is a greater shared interest in reducing sedimentation beyond the agricultural sector. TNC is interested in exploring a mechanism for sustainably financing soil conservation by tapping into these other stakeholders. By quantifying costs that non-agricultural stakeholders indirectly pay, TNC seeks to incentivize them to help fund larger, edge-of-field conservation practices for farmers to implement that could further reduce sedimentation. The funding could come from public sources, such as a state-based tax incentive, or private sources, such as a private Payments for Ecosystem Services (PES) model. In either case, TNC needs a scalable, cost-effective approach for producing discrete, measurable, and attributable reductions in sedimentation.

One initiative has already been piloted and proven effective in Michigan. The Gratiot Watershed Program (GWP) offers a template for a scalable, evidence-based, and potentially market-driven approach for reducing agriculture sedimentation in Michigan. By offering payments to farmers based on actual sedimentation reduction, GWP has demonstrated the effectiveness of aligning the incentives of farmers with conservation goals. Furthermore, payments to farmers can be directly connected to quantifiable downstream environmental and economic benefits, so there may be opportunities to monetize those benefits to create a sustainable source of revenue for the for the program.

To achieve this vision of a sustainable financing mechanism, we recommend TNC refine and scale up the GWP by focusing on three key areas:

1. Quantify the downstream economic benefits from sediment reduction
2. Expand watershed modeling
3. Develop a new pricing strategy

In the following sections we begin by providing an overview of the GWP and its advantages over alternative approaches to agriculture sedimentation reduction. We then explore each of the three recommendations above in greater detail, with particular attention to the research needed to better understand downstream savings.

Overview of the Gratiot Watershed Program (GWP)

The GWP was launched in 2013 by the Gratiot Conservation District with funding from the Great Lakes Commissions' Great Lakes Restoration Initiative. The Bad River Watershed in Gratiot County was chosen because of the high proportion of agriculture for land use in the Saginaw Bay area, the area's leading source of sedimentation. Moreover, the existence of robust data and sedimentation modeling for the area, thanks to MSU's "Sedimentation Calculator," meant the program managers could easily identify landowners of fields with high sedimentation potential. This allowed for more accurate estimates of sediment reduction outcomes per dollar spent on the program.

This "pay-for-performance" (PFP) approach to incentivize farmers to reduce sedimentation from their fields is a crucial component of GWP. PFP models make cash payments to participants based on their success in achieving a set goal. In this case, that goal is sediment reduction from a given agricultural field, measured as the difference between the baseline sedimentation before intervention and actual sedimentation after. This stands in sharp contrast to the traditional approach used in USDA's widespread and longstanding Regional Conservation Partnership Program (RCPP), which follows a "pay for practice" approach. Under RCPP, enrolled farmers are simply paid for undertaking certain actions, independent of the actual sediment reduction accomplished.

PFP has several advantages over RCPP. First, by paying farmers for incremental improvements in the effectiveness of their sedimentation reduction efforts, PFP aligns the incentives of farmers with soil conservation objectives. Second, it encourages farmers to use the practices with the most favorable cost-benefit. Lastly, PFP offers higher payments for fields and farms where sedimentation is likely to be greatest, thus maximizing the utility of each dollar spent.

In Gratiot County, farmers had access to both GWP and RCPP. While RCPP reduced sedimentation by 2.2 pounds per dollar spent, the GWP achieved four times more reduction per dollar (9.6 pounds per dollar).[vi] Given the direct relationship between sedimentation and other adverse impacts, like excess phosphorous and nitrogen discharge, the GWP's approach significantly outperforms USDA's. The PFP approach helped quantify the cost per ton of sediment reduced, essential to the goal of getting downstream beneficiaries onboard with funding support to create that sustainable financing mechanism.

In addition to more transparent cost-to-outcome data, GWP provides a streamlined application process for farmers. Whereas RCPP requires farmers to complete a burdensome application process and wait as long as four months for enrollment, GWP's managers can identify priority fields, negotiate prices, and complete farmer enrollment all within a single visit. GWP's managers argue that this enabled them to outcompete RCPP on numerous occasions, despite offering lower payments on average. From the farmer's perspective, this makes sense: the payments from these programs are limited, so the amount of time spent enrolling is not an economically trivial factor.

Recommendation 1: Quantify Economic Impacts of Agricultural Sedimentation

TNC hypothesizes that there may be opportunities to monetize downstream cost savings from reduced sedimentation to sustainably fund the upstream mitigation efforts. Research on these economic impacts from sedimentation is limited, and most studies are either dated and/or not specific to Michigan. Our team was tasked with developing a method of quantifying downstream cost savings, so we focused on the potential savings for water treatment facilities from reduced sedimentation and suggest other industries to which this model could be applied.

Methodology to Quantify Cost Savings to Water Treatment Plants (WTP)

As a part of our background research, we conducted key interviews with TNC employees to understand current efforts to mitigate sedimentation in Michigan. Our interview with Ben Wickerham (Appendix B), who is TNC's innovation assistant for Saginaw's Conservation District, was crucial to our understanding of high-risk sedimentation areas in Michigan and how our cost analysis might fit into PFP soil conservation models in Michigan. We also reviewed the existing sedimentation literature to understand the potential impacts of sedimentation in Michigan. Using a variety of reports, journal articles, and government documents, we compiled data into a literature review and summarized the key impact areas for sedimentation in Michigan (Appendix C).

We then conducted a vulnerability analysis for sedimentation statewide (Appendix D). This analysis, completed using ArcGIS Pro 2.6 software, the USGS Sparrow Model, and the EPA Preliminary Healthy Watershed Assessment (PHWA), identified priority watershed areas where the costs of sedimentation may be highest (see Appendix I for data sources). Watersheds considered to have high sedimentation from agriculture, high vulnerability, and low health (Appendix D, Figure 3, Figure 4, and Figure 5, respectively) are overlayed with the location of water treatment plants that rely on surface water (Appendix D, Figure 2).

Following the vulnerability analysis, we identified water treatment plants (WTPs) in Michigan that rely on surface water, whether from the Great Lakes or smaller bodies of water and captured their water treatment costs through two methods. First, we used a simple linear regression to determine whether a significant association between watershed-level sedimentation and WTP costs (per capita) exists. Second, we calculated pollutant loads of sedimentation using the USGS sedimentation and streamflow data to estimate the quantity of sediment delivered to surface WTPs. Using cost data identified in the literature (i.e., water treatment costs per ton of sediment delivered), we estimated whether WTPs are significantly impacted by sediment. Additional methodology details for the cost model are in Appendix E.

Results of Vulnerability and WTP Analysis

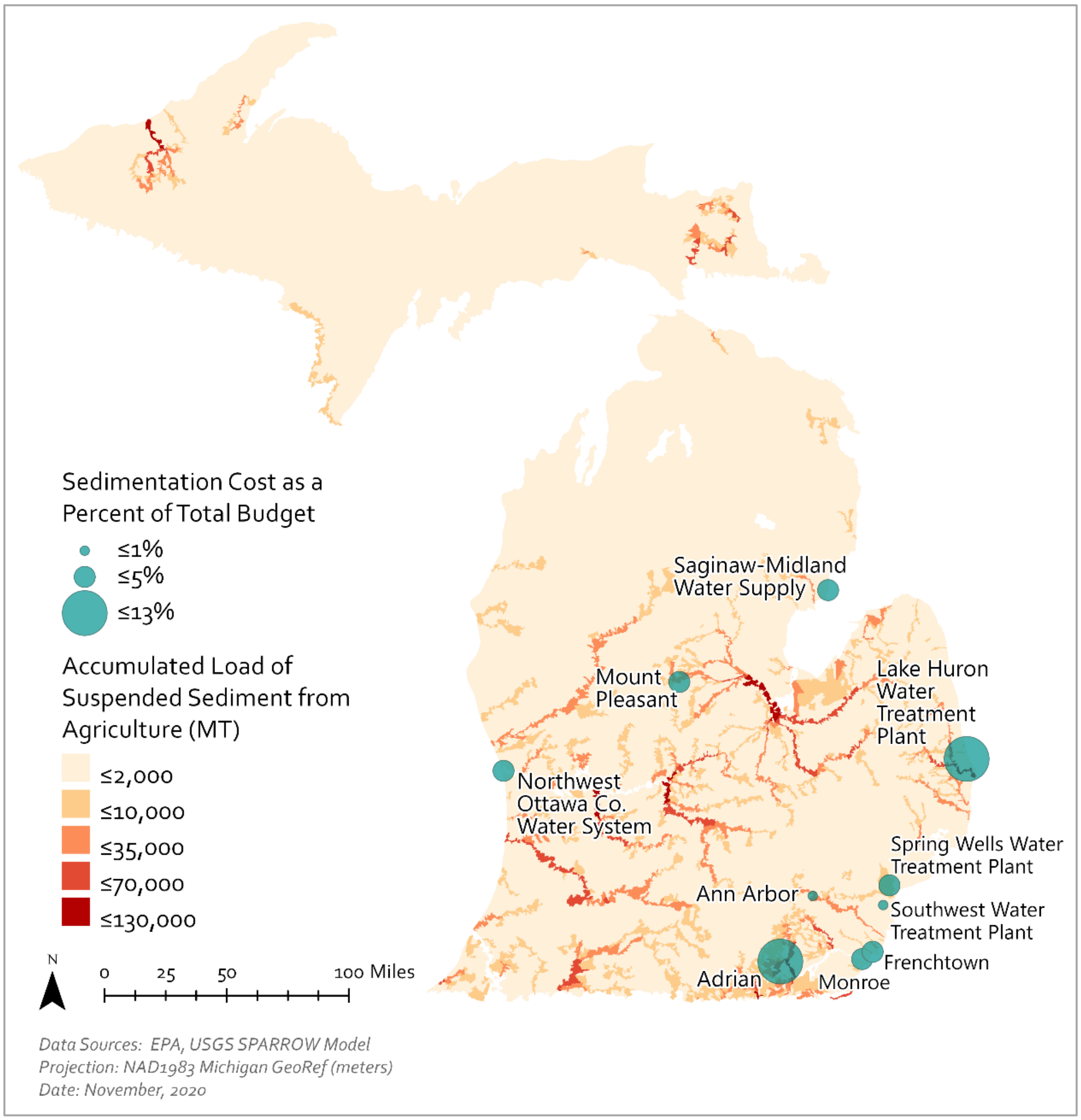
The regression results of the watershed-level sediment and WTPs indicate a moderate association between sediment and WTP spending (Appendix E, Figure 7). There appears to be an increase in WTP spending (per population served) as sedimentation levels increase, but after ~20 MT/km, there is sufficient variability, and the upward trend is discontinued. This relationship is also evident in the smoothing spline (Appendix E, Figure 8) which uses three degrees of freedom to capture the variability in per-capita spending. These results are unsurprising since there exist numerous factors that influence WTP budgets that remain unaccounted for even when budgets were averaged across three fiscal years.

The cost model was our second method to understand costs to WTPs. WTPs generally incur both operating and non-operating costs. Generally, plants retain water in a basin which captures larger solids with the help of chemical coagulants. Often a filtration process follows whereby sand, or another material filter out sediment before the water is disinfected to remove microorganisms, many of which may have been attached to the sediment[vii]. Soil erosion increases the amount of sediment needing treatment at a WTP, though an increase in sediment may not increase capital investments. These treatment processes will likely be required regardless of changes in sediment level, but the operating costs are likely to change with big increases. This model is projected to reflect these variable costs because of sedimentation.

After accounting for the differences in sediment concentrations, streamflow, and gallons treated per day, the cost model identified the surface WTPs in Michigan with the overall highest yearly costs related to sediment, namely the Lake Huron, Adrian, Spring Wells, Monroe, and Saginaw-Midland. These results are in part related to the high capacity of WTPs in these cities. The WTPs with the highest sediment costs *per gallon* are Deerfield, Frenchtown Township, Blissfield, Adrian, and Monroe. Overall, the model identified that statewide costs of sedimentation range from $1,023,093.91 to $3,069,119.74 (assuming $21.38 and $64.14 per ton of sediment delivered, respectively). If we examine the WTPs not directly reliant on water from the Great Lakes, this high estimate is reduced to $699,621.35. We crudely applied two other models to understand how our estimates might change. Using an adjusted version of EPA's 1979 data[viii] of the cost to water treatment from cropland erosion, the total cost (excluding plants with no sediment load in Sparrow) was estimated to be $6,612,835.16 (or a cost of $138.20 per ton of sediment delivered to the WTP). Another estimate based on an Ohio study in 1987 that outlined savings to be 0.15 cents per 10% reduction in sediment[vii] and put the total cost over seven million ($7,540,989.00 or a cost of $157.60 per ton of sediment delivered). Both the EPA and the Ohio study's application to this model is limited, since the estimates do not rely on any location-specific measure of delivered sediment based on the SPARROW model, only on the application of existing cost data to the number of people served by the WTP and number of gallons pumped, respectively. Still, they provide an interesting lens with which to view the model's estimates and could indicate that our models are conservative.

Based on the cost model, the ten WTPs with the highest sedimentation costs align with the findings from our vulnerability analysis. Our vulnerability analysis found South Central, Southwestern, and Central Michigan as high priority areas (Appendix D, Figure 2), and the cost model found South Central or Southwestern Michigan as key areas. If a program similar to the scale of GWP (which removed ~1,000 tons of sediment per year) was implemented near these eight WTPs, there is potential for significant cost reduction to WTPs. More specifically, sensitivity analysis for these top ten WTPs indicate savings of $884,251.58 if sediment was reduced by 30% (Appendix E, Table 1). Of these ten WTPs, two spend upwards of 10% of their total operating and non-operating budget on sedimentation related water-treatment and six spend between 1-5% (Figure 1).

Figure 1. Map of areas with high sedimentation from agriculture and sedimentation costs as a percent of total WTP budgets for the ten WTPs with the highest sedimentation costs



Refining Cost Model and Investigating Additional Cost Areas

Our cost model estimates the costs of agriculture sediment pollutant loads to 58 surface water treatment plants in Michigan. Below, we recommend a few revisions to the model to improve accuracy and applicability, along with recommendations for applying the cost model framework to additional sectors affected by sedimentation from agriculture.

Model Revisions:

- **Hydrology**. Define catchment areas around each WTP and reallocate sedimentation loads to more accurately estimate the amount of sediment delivered to WTPs. Given that the current average catchment size is sufficiently small (2.5 km^2), reallocating sedimentation deliver would likely have only minor effects on cost estimates while improving accuracy.
- **Costs**. We derived the current base estimates for the cost sedimentation on WTPs and then adjusted the values for inflation. More recent baseline cost data would improve the model. The yearly operating costs in the model should also be validated by WTPs in Michigan before use in decision-making analysis.
- **Budgets**. The current model includes annual operating budgets for cities and villages with affected WTPs. We pulled data from 2019-2020 for cities' budget allotted to the Water Fund (591), which only captures a snapshot of the cities' water treatment expenditures. Capturing long-term average costs would improve the model's capacity by incorporating higher fixed costs from capital replacement that can be attributed to higher sediment loads.

Additional Cost Areas to Investigate:

Our initial cost model provides a framework for assessing costs of sedimentation in other sectors. Based on our review of the sedimentation cost literature, we recommend applying a similar sedimentation pollutant load framework to estimate the costs of agricultural sedimentation in infrastructure, tourism and recreation, and public health. We compiled initial cost estimate research for these areas in Appendix F, Table 2.

In addition to these sectors, future work could assess the costs of nutrient pollution due to sedimentation. During the process of sedimentation, sediment particles transports absorbed nutrients, such as nitrogen, phosphorus, and pesticides, through the aquatic system (of these, phosphorus has the highest affinity for sediment)[ix]. These nutrients are known to cause harmful algal blooms in water bodies, hypoxic aquatic environments, and toxic bioaccumulation in wildlife, incurring costs to tourism, recreation, commercial fisheries, drinking water, and health industries.

Recommendation 2: Invest in Expanded Watershed Modeling

GWP uses sophisticated modeling developed by Michigan State University (MSU) to identify priority farms within the Gratiot Watershed. MSU's GLWMS combines a high impact targeting (HIT) model, nutrient models, and a groundwater recharge model. The HIT model allows the GWP's implementers to identify priority farms and fields within a farm, to target for sedimentation reduction interventions. Unfortunately, the HIT model covers only a limited number of watersheds in Michigan, hampering efforts to scale the program cost effectively.

High-quality modeling is critical for two reasons. First, it ensures that program funds are directed to areas of highest impact, thereby improving cost-effectiveness. Second, program staff are better able to estimate the amount of sediment reduced from a given watershed based on the actions farmers agree to undertake. This information allows staff to demonstrate the extent to which upstream investments in sediment reduction result in downstream cost-savings, a critical component in building the case for funding, which we discuss further in the next section. Thus, we recommend that TNC partners with MSU to expand the model across all watersheds in Michigan with significant agricultural activity.

Recommendation 3: Refine Payment Pricing Strategy

Background on GWP Payment Pricing

The approach to payments in the GWP has evolved considerably throughout the project's implementation. Today, the program offers an average contract payment of $31 per acre, though the actual payment amount is tied to resulting environmental benefits since it is a PFP program. Generally, payment amounts increased with higher sedimentation risk (Appendix G, Figure 10), demonstrating the program's prioritization of environmental outcomes.

GWP's average payment amount has risen over the years, which they attribute to competition with RCPP currently offering farmers $53 per acre. GWP targets farms that are not yet participants in RCPP, and they achieved a relatively high sign-up rate among those farmers thanks to GWP's simple contracting process. However, once farmers learn about the higher rate they can receive from RCPP, they oftentimes switch programs. GWP's lower payment amount limits the program's retention and its ability to convince others to switch from RCPP. GWP's inability to outcompete the RCPP is problematic in that the latter program is vastly less effective at limiting sedimentation.

Pricing Principles

To achieve more widespread adoption, GWP needs to raise its average payment to be competitive with RCPP. RCPP's payment level is not the only consideration, however. To maximize adoption, prices must at least exceed farmers' total economic costs of participation, which include both accounting costs (e.g., equipment, labor) and opportunity costs. Unless participation is somehow compulsory, prices set below total economic costs will fail to incentivize all but the most motivated farmers. In fact, farmers may demand a premium above economic cost to participate, so we should also explore key considerations for setting an upper bound on prices.

By limiting sedimentation and runoff, GWP reduces negative externalities from agriculture, that is to say it provides indirect downstream benefits, like lowering the amount of sediment that has to be filtered by WTPs, decreasing turbidity that may hamper the productivity of fisheries and lower property values, and reducing stress on infrastructure. These benefits can be directly and indirectly quantified in financial terms, which enables program managers to assign a downstream economic benefit to each ton of sedimentation reduced upstream, as we modeled out in our first recommendation. This leaves us with a lower bound for prices of total economic cost to the farmer and an upper bound of downstream economic externalities that can be attributed to a given acre, as shown in Appendix G, Figure 11.

Pricing Recommendations

Based on these principles, there are two tasks critical to the expansion of the program:

1. Model total economic costs of participation. When setting prices, take the higher of a) total economic cost and b) the price offered by RCPP.
2. Model and assign downstream benefits to quantify the full range of theoretical prices.

It may be possible for TNC to monetize and sell these downstream environmental benefits. For instance, if it is cheaper to reduce sedimentation at the source than it is to filter that same sedimentation from drinking water, a downstream WTP should be willing to pay for that benefit, especially as WTPs face rising infrastructure demands and rates for drinking water[x]. While they should theoretically be willing to pay any amount up to the total value they receive, it may be savvy to allow them to hold on to some portion of the surplus as this will likely lead to easier negotiations and more willingness on the part of these "customers" to speak well of the program to others. Moreover, it may be that TNC or other program administrators need to hold some portion of the surplus to cover administrative or other expenses.

Additionally, TNC should carefully evaluate the cost effectiveness of the program. The benefits of the PFP approach and quantifying downstream impacts include incentivizing additional effort on the part of landowners to improve performance and to ensure TNC doesn't spend money in places with scant downstream benefit. While these are important features of the program, it may be the case that there are other, cheaper ways to achieve these same downstream benefits and, if so, TNC may wish to ensure limited resources are dedicated to these in order to have greater total impact. It is worth noting that even if other approaches can theoretically achieve more impact per dollar, the GWP approach may ultimately be more sustainable for its ability to sell downstream benefits and potentially create a revolving fund to sustain the program.

Project Impact & Conclusion

As climate change causes more high precipitation events, the risk of soil displacement increases and thus so does the risk to land productivity, water quality, and community health in Michigan[xi]. A brief analysis of the changes in precipitation measured across 22 weather stations in Michigan[xi] and the corresponding sediment measured by the Sparrow model confirms this association: over past decades, sedimentation appears to be correlated with increases in precipitation (Appendix E, Figure 8). This underscores the importance of reducing sediment loads, as Michigan is projected to be particularly impacted by increases in rainfall and severe weather due to climate change[xi]. Our recommendations on how to scale the existing GWP to be more effective on a statewide level can help TNC mitigate this risk by establishing an initial proof of concept for its sustainable financing mechanism to promote soil conservation. The vulnerability analysis map provides a visual for TNC to prioritize the scale-up of GWP based on highest risk from sedimentation. Additionally, our model to quantify water treatment costs based on sediment load provides a foundation for TNC and future Dow Sustainability Fellows to develop a cross-sector cost model that can be used to advocate for public or private funding.

Based on our research and analysis, TNC can prioritize municipalities with which to initiate conversations around sediment cost following our pricing principles. If they buy into the financing program, these communities could generate cost savings in water treatment and contribute funding to farmers to implement erosion and sediment-reducing practices and technologies. In turn, this would help farmers improve their cropland productivity from reduced runoff and support communities by alleviating the effects of sedimentation, such as risks to recreation and tourism, property values, water quality, and public health.

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Table of Appendices

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Appendix B Interview Notes with Ben Wickerham

Overview of TNC Michigan Saginaw Bay Conservation Project

- Ben worked on the Gratiot County conservation project, which was scaled up by TNC.
- Saginaw Bay has 50% of its land in agriculture, which is a stressor on the water system.

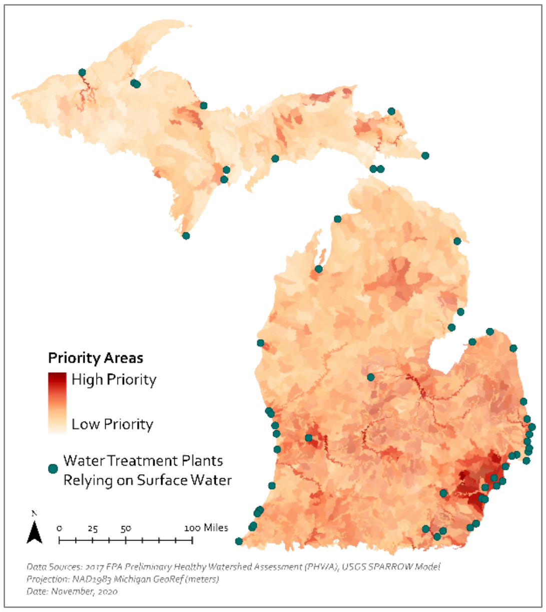
- They supplement an NRCS Pay for Practice program (RCPP) with a Pay for Performance (PFP) program that tries to incentivize farmers to actually achieve sediment runoff reduction by providing payments based on environmental benefits.
- Their program was oftentimes outcompeted by RCPP because their payments were less. Some farmers adopted PFP because the NRCS program had more barriers to signing up. In the future, they would want to increase payments to be more competitive
- If they did it again, they would want to put a ceiling and floor value on the grant funding to ensure they do not run out of money
- MSU made a Great Lakes Watershed Management System to track different conservation practices by combining many existing models related to nutrients, groundwater recharge, and high impact targeting (HIT).

Appendix C Summary of Key Impact Areas from Sedimentation

Impact Area	Impact Description
Infrastructure	High turbidity shortens pump lifespan and reduces infiltration capacity
Tourism	Sediment and nutrient-polluted waters less appealing to tourists, reducing revenues Loss of recreational fishing revenue and increased cost of fisheries management
Agriculture	Soil and nutrient loss from erosion, reducing cropland productivity
Environment	Reduced sunlight availability in water, altering ecosystems and wildlife behavior Transport of nutrients on eroded sediment through water system
Health	Transport of nutrients and antibiotics on eroded sediment that are harmful to human health and degrade drinking water
Property Values	Reduced property values resulting from accelerated streambank erosion

Appendix D Vulnerability Analysis

Figure 2. Combined Maps Prioritizing Areas for Sediment Reduction Intervention.



Priority Areas are based on USGS agricultural sedimentation data and EPA watershed indices, depicted in Figures 3-5 below.

Figure 3. Accumulated Load from Agricultural Suspended Sediment Map.

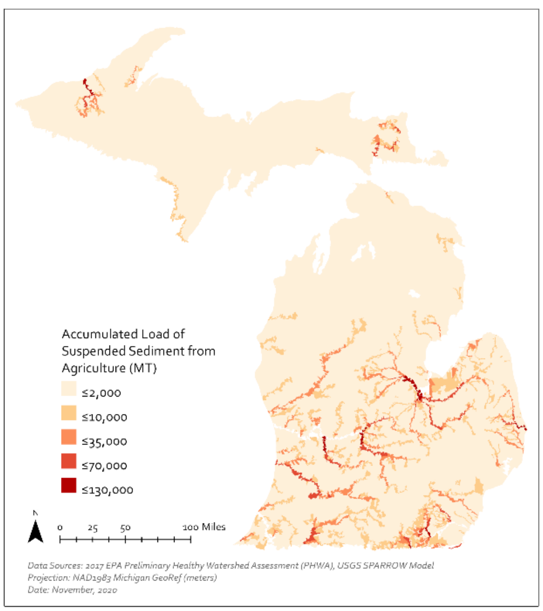
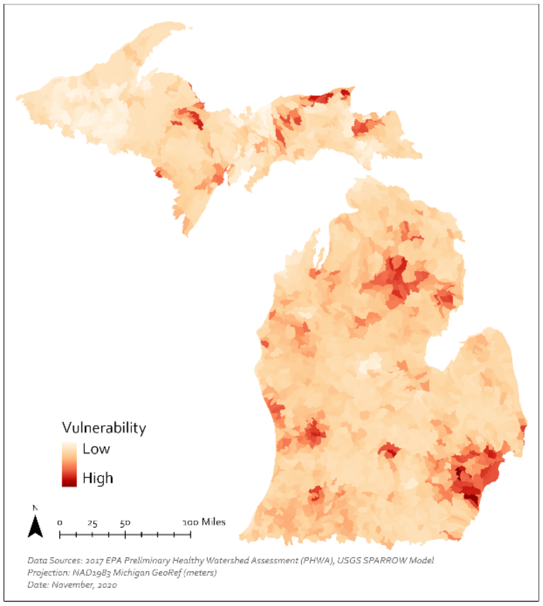
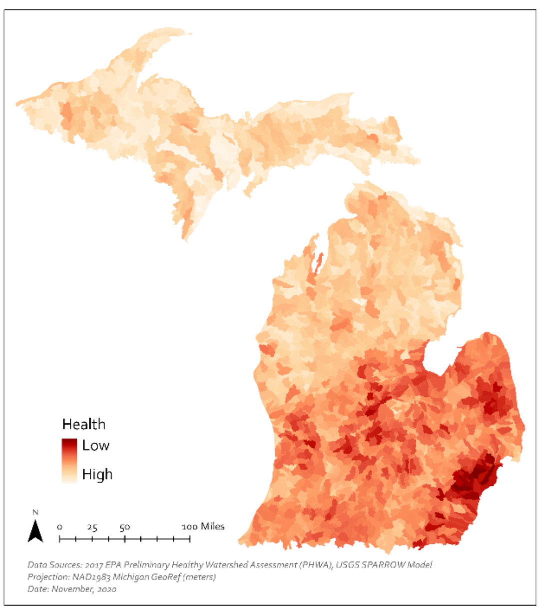


Figure 4. Watershed Vulnerability Risk Map



Vulnerability metrics are determined by the 2017 EPA PHWA and include land use change, water use, and wildfire risk.

Figure 5. Watershed Health Risk Map



Health metrics are determined by the 2017 EPA PHWA and include landscape condition, habitat, hydrology, geomorphology, water quality, and biological condition.

Appendix E   Water Treatment Costs and Sedimentation Model

Model Methodology Details:

WTPs reliant on surface water in Michigan were identified through the EPA's Annual Drinking Water Quality Reports for Michigan. The addresses of these WTPs were utilized in order to pair the WTPs with sediment load data at the catchment level (we used the USGS 2012 Sparrow model estimates for sediment in metric tons per kilometer square (MT//km^2) at the catchment level). To estimate the total quantity of sediment in the catchment, we multiplied the MT/km^2 by the cumulative area within the catchment. We then used the "Computation of Instantaneous Constituent Discharge" formula to turn the total amount of sediment in MT into a concentration (Figure 7, Appendix E). This model allows for the calculation of a concentration *C* in *mg/L* when streamflow is in cubic feet per second and when discharge is in metric tons per day. Thus, 'pollutant loads' or sediment loads for each WTP were calculated and then transformed into MT/gallon in order to multiply the MT/gallon by the number of gallons processed by WTPs on the average day. Estimates for the number of gallons processed per day came most often from WTP websites but if unavailable, imputed values were used. Imputed values were calculated by taking the median value of the gallons per population served for the WTPs with data and then multiplying this median (183 gallons/person served) by the total population served for the WTPs with missing processing information. Finally, with the estimates of the tons of sediment reaching WTPs per day, high and low-cost estimates per ton were applied for each WTP. These estimates, originally in 1987 Canadian dollars, were adjusted for inflation and converted to USD to get the most accurate estimates for 2020 USD.

Figure 6. Formula for calculating sediment pollutant load

Computation of Instantaneous Constituent Discharge

$$Q_s = Q_w C k$$

- When streamflow (Q_w) is in cubic feet per second and concentration (C) is in milligrams per liter:

$$k = \left(\frac{62.4 lb}{ft^3}\right)\left(\frac{86{,}400 s}{day}\right)\left(\frac{ton}{2204.62 lb}\right)\left(\frac{liter}{1x10^6 mg}\right) = 0.00245$$

if constituent discharge (Q_s) is desired in metric tons per day

Figure 7. Sedimentation and Per Capita Spending on Water Treatment

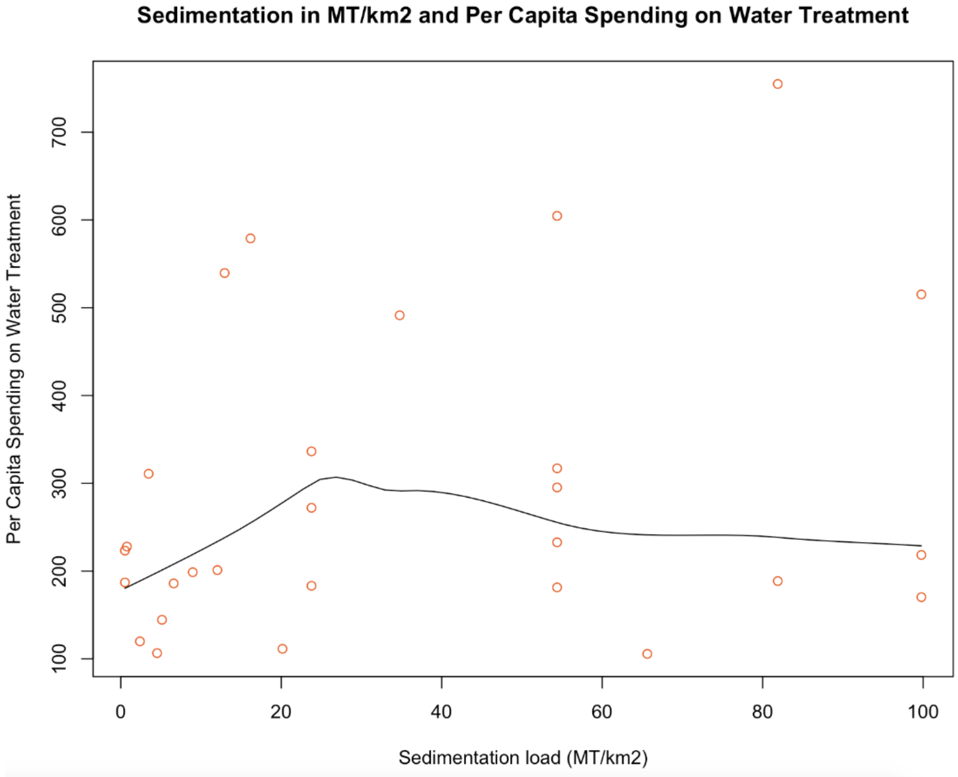


Figure 8. Regression Spline of Water Treatment Spend and Sediment Levels

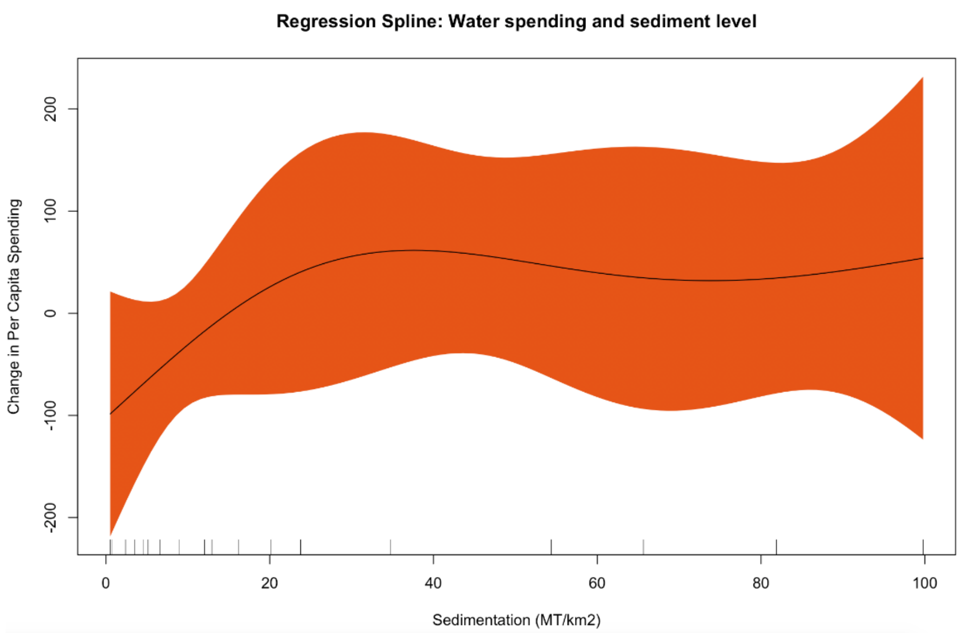


Figure 9. Association between precipitation changes and sedimentation across Michigan

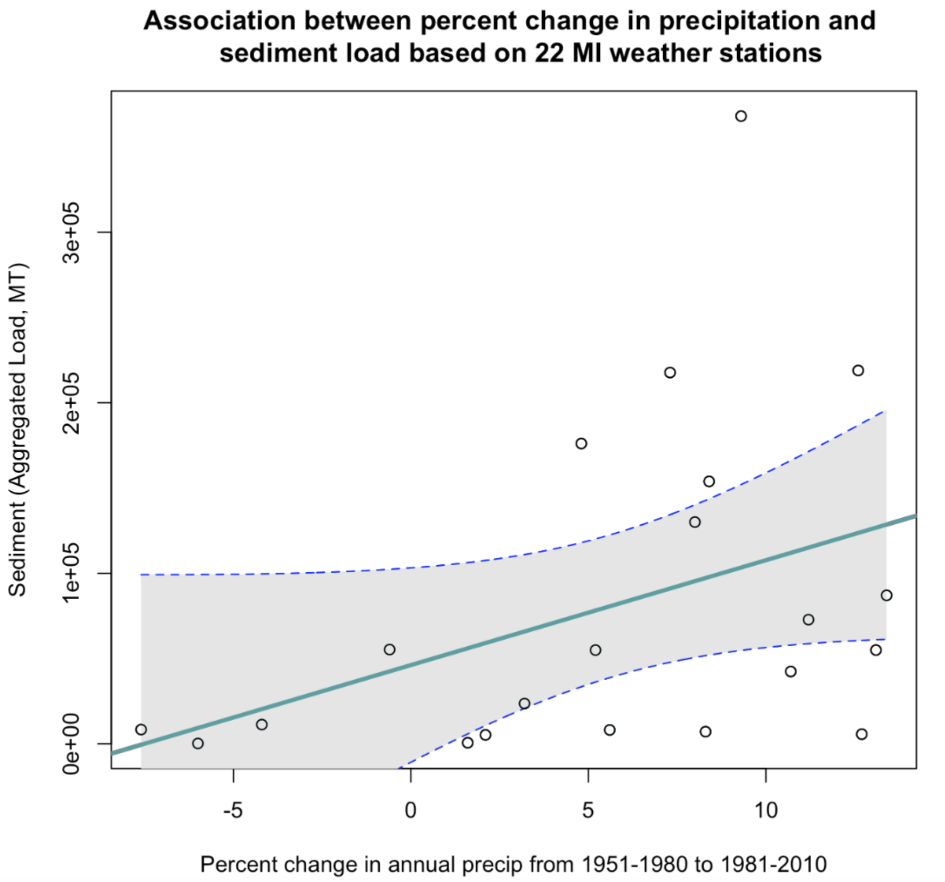


Table 1. Sensitivity analysis for top 10 WTPs in the cost model

Water System	Tons of sediment reaching plant per year	Cost per year (high estimate)	Percent of total budget	Cost per year if sediment load was reduced by 30%	Translated savings
LAKE HURON WATER TREATMENT PLANT	24199.54	$ 1,552,158.40	12.58%	$ 1,086,510.88	$ 465,647.52
ADRIAN	5506.97	$ 353,217.16	7.65%	$ 247,252.01	$ 105,965.15
SPRING WELLS WATER TREATMENT PLANT	3649.93	$ 234,106.74	1.90%	$ 163,874.72	$ 70,232.02
MONROE	3632.79	$ 233,007.38	2.81%	$ 163,105.17	$ 69,902.21
SAGINAW-MIDLAND WATER SUPPLY	3000.71	$ 192,465.31	4.69%	$ 134,725.72	$ 57,739.59
FRENCHTOWN TOWNSHIP	2034.31	$ 130,480.47	1.62%	$ 91,336.33	$ 39,144.14
SOUTHWEST WATER TREATMENT PLANT	1446.22	$ 92,760.41	0.75%	$ 64,932.29	$ 27,828.12
MOUNT PLEASANT, CITY OF	1033.57	$ 66,293.36	2.30%	$ 46,405.35	$ 19,888.01
NORTHWEST OTTAWA CO WATER SYST	933.82	$ 59,895.37	2.87%	$ 41,926.76	$ 17,968.61
ANN ARBOR	516.38	$ 33,120.64	0.15%	$ 23,184.45	$ 9,936.19
TOTAL	**45,954.24**	**$ 2,947,505.26**		**$ 2,063,253.68**	**$ 884,251.58**

Appendix F Cost Information on Additional Impact Areas

Table 2. Summary of existing literature on costs of sedimentation on infrastructure, tourism & recreation, and public health

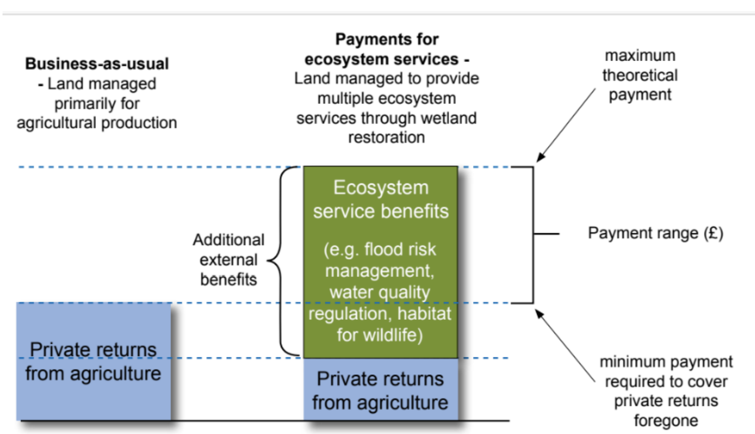
Category	Rationale	Cost Information
Infrastructure		
Dams	Sedimentation around dams causes upstream flooding and downstream bank destabilization[xii].	Resolving the impacts of sedimentation has been shown to cost 70% of the original dam construction cost[xii].
Dredging	Sediment deposits alter riverbeds and navigation channels[xiii].	Installing buffer strips and changing agricultural practices reduces drain and ditch dredging costs by $6.41/hectare in Ontario[xiv]. Additionally, researchers have used the cost value of $2.96 to dredge 1 ton of sediment as a proxy to estimate the costs avoided by reducing 1 ton of sediment in dredged areas[xv].
Structures	Sediment erosion damages structures built along shorelines.	The estimated cost of structural replacement along the Lake Huron coast is $2,284/meter[xvi].
Roads	Ditches, culverts, and storm drains clogged with sediment increase flooding risk and damage to road and structures[xvii].	Erosion increases road maintenance and repair costs[xvii].
Tourism & Recreation		
Fishing	Excess sediment in aquatic systems clogs fish gills and alters stream habitats, negative affecting fish populations and increasing costs of fisheries management[xiii,xviii].	In Southern Ontario, a 1-ton decrease in sedimentation was associated with a 1.47 to 4.41 increase in fishing days[xix].
Recreation	Excess sediment in water causes turbidity and reduced water clarity, which are associated with a loss of recreational revenue[iv,xx].	The travel cost method can be used to estimate value of sediment reduction to recreationalists[xxi,xxii].
Property Values[xxiii]	Increased sediment in water decreases water clarity, which is undesirable for homeowners, communities, and tourists[iv].	Hedonic price models can be used to measure the impact of water clarity on property values. Across multiple studies, the impact of 1-meter change in water clarity ranges from <1% to 78% of home price ($267 to $90,539)[xx]. A one-tenth meter

		change in water quality is associated with a 1% change in housing price[xxiv].
Public Health		
Emergency Health Care	Sediment can carry heavy metals and microbes that are implicated in gastrointestinal illness, which can increase emergency room utilization[xxv].	Emergency room visits are costly to both individuals and healthcare systems.
Polluted Water	Transport of nutrients and antibiotics on sediment are harmful to human health and degrade drinking water[xxvi].	Polluted water increases health care costs globally[xxvii].

Appendix G GWP Outcomes

Figure 10: GWP Estimated Payments[xxviii].

Figure 11. Total Economic Costs with Externalities



Source: Department for Environment, Food, and Rural Affairs (UK)

Figure 12. GWP Estimated Sediment Yield Reduction

Appendix H Conservation Practices to Reduce Erosion and Sedimentation

Of the NRCS conservation agriculture practices that reduce erosion and sedimentation, these five practices have the highest combined scores for sedimentation reduction, nutrient reduction, and overall erosion reduction.

Table 3. NRCS conservation practices with high erosion and sedimentation reduction scores[xxix].

NRCS Practice	Description
Silvopasture	Establishment and/or management of desired trees and forages on the same land unit.
Conservation Cover	Establishing and maintaining perennial vegetative cover to protect soil and water resources on lands needing permanent protective cover that will not be used for forage production.
Riparian Forest Buffer	An area predominantly covered by trees and/or shrubs located adjacent to and up-gradient from a watercourse or water body.
Cover Crop	Growing a crop of grass, small grain, or legumes primarily for seasonal protection and soil improvement.
Tree/Shrub Establishment	Establishing woody plants by planting seedlings or cuttings, by direct seeding, and/or through natural regeneration.

Appendix I Data Sources and Endnotes

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