Lower Green Bay & Fox River Remedial Action Plan Update

2019 UPDATE

Wisconsin Department of Natural Resources
Office of Great Waters

Remedial Action Plan Update for the Lower Green Bay & Fox River Area of Concern

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Cover Photo: Steve Hogler, retired Wisconsin DNR Fisheries Biologist, to whom this Remedial Action Plan Update is dedicated for his decades of work to improving the AOC.

Disclaimer

The Great Lakes Water Quality Agreement is a non-regulatory agreement between the U.S. and Canada, and criteria developed under its auspices are non-regulatory. The actions identified in this document to meet beneficial use impairment (BUI) delisting targets are not subject to enforcement or regulatory actions.
The actions identified in this Remedial Action Plan Update do not constitute a list of preapproved projects, nor is it a list of projects simply related to BUIs or generally to improve the environment. Actions identified in this document are directly related to removing a BUI and are needed to delist the Area of Concern.

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Purpose Statement

This Remedial Action Plan (RAP), which updates the 2018 RAP, documents and communicates the progress made in the AOC from January 2019 through February 2020 and shares the path forward with our partners and stakeholders. The RAP includes a concise summary of BUI status and tracks progress on specific actions that are important for reaching BUI removal targets. These “actions” include on-the-ground restoration projects, monitoring and assessment projects, and stakeholder engagement processes. As the primary agency with the responsibility to develop and implement the RAP, the Wisconsin Department of Natural Resources (WDNR) Office of Great Waters and other WDNR programs are committed to making progress in remediating and restoring Wisconsin’s Areas of Concern. In order to be lasting and effective, the RAP must be a program of continuous improvement, evaluating its course as new information and technology become available. Subsequent RAP updates will be produced as needed to incorporate new information.

Remedial Action Plans are required by Annex 1 of the Great Lakes Water Quality Protocol of 2012 (which replaced the 1987 Protocol amending the Revised Great Lakes Water Quality Agreement of 1978). The 2012 Protocol indicates that RAPs must include the following elements:

1. Identification of beneficial use impairments (BUIs) and causes;
2. Criteria for the restoration of beneficial uses that consider local conditions and are established in consultation with the local community;
3. Remedial measures to be taken, including identification of entities responsible for implementing these measures;
4. A summary of the implementation of remedial measures taken and the status of the beneficial use; and
5. A description of surveillance and monitoring processes to track the effectiveness of remedial measures and confirm restoration of beneficial uses.

2019 Progress Summary

In 2019, the WDNR and its many partners continued 31 years' worth of progress to remove the significant limitations impeding recovery of several beneficial uses in the Lower Green Bay & Fox River Area of Concern (AOC; Figure 1). After thirty years of work through the AOC/RAP program, 2019 marked near completion of both contaminated sediment projects, several BUI assessments to inform status and/or restoration criteria continued or began, and the development of management action lists for key BUIs continued. More information regarding the status, current remedial actions, and next steps for each respective BUI can be found in the next section of this document. Project-specific details are included in Appendices as relevant.

Chase Reyer, 13, participates in a waterfront cleanup event held by the Fox-Wolf Watershed Alliance at Voyageur Park. To sign up for waterfront cleanup and other volunteer events held by Fox-Wolf Watershed Alliance, visit their website at https://fwwa.org/join-us/volunteer-with-fwwa/

The **Fish Tumors or Other Deformities** BUI is listed as suspected due to the presence of persistent toxic substances such as polychlorinated biphynels (PCBs) and polycyclic aromatic hydrocarbons (PAHs). In 2015, a draft target for this BUI was developed based on those of other Wisconsin AOCs. Stakeholders indicated that they preferred an approach where contaminated sediments would be addressed before assessing the status of this BUI. WDNR, with assistance from West Virginia University and the U.S. Geological Survey (USGS), will begin conducting this fish tumor assessment in spring 2021.

In 2019, 425,000 cubic yards of material were dredged as part of the in-river remedial action work for the Lower Fox River PCB cleanup project. In total, 59 acres were sand-covered and 12 acres stone-capped. In addition, dredging of sediment polluted with PAHs and heavy metals was completed at the North Focus Area of the Wisconsin Public Service (WPS) Green Bay former Manufactured Gas Plant (MGP) site, located at the East River confluence, with approximately 35,000 cubic yards of material dredged in 2019. Both cleanup projects are key to addressing several BUIs, including **Fish Tumors or Other Deformities, Bird or Animal Deformities or Reproduction Problems, Restrictions on Fish and Wildlife Consumption, Restrictions on Dredging Activities, Degradation of Benthos, Degradation of Phytoplankton and Zooplankton Populations, Degradation of Fish and Wildlife Populations, and Restrictions on Drinking Water Consumption**. The project is anticipated to be complete by mid-2020, after which WDNR anticipates recommending removal of the **Restrictions on Dredging Activities BUI** to AOC stakeholders in 2021.

Photo credit: J.F. Brennan Inc.

Remedial action being undertaken at the North Focus Area of the WPSC MGP site in 2019.

An assessment of the **Degradation of Benthos** BUI began in 2019 and extended a grant awarded in 2018 by UW Sea Grant to UW-Green Bay researchers to evaluate the benthic community throughout the Bay of Green Bay by expanding the area of interest to include more sites within the AOC. The results of this assessment will allow WDNR to determine the status and next steps for this BUI and provide supplemental information to assist with management action development for the Loss of Fish and Wildlife Habitat and Degradation of Fish and Wildlife Populations BUIs.

WDNR continued its partnership in 2019 with UW-Green Bay researchers, the U.S. Fish and Wildlife Service Technical Review Lead (TRL), and the AOC Fish and Wildlife Populations and Habitats Technical Advisory Committee (TAC) to refine the BUI removal targets and develop a list of management actions that, once implemented, are expected to meet BUI removal targets for the **Loss of Fish and Wildlife Habitat** and **Degradation of Fish and Wildlife Populations** BUIs. Metrics for a set of 18 priority habitats and 22 priority populations were refined and a metric guide was drafted. These metrics serve as the basis for the final BUI removal targets, and the TAC recommended the adoption of the refined BUI removal target language in January 2020. An initial list of restoration activities that could improve priority populations and habitats was generated from 2018 to early 2019 through consultation with many technical experts, and the TAC continued to refine this list and develop specific management actions through 2019. The draft management actions are presented in the metric plan to compile additional stakeholder input. Adjustments to the draft management actions may be made in consideration of the comments. WDNR will send the draft list to USEPA with pre-proposals in June 2020, and further revisions to the list will likely be made over the next several months as feasibility, cost, and other project elements become more well-understood. Project proposals will begin to be submitted to USEPA for GLRI funding consideration in 2021.

WDNR staff continued in 2019 to build upon several years' worth of work in compiling available information to complete an assessment of the **Restrictions on Drinking Water Consumption, or Taste and Odor Problems** BUI. If results indicate that the BUI removal targets are being met, WDNR OGW will recommend the removal of this BUI in late 2020. The results of the assessment will be completed and presented for additional stakeholder input prior to a BUI removal recommendation being provided to USEPA.

WDNR also continued its partnership with UW-Milwaukee, NEW Water, UW-Madison, and UW-Green Bay researchers to evaluate the **Beach Closings** BUI in the AOC through an assessment of cyanobacterial harmful algal blooms (CHABs) that was underway from 2016-2018. The primary study goals are to understand the nature and extent of algae blooms in the lower bay, to recommend best management practices for evaluating CHABs and tools for managing recreational risk, and to provide additional information in support of the **Restrictions on Drinking Water Consumption, or Taste and Odor Problems** and **Degradation of Phytoplankton and Zooplankton** BUIs. The project was extended in 2018 to continue through 2020. WDNR, CHABs researchers and other experts will use project data to recommend a revised BUI removal target that will consider USEPA's recommended recreational criteria and specific, measurable, achievable, realistic and time-bound (SMART) objectives.

WDNR continued to explore ways in which the AOC program can address the **Eutrophication or Undesirable Algae** impairment while acknowledging the scope of the program, which focuses on defined geographic areas and legacy pollutants rather than watershed-wide non-point pollution that contributes to continued water quality issues in the AOC. In 2019, WDNR continued working with a group of technical advisors in developing rough estimates of phosphorus and sediment reductions that could be realized by implementing select structural practices within the Lower Fox Basin. These AOC-sponsored practices are intended to provide additional water storage capacity on the landscape, and a draft BUI removal target revision primarily based on restored storage capacity within selected HUC12s (hydrologic unit code; subwatersheds) in the Lower Fox River Basin was presented to AOC stakeholders in May 2019. In order to determine where additional water storage capacity is needed on the landscape, WDNR partnered with Outagamie County Land and Water Conservation Department to complete a study of where storage capacity has been lost within the Lower Fox Basin. The outcome of this study is to produce a set of "Action Maps" for selected HUC12s which will guide where implementation of AOC-sponsored practices (e.g. management actions) is needed. WDNR will continue to work with AOC stakeholders on the development of the management action list for this BUI and broader TMDL implementation plans. Management actions are expected to partially address several other BUIs.

The final year of aesthetics monitoring was completed in 2018 to assess the status of the **Degradation of Aesthetics** BUI. Results from the 2011 – 2013 and 2015 – 2018 aesthetics monitoring survey years were evaluated in 2019 and indicate very limited interference by objectionable substances on public use in the waters or shorelines at each survey station, and a generally positive overall aesthetic impression score at all survey stations in the AOC. Given these results, WDNR OGW is recommending both a partial BUI removal target revision and the removal of this BUI in late 2020.

In September 2019, the Clean Bay Backers hosted legislators, local officials and community leaders to tour the Fox River clean-up aboard the River Tyme (Fox River Tours) and discussed the economic benefits of a cleaner river. To learn more about the Clean Bay Backers, visit https://fyi.extension.wisc.edu/aocs/fox-river-green-bay/clean-bay-backers/

Having reviewed with stakeholders the historical and recent information that can help inform the status of the **Tainting of Fish Flavor** BUI, WDNR has concluded that there is sufficient evidence to remove this suspected BUI and received stakeholder support in 2017 to move forward with drafting a BUI removal package. In response, a draft BUI removal package was completed in 2019 that will be available for stakeholder review in early 2020. An updated removal package will then be provided to USEPA for concurrence.

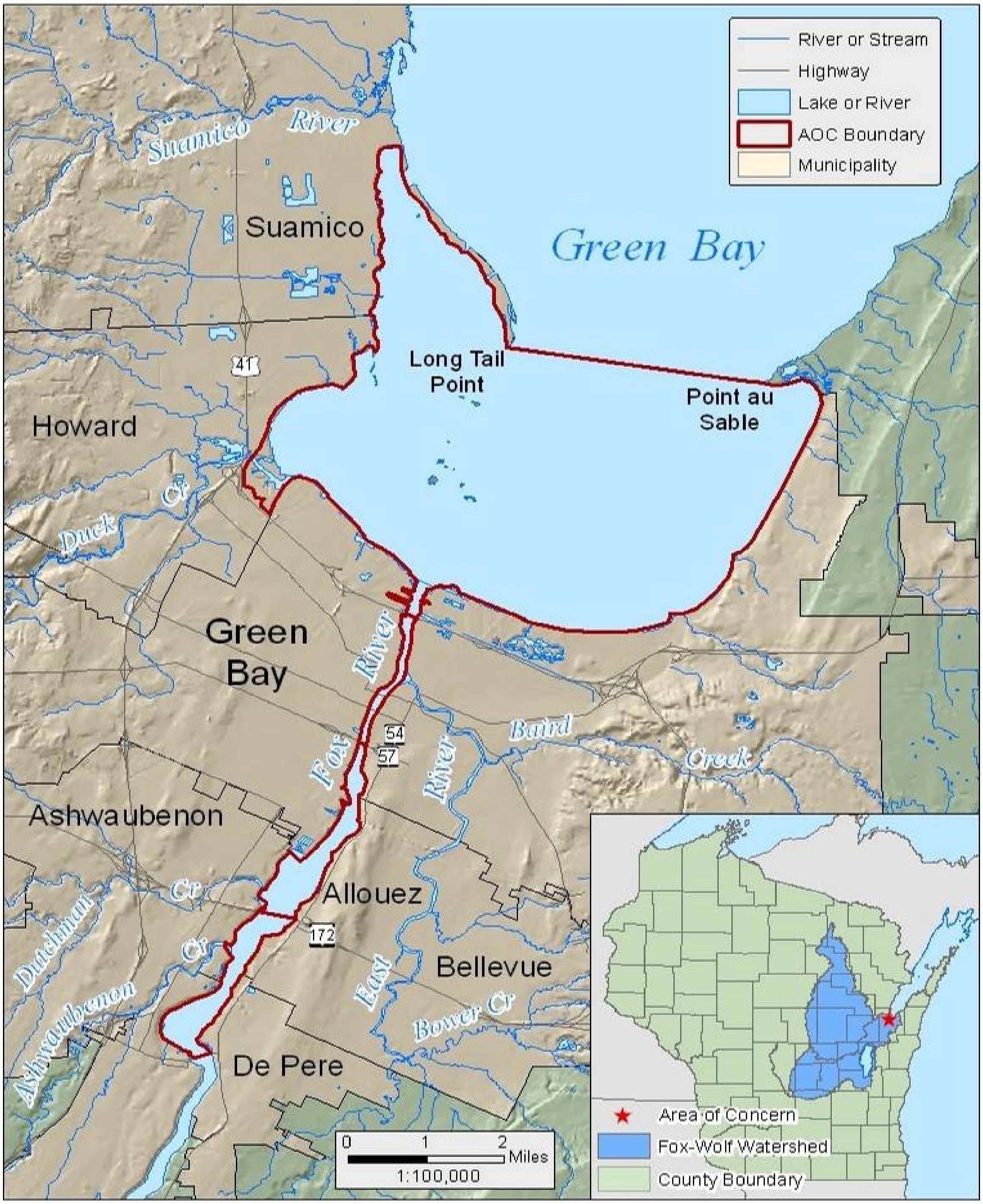


Figure 1. The boundaries of the Lower Green Bay & Fox River Area of Concern. For additional information about the history of the AOC and a narrative description of the AOC boundary, please refer to previous RAP documents which are available online: http://dnr.wi.gov Search "Lower Green Bay and Fox River AOC"; RAP documents are stored on the "AOC Plans" tab. A listing of previous RAPs, RAP Updates, and important historical documents is included in the References section.

Table 1. Current status of BUIs in the Lower Green Bay & Fox River AOC (Refer to BUI summaries for more detail).

Beneficial Use Impairment	Beneficial Use Remains Impaired	Summary Status
Fish tumors or other deformities	Suspected	Assessment of this BUI will begin in 2021 after the contaminated sediment projects are complete. Federal Fiscal Year 2020 GLRI funds have been requested from USEPA for an assessment, with the goal of collecting fish in spring 2021.
Bird or animal deformities or reproductive problems	Yes	Complete the contaminated sediment projects (PCB and former MGP site), which are known to cause deformities and reproduction problems. A repeat assessment of tree swallows is planned from 2020 to 2022 with USGS continuing to lead that work.
Restrictions on fish and wildlife consumption	Yes	Removal of sediments containing PCBs is anticipated to be complete in mid-2020. Responsible parties will begin fish consumption assessments after the project is complete and continue until EPA and WDNR agree long term monitoring requirements are met. Information from other Wisconsin AOCs indicates a lag in PCB concentration reductions for waterfowl post-remediation. WDNR will evaluate waterfowl consumption data from the Sheboygan River AOC to inform our timeline for future assessments.
Restrictions on dredging activities	Yes	Cleanup of sediment polluted with PAHs and heavy metals at the WPS Green Bay former MGP site was completed in 2019, and cleanup of riverbed sediments containing PCBs in the Lower Fox River is anticipated to be complete by mid-2020. WDNR anticipates drafting a BUI removal recommendation in 2021, with the goal of having this BUI removed in late 2021.
Degradation of benthos	Yes	UW-Green Bay began an assessment of the benthic community in April 2019, and assessment will continue through June 2021, with a BUI status check scheduled for 2022.
Degradation of phytoplankton and zooplankton populations	Yes	Assessment data on soft algae from the Harmful Algal Blooms project will help inform the status of this BUI, in addition to other plankton assessments completed in the AOC. A status check will be done in 2020 to evaluate data and determine next steps.
Loss of fish and wildlife habitat	Yes	The Fish and Wildlife Populations and Habitat Technical Advisory Committee developed a draft list of management actions which will be submitted to USEPA in April 2020. Timeline of implementation will be determined once the projects are selected.

Degradation of fish and wildlife populations	Yes	The Fish and Wildlife Populations and Habitat Technical Advisory Committee developed a draft list of management actions which will be submitted to USEPA in April 2020. Timeline of implementation will be determined once the projects are selected.
Restrictions on drinking water consumption, or taste and odor problems	Yes	Assessment data on bacteria, toxins, and substances causing taste and odor problems in drinking water are being collected and evaluated to determine if waters in the lower Bay are meeting standards for drinking water. WDNR anticipates recommending removal of this BUI in 2020.
Beach closings	Yes	The assessment of harmful algal blooms will be completed in 2021 and will inform any necessary target revisions for this BUI. WDNR and other experts will propose a target change in 2020.
Eutrophication or undesirable algae	Yes	Technical groups and stakeholders are continuing to work on finalizing the delisting target and identifying the necessary management actions to address eutrophication in the AOC.
Degradation of aesthetics	Yes	Assessment of monitoring data was completed in 2019. A target revision is recommended for this BUI; recommended revisions will be shared with stakeholders in 2020. WDNR anticipates recommending the removal of this BUI in 2020.
Tainting of fish and wildlife flavor	Suspected	Information from angler surveys and historical documents were compiled, and a BUI removal document was prepared and shared with stakeholders in 2019. WDNR anticipates removing this BUI by early 2020.


Photo credit: Brie Kupsky

Pelicans congregating at the eastern-most portion of the Cat Island Restoration Chain. To learn more about the Cat Island Restoration Chain project, visit the Port of Green Bay's website at https://www.portofgreenbay.com/cat-island-restoration-project

BENEFICIAL USE IMPAIRMENT UPDATES

For each BUI section, the following symbols indicate the status of the management actions listed:

Photo credit: Steve Seilo

= NOT STARTED

= UNDERWAY

✓ = COMPLETE

FISH TUMORS AND OTHER DEFORMITIES

Target	Status
Removal may occur if: • All known major sources of PAHs and chlorinated organic compounds within the AOC and tributary watershed have been controlled or eliminated • A fish health survey of resident benthic fish species, such as white suckers, finds incidences of tumors or other deformities at a statistically similar incidence rate of minimally impacted references sites.	Action needed
OR, in cases where tumors have been reported: • A comparison study of resident benthic fish such as white suckers of comparable age and maturity, or of fish species found with tumors in previous fish health surveys in the AOC, with fish at minimally impacted reference sites indicate that there is no statistically significant difference (with 95% confidence) in the incidence of liver tumors or deformities.	TBD

Status

In 2019, the Lower Fox River PCB cleanup project continued downriver, with the active portion of the Fox River PCB cleanup anticipated to be complete in 2020. Dredging began in 2018 at the South Focus Area and 2019 at the North Focus Area of the former MGP site located at the East River confluence. Remedial action was completed at both Focus Areas of the former MGP site in 2019. See the “Restrictions on Dredging” section for more details.

WDNR and stakeholders agreed that an initial assessment of this suspected BUI should occur after completion of contaminated sediment remediation. With the anticipated completion of the contaminated sediment projects by mid-2020, WDNR requested GLRI assessment funds from USEPA for late 2020. WDNR, with assistance from West Virginia University and the U.S. Geological Survey (USGS), will begin this fish tumor assessment in spring 2021.

A status check is scheduled for this BUI in 2023.

Management actions

- *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional actions

- *Complete an AOC fish tumor assessment once the PCB remedial work has been completed*

BIRD OR ANIMAL DEFORMITIES OR REPRODUCTION PROBLEMS

Target	Status
PCB remedial actions have been implemented and the AOC is in recovery	In progress
Studies indicating the incidence rates of deformities (e.g., crossbill syndrome) or reproductive problems (e.g., eggshell thinning) in sentinel wildlife species (avian, amphibian, mammalian, predatory fish, and reptilian) do not exceed background levels of reference populations from unimpacted sites of comparable physical and chemical characteristics. A stepwise approach will be used to conduct <u>both</u> of the following evaluations in the AOC to determine when the BUI can be delisted: 1. If fish tissue or other food sources (e.g., insects and amphibians) concentrations of contaminants of concern identified in the AOC are: a. at or lower than the Lowest Observable Effect Level (LOEL) known to cause reproductive or developmental problems in fish, fish-eating birds, and mammals, the BUI can be delisted, or b. not statistically different than Lake Michigan (at 95% confidence interval), then the BUI can be delisted. Fish and other food sources (e.g., insects and amphibians) should be of a size and species considered prey for the species under consideration; 2. Field studies including observational data and direct measures of birds and other wildlife (including predatory fish) exhibit deformities or reproductive problems are verified through an: – Evaluation of observational data of bird and other animal deformities for a minimum of two successive monitoring cycles in indicator species identified in the initial studies as exhibiting deformities or reproductive problems. If deformity or reproductive problem rates are not statistically different than those at minimally impacted reference sites (at a 95% confidence interval), or no reproductive or deformity problems are identified during the two successive monitoring cycles, then the BUI can be delisted. If the rates are statistically different than the reference site it may indicate a source from either within or outside the AOC. Therefore, if the rates are statistically different or the data are insufficient for analysis, then: Evaluation of tissue contaminant levels in egg, young and/or adult wildlife. If contaminant levels are lower than the Lowest Observable Effect Level (LOEL) for that species for a particular contaminant that are not statistically different than those at minimally impacted reference sites (at a 95% confidence interval), then the BUI can be delisted.	Assessment in progress

Status

In 2019, the Lower Fox River PCB cleanup project continued downriver, with the active portion of the Fox River PCB cleanup anticipated to be complete in 2020. Dredging began in 2018 at the South Focus Area and 2019 at the North Focus Area of the former MGP site located at the East River confluence. Remedial action was completed at both Focus Areas of the former MGP site in 2019. See the “Restrictions on Dredging” section for more details.

A study conducted from 2011 – 2017 by the Wisconsin Bald Eagle Bio-Sentinel Program found that PCB concentrations in nestling eagles were highest in the Lower Fox River and Green Bay regions as compared to five other regions in Wisconsin (Sean Strom, unpublished data). Data from this study indicate that some individual bald eagles sampled in the Lower Fox River region were observed to have plasma PCB concentrations above the estimated 190 µg/L threshold for adverse reproductive effects (Elliott and Harris 2001/2002), though these data were collected before completion of the contaminated sediment remediation projects in the AOC. WDNR plans to request funding to re-evaluate bald eagle plasma PCB concentrations after completion of the contaminated sediment projects to evaluate if concentrations of PCBs in fish-eating birds are at or lower than the lowest observable effect level (LOEL) and/or not statistically different from other bald eagle populations.

Data on fish consumption advisories collected after completion of the contaminated sediment remediation projects will be evaluated to determine if concentrations of PCBs in fish tissue are at or lower than the LOEL for indicator fish and mammal species and/or are not statistically different from Lake Michigan fish tissue.

From 2016-2018, USGS researchers published several articles detailing the results of contaminant levels in tree swallows in several AOCs throughout the Great Lakes region. The 2010-2015 results in the Lower Green Bay-Fox River AOC indicate a lack of effect on tree swallow reproduction due to PCB contamination, and concentrations of PCBs in eggs and nestlings were observed to decline by 70-80% after dredging at Ashwaubomay Park occurred (Custer et al., 2018). USGS will continue to evaluate the effects of contaminants on tree swallows until 2022.

WDNR will work with technical experts in 2020 to determine if the BUI is being assessed fully relative to the current target language and if a target revision is necessary.

Management actions

- *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional actions

- *Repeat assessment of fish and wildlife following completion of contaminated sediment projects*
- *Update the BUI removal target*

A tree swallow at a nesting box being monitored by USGS for reproductive problems caused by contaminated sediments along the Fox River.

RESTRICTIONS ON FISH AND WILDLIFE CONSUMPTION

Target	Status
The Fox River Contaminated Sediment Remediation has been completed and meets the target established in the plan (Surface Area Weighted Concentration of 0.25 ppm or that determined acceptable by the agencies for completion of the PCB remedial action)	In progress
Fish and wildlife consumption advisories are the same or lower than those in the associated Great Lake or appropriate control site.	Assessment in progress

Status

In 2019, the Lower Fox River PCB cleanup project continued downriver, with the active portion of the Fox River PCB cleanup anticipated to be complete in 2020. Dredging began in 2018 at the South Focus Area and 2019 at the North Focus Area of the former MGP site located at the East River confluence. Remedial action was completed at both Focus Areas of the former MGP site in 2019. See the “Restrictions on Dredging” section for more details.

Following the completion of the PCB cleanup, post-project monitoring to assess fish consumption advisories for PCBs will begin and will be repeated every three to five years until EPA and WDNR agree that long term monitoring requirements are met through a combination of WDNR Fisheries Program and Responsible Party data.

Waterfowl consumption advisories were reassessed in 2016, using data from mallards and Canada geese collected from the AOC in 2014 and 2015. The results of the assessment indicated that PCB levels have remained virtually unchanged since the original consumption advisories were issued in 1987, and the advisory for mallards remains (Strom, 2016). A limited consumption advisory for mercury was also proposed with no more than one meal per week recommended for children and women of childbearing age (Strom, 2016). This change was published in the *2018 Migratory Bird Hunting Regulation* booklet. Information from the Sheboygan River AOC indicates a lag in PCB concentration reductions for waterfowl post-remediation. WDNR will evaluate waterfowl consumption data from the Sheboygan River AOC to inform our timeline for future assessments in the Lower Green Bay & Fox River AOC.

A status check will be scheduled for this BUI when the current consumption advisory evaluation in Sheboygan River AOC is completed and rates of PCB concentration declines in waterfowl tissue are better understood.

Management actions

- ➲ *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional actions

- *Assess waterfowl and fish consumption advisories after sediment cleanup projects have been completed*

RESTRICTIONS ON DREDGING ACTIVITIES

Target	Status
All remediation actions for known contaminated sediment sources are completed and monitored according to the approved remediation plans, the remedial action goals have been achieved, and institutional controls have been implemented.	In progress

Status

In 2019, 452,121 cubic yards of material were dredged as part of the in-river remedial action work for the Lower Fox River PCB cleanup project. This was accomplished using three hydraulic dredges working simultaneously around the clock over 33 weeks of field effort. 246,769 tons of material were sent to landfill, and 169,600 tons of clean sand were separated from the fine sediment and used beneficially offsite. 59 acres were sand covered with 12 acres stone capped. In addition, dredging of sediment polluted with polycyclic aromatic hydrocarbons (PAHs) and heavy metals was completed at the North Focus Area of the Wisconsin Public Service (WPS) Green Bay former Manufactured Gas Plant (MGP) site, located at the East River confluence, with approximately 35,000 cubic yards of material dredged in 2019. The MGP site remedial action work was conducted by the Fox River Group of Companies (FRG respondents) as part of a joint effort between the FRG and WPS. PCB cleanup on the Fox River has been adjusted, and the active portion of the cleanup is anticipated to be complete in mid-2020.

After completion of the contaminated sediment projects, WDNR anticipates drafting a BUI Removal Recommendation that will be presented to stakeholders prior to submission to USEPA in 2021.

Management actions

- *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional actions

- *After completion of management actions, determine if BUI targets are being met and draft a BUI removal recommendation*

Photo credit: The Boldt Company

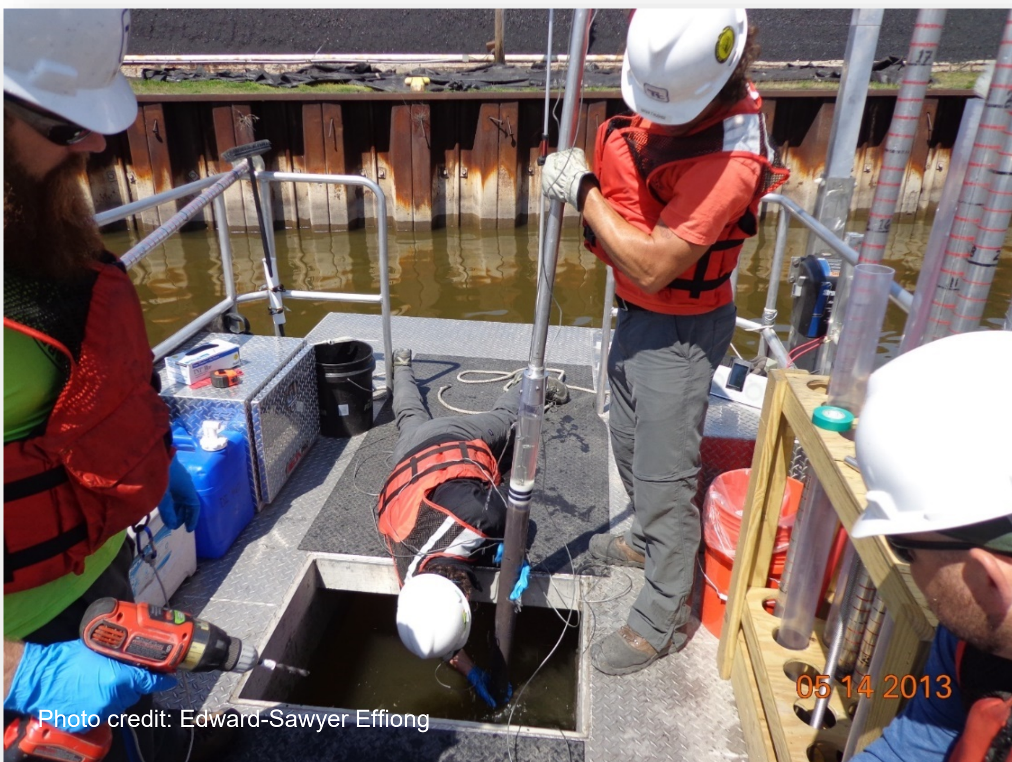


Photo credit: Edward-Sawyer Effiong

To learn more about the cleanup operations, visit [*http://foxrivercleanup.com/project-update/*](http://foxrivercleanup.com/project-update/)

DEGRADATION OF BENTHOS

Target	Status
All remediation actions for known contaminated sediment sources are completed and monitored according to the approved plan and have met their remedial action goal.	In progress
The benthic community IBI within the site being evaluated is statistically similar to a reference site with similar habitat and minimal sediment contamination.	Assessment in progress
Burrowing mayfly (*Hexagenia*) populations return to the AOC in stable annual abundances between 100-400 nymphs/m^2 (measured as a 3-year running average) or as otherwise indicative of adequate levels of dissolved oxygen in overlying waters and uncontaminated surficial sediments in Lake Michigan.	In progress
Sediment toxicity (due to ammonia, PCB, or dissolved oxygen) is not present at levels that are acute or chronically toxic (as defined by relevant, field validated, bioassays with appropriate quality assurance/quality controls) to the benthic community.	Assessment needed
Native benthic communities adequately support the trophic levels that depend upon them.	Assessment needed

Status

In 2019, the Lower Fox River PCB cleanup project continued downriver, with the active portion of the Fox River PCB cleanup anticipated to be complete in 2020. Dredging began in 2018 at the South Focus Area and 2019 at the North Focus Area of the former MGP site located at the East River confluence. Remedial action was completed at both Focus Areas of the former MGP site in 2019. See the "Restrictions on Dredging" section for more details.

USGS completed an assessment that addressed the second portion of the target through a project in which both the planktonic and benthic communities of the Lake Michigan AOCs and reference rivers were assessed in 2012 and 2014 (Eikenberry, B.C.S. et al, 2019). The results of the study indicate that EPT richness (a biological indicator evaluating the richness of Ephemeroptera, Plecoptera, and Trichoptera insects) was higher in the Fox River relative to the non-AOC comparison sites (Ahnapee and Kewaunee River) due to the presence of two caddisfly taxa, including a highly and moderately tolerant taxa. EPT richness was also higher in the Fox River in 2014 relative to the 2012 results. Additionally, the 2014 combined benthic community differed from the non-AOC comparison sites due to higher relative abundance of three pollution-tolerant oligochaete taxa, and oligochaetes were by far the most dominant taxonomic group observed in the Fox River in 2014. While these results indicate that the Fox River may be meeting the second portion of the BUI removal target, re-assessment of this portion of the target will be necessary following completion of the Fox River contaminated sediment projects. Additionally, given the difficulty in finding an appropriate non-AOC reference site for lower bay of Green Bay, it is likely that a target revision may be needed to encompass appropriate benthic community metrics for the bay portion of the AOC.

In response to this, WDNR staff began compiling historic benthic community data in 2018 to help interpret changes in the benthic community pre- and post-contaminated sediment remediation, to recommend any necessary target revisions, and to develop goals for a project that would address the second through fifth portions of the target in which additional assessment work is needed.

In 2018, WDNR requested funding to assess this BUI in partnership with UW-Green Bay. The funding was approved in 2019 and builds upon UW – Green Bay's current UW Sea Grant project which is evaluating the benthic community in the Bay of Green Bay. The AOC project expands the area of interest from the UW Sea Grant project to include new sites in the Fox River and additional sites in the lower bay in evaluating benthos, habitat suitability, and whether the benthic community adequately supports higher trophic levels in the AOC. The results of this assessment will allow WDNR to determine the status and next steps for this BUI and provide supplemental information to assist with management action development for the "Loss of Fish and Wildlife Habitat" and "Degradation of Fish and Wildlife Populations" BUIs.

A status check is scheduled in 2022 for this BUI. In the interim, WDNR will continue to work with technical experts to identify and propose any necessary BUI removal target revisions. Stakeholders will have the opportunity to review this BUI removal target revision prior to WDNR formally adopting the revised target.

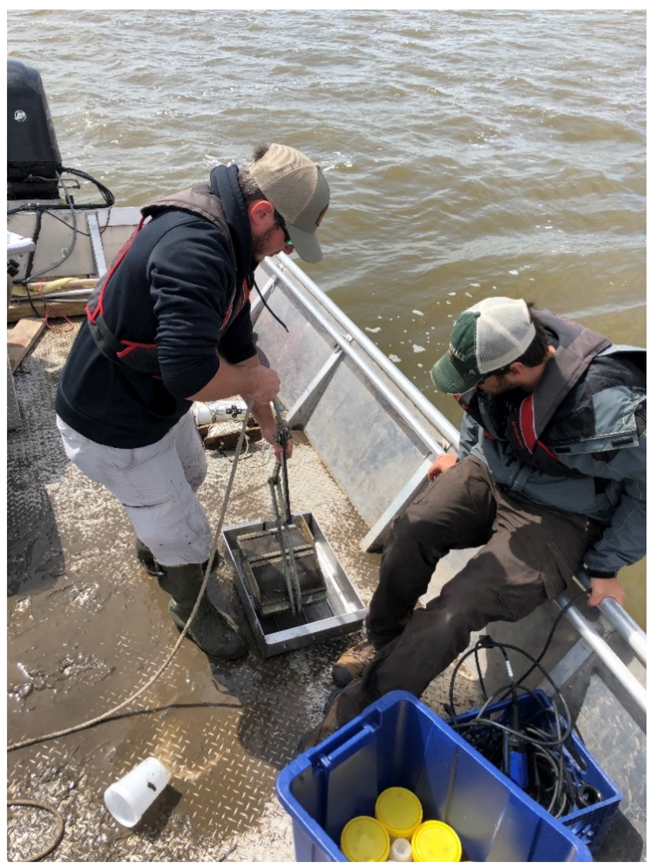
Management actions

- *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional actions

- *Implement a benthic community and habitat suitability (including substrate characterization, dissolved oxygen, and sediment toxicity) assessment*

- *Continue to work with experts to identify any necessary BUI removal target revisions*



Students at UW-Green Bay collecting and identifying benthic invertebrate samples collected in the AOC.

DEGRADATION OF PHYTOPLANKTON AND ZOOPLANKTON POPULATIONS

Target	Status
Plankton and zooplankton structure and function do not significantly diverge from unimpaired reference conditions with comparable physical and chemical characteristics, recognizing the uncontrollable impact of invasive species. The following specific objectives should also be met: *Sources contributing to nutrient enrichment are identified and controlled; and* *AOC total phosphorus concentrations consistently meet water quality standards and/or water quality targets of a State and US EPA approved TMDL; and* In lower Green Bay, the amount of energy from phytoplankton and zooplankton that reaches the open water food chain has increased, and the amount of energy reaching the bottom sediments has decreased. (In other words, the carbon transfer efficiency of the phytoplankton and zooplankton levels of the food chain in lower Green Bay is increased such that the amount of energy channeled into the detrital food chain is decreased and the amount of energy channeled into the pelagic food chain is increased). This is expected to occur when phosphorus levels and the corresponding percentage of blue-green algae in the phytoplankton are reduced.	Assessment in progress
Phytoplankton or zooplankton bioassays confirm no significant toxicity in ambient waters in the AOC.	Unknown

Status

In 2019, the Lower Fox River PCB cleanup project continued downriver, with the active portion of the Fox River PCB cleanup anticipated to be complete in 2020. Dredging began in 2018 at the South Focus Area and 2019 at the North Focus Area of the former MGP site located at the East River confluence. Remedial action was completed at both Focus Areas of the former MGP site in 2019. See the “Restrictions on Dredging” section for more details.

USGS was contracted to assess both the planktonic and benthic communities of the Lake Michigan AOCs and reference rivers in 2012 and 2014. This study compared the Fox River to two reference sites, the Ahnapee and Kewaunee Rivers and to a group of Lake Michigan non-AOC sites including Ahnapee, Kewaunee, Oconto, Manitowoc, and Root Rivers in Wisconsin and the Escanaba River in Michigan (Eikenberry, B.C.S. et al, 2019). Phytoplankton richness, diversity, and density from the Fox River portion of the AOC were not statistically different from non-AOC reference sites, nor from all Lake Michigan non-AOC reference sites. However, the phytoplankton assemblage did differ from the two non-AOC comparison sites primarily because of the presence of cyanobacteria in the Fox River and absence of the diatom *Staurosira construens*, a diatom sensitive to eutrophic conditions. Zooplankton richness and diversity did not differ from the paired non-AOC sites nor from the group of all Lake Michigan reference sites, but zooplankton density did differ between the Fox River and the non-AOC paired reference sites in 2014. Density at the Fox River site was lower, indicating that the zooplankton assemblage may be degraded relative to non-AOC sites.

Additionally, assessment data on soft algae collected via the harmful algal blooms (HABs) project from 2016 - 2018 in support of the Beach Closings BUI will help inform the status of this BUI. When data analyses are complete and fully evaluated, any necessary next steps for this BUI will be determined in 2020 and beyond.

Finally, there is a need to investigate if nutrient enrichment and/or water column toxicity are causes of the plankton impairment after completion of the sediment remediation projects and is scheduled for 2021. Any additional management actions identified for this BUI would likely mirror management actions for sediment remediation and nutrient management. As we learn more through the USGS and HABs studies, the target may be adjusted to reflect new information on mechanisms impacting the ecological condition of the plankton community within the AOC.

A status check will continue into 2021 for this BUI. WDNR will work with technical experts to identify and propose any necessary BUI removal target revisions as the status check is completed. Stakeholders will have the opportunity to review this BUI removal target revision prior to WDNR formally adopting the revised target.

Management actions

- *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional actions

- *Complete water column toxicity testing in 2021*
- *Review the results of the USGS and HABs studies and determine next steps and/or if a BUI removal target revision is necessary*

LOSS OF FISH AND WILDLIFE HABITAT

WDNR adopted a revised BUI removal target for the Loss of Fish and Wildlife Habitat BUI through this RAP Update. The original 2009 target is shown below, followed by the 2020 revised target. The revised target was developed in a science-based collaborative process with stakeholders; please see the "Status" section below the target tables for additional information. Subsequent RAP Updates will only include the 2020 revised target.

2009 BUI Removal Target

Target	Status
Fish and wildlife management goals are achievable as a result of the physical, chemical, and biological integrity of the AOC waters, including wetlands.	Assessment Completed
A balance of diverse habitat types exists within the AOC that supports all life stage requirements of fish and wildlife populations including: 1. Multiple wetland types (for example: submerged aquatic vegetation, emergent vegetation, sedge meadows, forested & shrub) that adequately represent historic wetland types 2. Quality fish spawning habitats 3. Islands for colonial nesting birds, amphibians, and furbearers 4. Intact migration corridors (both shoreline and water) 5. Unconsolidated beaches (for shorebirds) 6. Habitat for State or Federally listed species (special concern, threatened, or endangered)	Assessment Completed
The hydrologic connectivity between wetlands and the AOC is maintained and restored sufficiently to support fish spawning and allow for fish passage.	In progress
The Green Bay portion of the AOC contains water clarity and other conditions suitable for support of a diverse biological community, including a robust and sustainable area of submersed aquatic vegetation in shallow water areas.	Action Needed
The AOC contains a diversity of plants, an abundance of submersed aquatic vegetation, and sufficient invertebrates to provide adequate food supplies to support a diverse assemblage of migratory diving ducks (both mussel and vegetation feeding), fish, and other wildlife (including aquatic invertebrates, amphibians, and reptiles).	Assessment Completed
The AOC meets water quality standards and/or water quality targets of a State and US EPA approved TMDL. The approved TMDL targets are summer median concentrations of 0.10 mg/L TP and 20 mg/L TSS at the mouth of the river.	Action Needed
The AOC meets Wisconsin water quality criteria for dissolved oxygen and water temperature that are protective of fish and wildlife populations.	Action Needed
No waterbodies within the AOC are listed as impaired due to physical or water chemistry conditions in the most recent Wisconsin Impaired Waters List (303(d) List).	Action Needed

2020 BUI Removal Target Revision

Target	Status
The cumulative fish and wildlife habitat condition score reaches a 6.0 averaged over a verification monitoring period taking place after all management actions have been completed. This cumulative score will be calculated as outlined in the "*Evaluating Progress Toward Removing the Degradation of Fish and Wildlife Populations and Loss of Fish and Wildlife Habitat Beneficial Use Impairments*" Plan	Action needed

Status

In early 2018, UW-Green Bay and The Nature Conservancy (TNC) submitted the Habitat Restoration Plan and Path Toward Delisting Project Final Report (Howe, R. et al., 2018). The report identified 18 priority habitats and their respective baseline condition score from which a cumulative AOC habitat condition score of 3.53 was calculated using the Fish and Wildlife BUI Assessment Tools developed by UW-Green Bay. Following the completion of the final report, WDNR and UW-Green Bay received support from USEPA to continue collaborating from 2018 – 2020 to:

- → *Develop a list of high priority, impactful, and cost-effective AOC habitat improvement projects (e.g. management action list)*
- → *Develop and refine priority habitat metrics evaluated in the Fish and Wildlife Habitat Assessment Tool*
- → *Produce a user manual/evaluation plan that will ensure consistent scoring of management actions, evaluation of priority habitat condition scores pre and post implementation of management actions, and to map out a path for tracking progress toward BUI removal after management actions are completed.*

To assist with revising priority habitat metrics, formally recommending a BUI target revision, and developing the management action list, WDNR convened the Fish and Wildlife Habitat and Populations Technical Advisory Committee (TAC) in April 2018. In 2018, the TAC unanimously agreed to adopt the cumulative priority habitat target of 6.0 recommended by UW-Green Bay and formally recommended the adoption of revised target language in January 2020. This recommendation by the TAC comes after several years of stakeholder engagement on revising the BUI removal target led by UW-Green Bay as they developed the BUI assessment plan, and a summary of stakeholder engagement can be found in Appendix D. The proposed target revision was formally adopted after the plan's public review period concluded on May 22, 2020. No comments or feedback regarding the revised target language for this BUI were received.

In February 2020, the TAC formally recommended a suite of 18 specific management actions (e.g. restoration projects) that are anticipated to achieve the revised BUI removal target once completed. The current draft project profiles can be found on UW-Green Bay's website in the document titled Draft AOC Management Action List. The TAC and other partners will submit these project profiles with pre-proposals to USEPA in mid 2020, and partners will likely continue to adjust both the overall list of projects and individual projects elements as cost, feasibility, and other characteristics are better understood over the next several months. Once partners agree on a final list of management actions, full project proposals are expected to be submitted to USEPA for consideration of GLRI funding from 2021 – 2023, with a goal of completing the construction of all management actions by 2024.

It is important to note that several other ongoing efforts are contributing toward improving fish and wildlife habitat within the AOC boundaries and surrounding landscape. For example, over the past 20 years the Fox River Trustees have utilized Natural Resource Damage Assessment (NRDA) settlement funds to restore, replace, and acquire natural resources injured by PCB discharge to the Fox River. The trustees have expressed an interest in exploring future opportunities to work with well-developed partnerships such as these and leverage matching funds for removal of this BUI. Additionally, UW-Green Bay has leveraged the expertise of a large contingency of local resource professionals to develop a West Shores Habitat Management Plan that outlines key restoration and conservation priorities, many of which align with AOC priorities for improving fish and wildlife habitat. Countless other local, state, federal, and NGO partners continue to make progress in leading critical assessments and habitat restoration activities within the AOC. These efforts are critical to meeting AOC and "life after BUI removal and delisting" goals, as well as other relevant goals outside the scope of the AOC program for continued habitat restoration, conservation, and protection in the area. The Office of Great Waters Lake Michigan Lakewide Action Management Plan program is committed to helping partners achieve goals beyond the scope of the AOC program.

A status check will be scheduled for this BUI once all management actions have been completed.

Management actions

- *A proposed list of management actions has been recommended by the TAC and will be submitted to EPA in April 2020*

Additional actions

- ✓ *Complete the fish and wildlife habitat and populations assessment*
- ✓ *Finalize the "Loss of Fish and Wildlife Habitat" BUI removal target*
- ✓ *Finalize the "Evaluating Progress Toward Removing the Degradation of Fish and Wildlife Populations and Loss of Fish and Wildlife Habitat Beneficial Use Impairments" plan*

Eagle flying over Peters Marsh

DEGRADATION OF FISH AND WILDLIFE POPULATIONS

WDNR adopted a revised BUI removal target for the Degradation of Fish and Wildlife Populations BUI through this RAP Update. The original 2009 target is shown below, followed by the 2020 revised target. The revised target was developed in a science-based collaborative process with stakeholders; please see the "Status" section below the target tables for additional information. Subsequent RAP Updates will only include the 2020 revised target.

2009 BUI Removal Target

Target	Status
The AOC contains healthy, self-sustaining, naturally reproducing, and diverse populations of native fish species (including walleye, northern pike, yellow perch, lake sturgeon, Great Lakes spotted muskellunge, and centrarchids) in abundances sufficient to provide ecological function in the fish community	Assessment Completed
Populations of traditionally harvested fish species are capable of supporting some level of exploitation	Partially complete (walleye); more assessment needed
The AOC contains healthy, self-sustaining, naturally reproducing, and diverse populations of native furbearers (including mink, muskrats, and otter), amphibians (including spring peepers, leopard frogs, American toads, eastern gray tree frogs, green frogs, bullfrogs, and salamanders), reptiles (including snapping and painted turtles), terns (common and Forster's), migratory diving ducks, dabbling ducks, marsh nesting birds and island-dependent colonial nesting birds in abundances sufficient to provide ecological function	Assessment Completed
Populations of traditionally harvested wildlife species are capable of supporting some level of exploitation Invasive species (lamprey, carp, gobies, white perch, and others) expansion is minimized and controlled as needed to protect native species within the AOC and upstream	Assessment in progress In progress
Contaminant levels in forage fish populations do not impair the reproductive success of fish-eating birds and wildlife (including predatory fish) and meet the criteria established in Annex 1 of the 1978 Great Lakes Water Quality Agreement as amended by Protocol in 1987, specifically "the concentration of total polychlorinated biphenyls in fish tissues (whole fish, calculated on a wet weight basis), should not exceed 0.1 micrograms per gram for the protection of birds and animals which consume fish"	Assessment in progress
The AOC supports fish and wildlife populations at levels consistent with extant fish and wildlife management plan objectives. Specifically, the following objectives should be met unless extant management plans have updated criteria (specific objectives identified in past RAP documents are listed in Appendix B of the 2015 RAP Update)	Partially complete; more assessment needed

2020 BUI Removal Target Revision

Target	Status
The cumulative fish and wildlife populations condition score reaches a 6.5 averaged over a verification monitoring period taking place after all management actions have been completed. This cumulative score will be calculated as outlined in the "*Evaluating Progress Toward Removing the Degradation of Fish and Wildlife Populations and Loss of Fish and Wildlife Habitat Beneficial Use Impairments*" Plan	Action needed

Status

In early 2018, UW-Green Bay and The Nature Conservancy (TNC) submitted the Habitat Restoration Plan and Path Toward Delisting Project Final Report (Howe, R. et al., 2018). The report identified 22 priority fish and wildlife populations and their respective baseline condition score from which a cumulative AOC fish and wildlife populations condition score of 4.75 was calculated using the Fish and Wildlife BUI Assessment Tools developed by UW-Green Bay. Following the completion of the final report, WDNR and UW-Green Bay received support from USEPA in early 2018 to continue collaborating to:

- → *Develop a list of high priority, impactful, and cost-effective AOC habitat improvement projects (e.g. management action list)*
- → *Develop and refine priority habitat metrics evaluated in the Fish and Wildlife Habitat Assessment Tool*
- → *Produce a user manual/evaluation plan that will ensure consistent scoring of management actions, evaluation of priority habitat condition scores pre and post implementation of management actions, and to map out a path for tracking progress toward BUI removal after management actions are completed.*

To assist with revising priority populations metrics, formally recommending a BUI target revision, and developing the management action list, WDNR convened the Fish and Wildlife Habitat and Populations Technical Advisory Committee (TAC) in April 2018. In 2018, the TAC unanimously agreed to adopt the cumulative priority population target of 6.5 recommended by UW-Green Bay and formally recommended the adoption of revised target language in January 2020. This recommendation by the TAC comes after several years of stakeholder engagement on revising the BUI removal target led by UW-Green Bay as they developed the BUI assessment plan, and a summary of stakeholder engagement can be found in Appendix D. The proposed target revision was formally adopted after the plan's public review period concluded on May 22, 2020. No comments or feedback regarding the revised target language for this BUI were received.

In February 2020, the TAC formally recommended a suite of 18 specific management actions (e.g. restoration projects) that are anticipated to achieve the revised BUI removal target once completed. The current draft project profiles can be found on UW-Green Bay's website in the document titled Draft AOC Management Action List. The TAC and other partners will submit these project profiles with pre-proposals to USEPA in mid 2020, and partners will likely continue to adjust both the overall list of projects and individual projects elements as cost, feasibility, and other characteristics are better understood over the next several months. Once partners agree on a final list of management actions, full project proposals are expected to be submitted to USEPA for planning/design and implementation of projects beginning in 2021.

Additionally, the 2018 native unionid mussel project led by DNR NHC was extended into 2019 to evaluate additional locations. A catalogue of 14 species from 34 sites within Ashwaubenon Creek, Duck Creek, Dutchman Creek, Fox River, Green Bay, Suamico River, and Wequiock Creek was established. Across all survey locations within the AOC, a total of 257 living individuals representing 8 species were encountered and an additional six species were identified as dead shell only. Results of the study indicate small, but potentially stable populations of native mussels within the AOC, primarily occurring on soft and stable sediments. The final report was completed in early 2020 and can be found in Appendix E.

It is important to note that several other ongoing efforts are contributing toward improving fish and wildlife populations within the AOC boundaries and surrounding landscape. For example, over the past 20 years the Fox River Trustees have utilized NRDA settlement funds to restore, replace, and acquire natural resources injured by PCB discharge to the Fox River. The trustees have expressed an interest in exploring future opportunities to work with well-developed partnerships such as these and leverage matching funds for removal of this BUI. Additionally, UW-Green Bay has leveraged the expertise of a large contingency of local resource professionals to develop a West Shores Habitat Management Plan that outlines key restoration and conservation priorities, many of which align with AOC priorities for improving fish and wildlife populations. Countless other local, state, federal, and NGO partners continue to make progress in leading critical assessments and fish and wildlife improvement activities within the AOC. These efforts are critical to meeting

AOC and “life after BUI removal and delisting” goals, as well as other relevant goals outside the scope of the AOC program for continued restoration, conservation, and protection of fish and wildlife in the area. The Office of Great Waters Lake Michigan Lakewide Action Management Plan program is committed to helping partners achieve goals beyond the scope of the AOC program.

A status check will be scheduled for this BUI once all management actions have been completed.

Management actions

- ➲ *A proposed list of management actions has been recommended by the TAC and will be submitted to EPA in April 2020*

Additional actions

- ✓ *Complete the fish and wildlife habitat and populations assessment*
- ✓ *Finalize the “Loss of Fish and Wildlife Populations” BUI removal target*
- ✓ *Finalize the “Evaluating Progress Toward Removing the Degradation of Fish and Wildlife Populations and Loss of Fish and Wildlife Habitat Beneficial Use Impairments” plan*


Photo credit: Brie Kupsky

Ruddy turnstone along the Green Bay shoreline

RESTRICTIONS ON DRINKING WATER CONSUMPTION OR TASTE AND ODOR PROBLEMS

Target	Status
Densities of disease-causing organisms or concentrations of hazardous or toxic chemicals or radioactive substances do not exceed human health standards, objectives, or guidelines.	Assessment in progress
Taste and odor problems are not present.	Assessment in progress
Treatment and costs needed to make raw water suitable for drinking is the standard treatment used in comparable portions of the Great Lakes which are not degraded, specifically disinfection, coagulation, sedimentation, and filtration.	Assessment in progress

Status

In 2019, the Lower Fox River PCB cleanup project continued downriver, with the active portion of the Fox River PCB cleanup anticipated to be complete in 2020. Dredging began in 2018 at the South Focus Area and 2019 at the North Focus Area of the former MGP site located at the East River confluence. Remedial action work was completed at both Focus Areas of the former MGP site in 2019. See the "Restrictions on Dredging" section for more details. Data collected from other operating units on the Fox River show a substantial decrease in surface water concentrations of PCBs, and the same outcome is expected to be observed in AOC waters once the long-term monitoring commences after completion of the contaminated sediment projects expected in 2020.

A status check was scheduled in 2019 for this BUI and will continue into 2020. The surrounding AOC communities have never obtained drinking water from AOC waters in recent history due to water quality issues that are typical of surface water bodies statewide as well as infrastructure constraints in both the Fox River and bay of Green Bay. Prior to 1950, surrounding communities primarily obtained drinking water from groundwater resources, and after 1950 from a pipeline that was constructed to Kewaunee and then Manitowoc to obtain drinking water from Lake Michigan. This presents difficulties in evaluating the BUI; therefore, WDNR is evaluating this BUI by comparing available data on primary and secondary drinking water compounds and cyanobacteria/cyanotoxins caused by blue-green algae in AOC waters to surface/raw water data collected by water utilities that are obtaining drinking water resources from Lake Winnebago and Lake Michigan. This will allow WDNR and stakeholders to better understand if AOC surface waters would meet standard treatment methods being utilized in other surface waters.

If the drinking water BUI is found to be impaired following the 2020 status check, any management actions identified for this BUI would likely mirror management actions for sediment remediation and nutrient management.

A status check will continue in early 2020 for this BUI. If it is determined that BUI removal targets have been met, WDNR will recommend the removal of this BUI to AOC stakeholders and USEPA.

Management actions

- *Complete the contaminated sediment projects (PCB and former MGP site)*

Additional Actions

- *Complete the status check and determine next steps*

BEACH CLOSINGS

Target	Status
Public swimming beaches within the AOC, including Bay Beach, Communiversity Park, and Long Tail, are open for 95% of the swimming season (between Memorial Day and Labor Day) for any 5-year period based on Wisconsin Coastal Beach monitoring protocols for E. coli monitoring	Complete
Public swimming beaches within the AOC, including Bay Beach, Communiversity Park, and Long Tail meet the blue-green algae target for 95% of the swimming season (geometric means of phytoplankton samples contain less than 100,000 cyanobacterial cells/ml or less than 20 µg/L of microcystin based on at least 5 monthly samples over at least 2 years)*	Assessment in progress
No waterbodies within the AOC are included on the list of impaired waters due to pathogen contamination or blue-green algae in the most recent Wisconsin Impaired Waters list	Complete (assessment of blue-green algae data needed)

Status

USEPA released ambient water quality and recreational criteria for cyanotoxins in 2019 that included a recommended analysis method for algal toxins. Related documents are available on USEPA's website: https://www.epa.gov/wqc/microbial-pathogenrecreational-water-quality-criteria.These criteria establish a recommended human health recreational ambient water quality criteria or swimming advisory of 8 µg/L microcystin and 15 µg/L cylindrospermopsin and focus on recreational risk to school-aged children. The USEPA criteria do not establish thresholds for cyanobacterial cell counts. The 2017 RAP update identified the need to update removal criteria for this BUI with consideration for the USEPA recommended guidelines. The current removal target reflects the World Health Organization recommended recreational guidelines for adults (*World Health Organization, 2003), whereas the USEPA recommended recreational guidelines reflect cyanotoxin impacts to children. In response, a revision to the 2009 BUI removal target will be proposed for this BUI in 2020.

Target changes should be made with the recognition that the AOC program is a framework for achieving parity with conditions in similar areas that reflect impacts from development and industrialization, but where the extent of the impacts did not rise to the designation of an AOC. Targets need to be viewed with the following attributes in mind: Specific, Measurable, Achievable, Reasonable, Time-bound (SMART). Reasons that WDNR would explore revisions to target language include the following:

- → *New information has become available*
- → *The target reflects goals that go beyond the AOC program framework (e.g. overlap existing permit or regulatory compliance program functions); and/or*
- → *The scope of achievable activities within the AOC program has become better understood as program implementation has occurred.*

The Cyanobacteria Harmful Algal Blooms (CHABs) monitoring project that commenced in 2016 continued through 2019 with both continuous monitoring at two buoys and sample collection at NEW Water's sites from the mouth of the Fox River to Long Tail Point and nearshore samples at Bay Beach and Joliet Park. NEW Water and UW - Milwaukee continued as primary project partners with sample collection assistance from the UW-Green Bay. In addition to algal cell counts, toxins, chlorophyll *a* and phycocyanin (the pigment associated with cyanobacteria), monitoring includes selected nutrients and water quality parameters as well as meteorology.

The 2016 – 2018 data analysis found more intense blooms are occurring over a period in mid-June and in late August through October, with microcystin concentrations at Bay Beach above the USEPA recreational guideline in an average of 1.97% of samples across the three monitoring seasons, and 0% of samples above the EPA recreational guideline for cylindrospermopsin. While these results suggest that the lower bay portion of the AOC is not impaired for recreation, microcystin concentrations were highly variable and observed to be hundreds of times above the USEPA recreational guideline in scum samples. This points to the need for a routine monitoring program implemented at Bay Beach once it is opened to ensure that recreational risk is mitigated. WDNR is working with the City of Green Bay and Brown County to develop a beach monitoring plan in 2020 that will be complete prior to Bay Beach being re-opened. Two additional years of monitoring (both sample collection and buoy deployment) began in 2019 and will provide comparable measurements with the USEPA proposed criteria and assessment methods, to assure that a representative data set is available for toxins and continuous measurements and to better understand algal dynamics in the long term.

Additionally, UW-Madison researchers began measuring waves and currents in 2018 to investigate how these characteristics influence algal dynamics, and if this data could assist in developing predictive models for algal toxins in the AOC. This data is being used to calibrate nearshore models with higher resolution than are currently available through NOAA. Additional equipment deployments were completed in 2019 both for model validation and to refine the models in Duck Creek Delta and south of Long Tail Point where complex circulation patterns are apparent.

A status check is scheduled for this BUI in 2021. In the interim, WDNR will continue to work with technical experts on a revised BUI removal target. Stakeholders will have the opportunity to review this BUI removal target revision prior to WDNR formally adopting the revised target.

Management actions

- *Management actions will be considered for this BUI upon completion of the study in 2021.*

Additional Actions

- *Continue to develop and discuss a revised BUI removal target with stakeholders in 2020*

EUTROPHICATION OR UNDESIRABLE ALGAE

Target	Status
Total phosphorus and total suspended solids concentrations at the mouth of the Lower Fox River meet water quality standards and/or water quality targets specified in a State and US EPA approved Total Maximum Daily Load. The approved TMDL targets are summer median concentrations of 0.10 mg/L TP and 20 mg/L TSS at the mouth of the river.	Action needed
There are no exceedances of the minimum dissolved oxygen concentrations established in Wisconsin Administrative Code Chapter NR 102 within the AOC due to excessive sediment deposition or algae growth.	Action needed
No waterbodies within the AOC are included on the 303(d) list of impaired waters due to nutrients or blue-green algae in the most recent Wisconsin Impaired Waters list.	Action needed
Cyanobacteria will be evaluated using the following methodology: • 90% of the geometric means of at least 5 monthly samples (collected between May 1 and September 30th in at least 2 years) of phytoplankton samples from waterbodies in the AOC contain less than 100,000 cyanobacterial cells/mL or less than 20 µg/L of microcystin. • Less than 50 - 60% of the relative biomass of phytoplankton is cyanobacteria when total phosphorus at the mouth of the Lower Fox River reaches the TMDL target of 100 µg/L (0.1 mg/L)	In progress In progress

Status

WDNR has worked with partners and stakeholders over several years to refine the outcomes that will define success for the AOC program with regard to this BUI. WDNR continues to engage stakeholders and technical experts in developing a revised version of the 2009 BUI removal target (shown above).

Target changes should be made with the recognition that the AOC program is a framework for achieving parity with conditions in similar areas that reflect impacts from development and industrialization, but where the extent of the impacts did not rise to the designation of an AOC. Targets need to be viewed with the following attributes in mind: Specific, Measurable, Achievable, Reasonable, Time-bound (SMART). Reasons that WDNR would explore revisions to target language include the following:

- → *New information has become available*
- → *The target reflects goals that go beyond the AOC program framework (e.g. overlap existing permit or regulatory compliance program functions); and/or*
- → *The scope of achievable activities within the AOC program has become better understood as program implementation has occurred.*

While meeting the TMDL remains an important goal that many resource professionals, agencies, and citizens continue to strive for in the region, BUI removal targets that overlap existing permit or regulatory compliance program functions are beyond the AOC program framework.

In 2016, WDNR and USEPA explored how AOC Great Lakes Restoration Initiative (GLRI) funding might be applied toward best management practice (BMP) implementation, with consideration for the project attributes that previous AOC GLRI-funded projects have shared and arrived at a set of five “AOC-like” practices for BMPs that could be installed on the landscape including:

- → *Agricultural runoff treatment systems (constructed/treatment wetlands)*
- → *Wetland creation/enhancement/restoration*
- → *Streambank protection/stabilization*
- → *Two-stage ditches*
- → *Saturated buffers*

In 2017 and 2018, WDNR continued to build upon this momentum by convening technical experts to estimate how much phosphorus and sediment reduction would potentially be realized if these practices were implemented on the landscape and where the opportunities were to implement these practices, and found that these practices have the potential to contribute significantly to nutrient and sediment reductions in the Lower Fox Basin if implemented. In 2019, WDNR presented these estimates to stakeholders along with a proposed BUI removal target revision that focused on restoration of water holding capacity within the Lower Fox Basin. Additionally, WDNR partnered with Outagamie County in 2019 to evaluate where restored water holding capacity was needed in the basin to help inform where to prioritize the implementation of AOC-sponsored practices (Outagamie County Land Conservation Department, 2020; Appendix F). The analysis was completed in early 2020, and conversations with stakeholders indicate that a broader implementation strategy for achieving reductions outlined in the TMDL is needed to determine the level of AOC-sponsored implementation that will define success for the AOC program. This broader implementation strategy will ensure that the AOC-sponsored implementation complements ongoing work in the basin to meet TMDL reductions and will provide confidence and support from stakeholders needed to remove this BUI in the likely event that overall nutrient and sediment reductions needed to meet the TMDL will not have occurred at the time of BUI removal.

Additionally, several other assessment projects that inform the status of the BUI continued in 2019. USGS continues to lead sediment fingerprinting studies in the Apple Creek watershed, and finished the Plum Creek study (Fitzpatrick et al., 2019; Appendix G). These studies characterize sources of sediment (upland vs. streambank), thereby ensuring effective siting of conservation practices in these watersheds. The results of both studies will be presented to stakeholders in 2020. Outagamie and Brown County completed 9 key element plans for Bower Creek and the Lower Fox main stem with Garners Creek HUC12s, adding to the plans already available for the Lower Fox Basin. The plans are important for ensuring coordinated implementation of conservation practices and provide important data for the AOC-like practice estimates. A tributary monitoring program completed its 5th year in 2019 which engaged volunteers in collecting water quality data to help characterize phosphorus levels in tributaries. Volunteers gained a valuable connection to the AOC and learned about water quality issues.

It is important to note that while the AOC program is currently developing the management action list, several other ongoing efforts have been made toward improving water quality within the AOC boundaries and surrounding landscape. WDNR will continue to work with partners to develop a broader nutrient reduction implementation plan and identify the subset of AOC-sponsored implementation of management actions that would fall under the broader plan in 2020. Additionally, WDNR will continue to work toward a revised BUI removal target focused on AOC-sponsored implementation of structural practices in 2020. Stakeholders will have the opportunity to review the BUI removal target revision prior to WDNR formally adopting the revised target. They will also have the opportunity to review the broader implementation plan and AOC management action list prior to formal adoption by WDNR and USEPA.

Management actions

- ➲ *Management actions are currently under development for this BUI*

Additional Actions

- ➲ *Continue to work with partners to outline a strategy for achieving nutrient reductions, identify what role AOC-sponsored implementation of management actions will play in that strategy, and update the BUI removal target*

DEGRADATION OF AESTHETICS

Target	Status
Total phosphorus and total suspended solid concentrations at the mouth of the Lower Fox River meet water quality standards and/or water quality targets specified in a State and US EPA approved Total Maximum Daily Load (TMDL). The approved TMDL targets are summer median concentrations of 0.10 mg/L TP and 20 mg/L TSS at the mouth of the river.	Action needed
Monitoring data within the AOC and/or surveys for any five-year period indicates that water bodies in the AOC do not exhibit unacceptable levels of the following properties in quantities which interfere with the Water Quality Standards for Surface Waters: a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water shall not be present in such amounts as to interfere with public rights in waters of the state or impair use. b) Floating or submerged debris, oil, scum, or other material shall not be present in such amounts as to interfere with public rights in waters of the state or impair use. c) Materials producing color, odor, taste, or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the state or impair use.	Assessment complete (initiated 2011)

Status

The final year of aesthetics monitoring was completed in 2018 in collaboration with the Fox-Wolf Watershed Alliance, a local nonprofit organization that implemented this volunteer program for three consecutive years. The intent of the program was to 1) better understand the public's perception of AOC waters by providing an empirical method of determining whether there are specific aesthetic-related issues that limit use or discourage access in AOC waterways relative to the BUI removal targets, 2) use the results to define what, if any, projects are needed to improve aesthetics within the AOC, and 3) expand public participation and outreach in the AOC through monitoring.

The assessment evaluated overall aesthetic value through an aesthetic impression score that was determined by the respondent by asking them to rate how pleasing or displeasing the site was. The survey also asked respondents to indicate whether objectionable properties were observed at the site and would preclude the surveyor from recreating there (e.g. garbage, algae, water clarity/odor). Results from this series of questions were used to tabulate an aesthetic assessment score.

Both the aesthetic impression and assessment scores were evaluated to determine if they had exceeded "action criteria thresholds," which would indicate that some activity was necessary to improve aesthetic value at the survey site (Table 2).

Table 2. Table includes action criteria values for the 2011-2013 and 2015-2018 survey periods. Any survey locations determined to be exceeding the action criteria values were considered to be in need of some action taken to improve aesthetic value.

Survey Period	Average Impression Score	Average Assessment Score	Average % Surveys
2011-2013	3.0	5.0	75
2015-2018	3.0	4.0	75

After a preliminary review of the 2011-2018 data, only one survey location (Riverview Place Park) exceeded the aesthetic impression threshold of 3.0 in the 2011-2013 survey years, though none of the 12 monitoring stations exceeded the 3.0 threshold in the 2015-2018 survey years (Table 3) Similarly, only one survey location (Riverview Place Park) exceeded the aesthetic assessment threshold in the 2011-2013 survey years, though none of the 12 monitoring stations exceeded the threshold in the 2015-2018 survey years (Table 3).

Surveyors indicated that at least one displeasing parameter was present in greater than or equal to 75% of surveys completed at Bay Beach, Leicht Park, and Riverview Place Park in the 2011-2013 survey period, and Porlier Pier, Regatta 220, and Riverview Place Park in the 2015-2018 survey period (Table 3). This portion of the survey was intended to identify possible community engagement or other such activities that could be implemented locally.

Table 3. Table includes action criteria exceedances observed in the 2011-2013 and 2015-2018 survey periods.

Survey Period	Exceeded Impression Score Threshold	Exceeded Assessment Score Threshold	Exceeded % Surveys Threshold		
2011-2013	Riverview Place Park	Riverview Place Park	Bay Beach	Leicht Park	Riverview Place Park
2015-2018	-	-	Porlier Pier	Regatta 220	Riverview Place Park

Per the project's Quality Assurance Project Plan, all three action criteria thresholds would need to be exceeded for the program to consider if some management action beyond local activities should be evaluated. Riverview Place Park was the only survey location in which all three action criteria were exceeded, but only in the 2011 – 2013 survey years, and not in the recent survey period. This suggests that actions implemented locally such as waterfront cleanup events, removal of invasive species, and improved access will continue to improve aesthetic value in the AOC, and that establishing management actions beyond the current and planned efforts to restore and remediate the AOC are likely not necessary.

The 2009 BUI removal target includes a provision to meet the TMDL water quality targets. While meeting the TMDL remains an important goal that many resource professionals, agencies, and citizens continue to strive for in the region, BUI removal targets that overlap existing permit or regulatory compliance program functions are beyond the AOC program framework.

Target changes should be made with the recognition that the AOC program is a framework for achieving parity with conditions in similar areas that reflect impacts from development and industrialization, but where the extent of the impacts did not rise to the designation of an AOC. Targets need to be viewed with the following attributes in mind: Specific, Measurable, Achievable, Reasonable, Time-bound (SMART). Reasons that WDNR would explore revisions to target language include the following:

- → *New information has become available*
- → *The target reflects goals that go beyond the AOC program framework (e.g. overlap existing permit or regulatory compliance program functions); and/or*
- → *The scope of achievable activities within the AOC program has become better understood as program implementation has occurred.*

Management actions

- *No management actions are anticipated at this time*

Additional actions

- *Continue to work with stakeholders on reviewing the results of the aesthetics monitoring survey and discuss a partial revision to the BUI removal target*

TAINTING OF FISH FLAVOR

Target	*Status*
No target was developed in 2009, as this is a suspected impairment.	BUI Removal Recommendation in Progress

Status

Having reviewed with stakeholders the historic and recent information that can help inform the status of this BUI, WDNR has concluded that there is sufficient evidence available to remove this suspected BUI. In response, WDNR has drafted a BUI removal recommendation that will be available for stakeholder review in early 2020. An updated removal package will then be provided. to USEPA for concurrence.

Management actions

Given that this is a suspected BUI in the AOC as there is no data or information to support its designation as a BUI, no management actions have been established to date.

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APPENDICES

Appendix A – Acronyms

Appendix B – Definitions

Appendix C – BUI Tracking Matrix

Appendix D – Summary of Stakeholder Engagement in Revising the Loss of Fish and Wildlife Habitat and Degradation of Fish and Wildlife Populations BUIs

Appendix E – Investigating Native Mussel Communities within Nearshore Habitats in the Lower Green Bay & Fox River

Appendix F - Non-Point Source Runoff Storage Capacity Opportunities for Sediment and Nutrient Reduction in the Lower Fox River Basin

Appendix G - Stream Corridor Sources of Suspended Sediment and Phosphorus from an Agricultural Tributary to the Great Lakes Final Report

Appendix H – Summary of changes to RAP and associated documents following public review period

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Appendix A

Acronyms

AOC	Area of Concern
BUI	Beneficial Use Impairment
EPT	Ephemeroptera, Plecoptera, Trichoptera richness
FWWA	Fox-Wolf Watershed Alliance
GLRI	Great Lakes Restoration Initiative
IJC	International Joint Commission
LGBFR	Lower Green Bay and Fox River
µg/L	Micrograms per liter
mg/L	Milligrams per liter
MGP	Manufactured Gas Plant
MS4	Municipal Separate Storm Sewer System
NAPL	Non-aqueous phase liquid
NOAA	National Oceanic and Atmospheric Administration
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
ppm	Part per million
RAP	Remedial Action Plan
SMART	Specific, Measurable, Achievable, Realistic, Timebound
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
TP	Total phosphorus
TSS	Total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
UW-Green Bay	University of Wisconsin – Green Bay
UW-Milwaukee	University of Wisconsin - Milwaukee
UW-Oshkosh	University of Wisconsin - Oshkosh
WDNR	Wisconsin Department of Natural Resources
WPSC	Wisconsin Public Service Corporation

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Appendix B

Definitions

Area of Concern (AOC)
Defined by Annex 2 of the 1987 Protocol to the U.S.-Canada Great Lakes Water Quality Agreement as "geographic areas that fail to meet the general or specific objectives of the Agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life." These areas are the "most contaminated" areas of the Great Lakes, and the goal of the AOC program is to bring these areas to a point at which they are not environmentally degraded more than other comparable areas of the Great Lakes. When that point has been reached, the AOC can be removed from the list of AOCs, or "delisted."

Beneficial Use Impairment (BUI)
A "beneficial use" is any way that a water body can improve the quality of life for humans or for fish and wildlife (for example, providing fish that are safe to eat). If the beneficial use is unavailable due to environmental problems (for example if it is unsafe to eat the fish because of contamination) then that use is impaired. The International Joint Commission provided a list of 14 possible beneficial use impairments in the 1987 Great Lakes Water Quality Agreement amendment.

Delisting Target
Specific goals and objectives established for beneficial use impairments, with measurable indicators to track progress and determine when BUI removal can occur.

Escherichia coli (E. coli)
A bacterium commonly found in natural bodies of water that serves as an indicator of the possible presence of other health risks in the water, such as bacteria, viruses, and other organisms.

Fish Consumption Advisory
Some fish from certain waterbodies contain harmful chemicals. These chemicals build up in the fish over time, and can build up in people when they eat the fish. The WDNR routinely tests fish and issues recommendations typically to "eat no more than" or "eat up to," on how much fish a person could eat based on protecting human health from contaminants that may be found in fish. Current Wisconsin fish consumption advisories are available online at http://dnr.wi.gov/topic/fishing/consumption/.

Microcystins
A class of toxins produced by freshwater cyanobacteria (also known as "blue-green algae"). These chemicals include microcystin-LR, which is the most common type. Microcystins can be produced in large quantities during algal blooms, and can cause adverse reactions in humans and animals that come in contact with the toxin.

Remedial Action Plan (RAP)
According to the 1987 Protocol to the U.S.-Canada Great Lakes Water Quality Agreement, a RAP is a document that provides "a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern…" RAPs were required by the 1987 Protocol to be submitted to the International Joint Commission at three stages:

- Stage 1: Problem definition
- Stage 2: When remedial and regulatory measures are selected
- Stage 3: When monitoring indicates that identified beneficial uses have been restored

Note that a renegotiated Great Lakes Water Quality Agreement was signed in 2012 by the U.S. and Canada which removed the "stage" terminology from the AOC Annex, and simply requires Remedial Action Plans to be "developed, periodically updated, and implemented for each AOC."

Total Maximum Daily Load (TMDL)
A TMDL is the amount of a pollutant a waterbody can receive and still meet water quality standards. It can be thought of as a pollution "budget" for a water body or watershed that establishes the pollutant reduction needed from each pollutant source to meet water quality goals.

Waterfowl Consumption Advisory
Some waterfowl from certain waterbodies contain harmful chemicals. These chemicals build up in the birds over time, and can build up in people who eat them. The WDNR tests waterfowl and issues recommendations on how much a person could eat based on protecting human health from contaminants that may be found in waterfowl. Current Wisconsin waterfowl consumption advisories are available in the Migratory Bird Hunting Regulation booklet and online at https://dnr.wi.gov/topic/hunt/waterfowl.html

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Appendix C

BUI Tracking Matrix

Project Name	BUI Short List	Project Type	Project Action Type	Action Modifier	Project Status	Project Start Date	Project End Date	Project Cost	Primary Funding Source	Project Lead Organization
Assessing Cyanobacterial Harmful Algal Blooms (CHABs) in Lower Green Bay	BUI 10	Beaches	Assessment	Implementation	In Progress	04/01/2016	2021	$537,000.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Assessment of Benthos and Plankton in Wisconsin's Lake Michigan Areas of Concern	BUI 6, BUI 13	Fish and Wildlife	Assessment	COMPLETED	Completed	2013	2019	$414,300.00	U.S. Environmental Protection Agency [GLRI]	USGS
Assessment of Migratory Waterfowl Populations and Native Wetland Plant Remnants	BUI 3, BUI 14	Fish and Wildlife	Assessment	COMPLETED	Completed	2016	2017	$42,661.00	U.S. Environmental Protection Agency [GLRI]	UWGB
Bay Beach Monitoring	BUI 8, BUI 10	Beaches	Assessment	COMPLETED	Completed	2015	2015	$550.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Benthos & Plankton BUIs Evaluation in Wisconsin's Lake Michigan Areas of Concern	BUI 6, BUI 13	Fish and Wildlife	Assessment	COMPLETED	Completed	2011	2015	$451,500.00	U.S. Environmental Protection Agency [GLRI]	USGS
Cat Island Chain Restoration - spine construction	BUI 14	Fish and Wildlife	Restoration	COMPLETED	Completed	2012	2014	$20,000,000.00	U.S. Environmental Protection Agency [GLRI]	USACE
Determining the Status of Fish Populations in the Lower Fox River/Green Bay AOC	BUI 3	Fish and Wildlife	Assessment	COMPLETED	Completed	2015	2016	$6,000.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Development of Projects and Management Actions Necessary for Habitat & Populations BUI Removal	BUI 3, BUI 14	Fish and Wildlife	Assessment	Implementation	In Progress	2018	2020	$87,000.00	U.S. Environmental Protection Agency [GLRI]	UWGB
Environmental Capping of Renard Island	BUI 7	Sediment	Remediation	COMPLETED	Completed	2010	2012	$3,114,000.00	U.S. Environmental Protection Agency [GLRI]	USACE
Evaluating the benefit of removing PCB contaminated sediments to nutrient management	BUI 7, BUI 8	Nonpoint	Assessment	COMPLETED	Completed	2014	2014	$11,500.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Evaluation of Waterfowl Consumption Advisories	BUI 1	Fish and Wildlife	Assessment	COMPLETED	Completed	2012	2016	$106,743.00	U.S. Environmental Protection Agency [Non-GLRI]	WDNR
Facilitation Support for Selecting Management Actions for the Eutrophication BUI in the LGBFR AOC	BUI 8	Nonpoint	Restoration	COMPLETED	Completed	11/01/2016	2019	$8,350.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Fish Tumors & Other Deformities Assessment	BUI 4	Fish and Wildlife	Assessment	Not Started	Established	2019		$170,400.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Frequency and Severity of Harmful Algal Blooms (HABs) of Cyanobacteria and Cyanotoxin (Microcystin)	BUI 8, BUI 10	Beaches	Assessment	COMPLETED	Completed	2011	2011	$3,200.00	U.S. Environmental Protection Agency [Non-GLRI]	WDNR
Green Bay Angler Survey Fish Flavor	BUI 2	Community Involvement	Information	COMPLETED	Completed	2013	2014	$5,000.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Habitat Management for Migratory and Breeding Birds at the Cat Island Restoration Project	BUI 3, BUI 14	Fish and Wildlife	Restoration	COMPLETED	Completed	2014	2015	$6,885.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Identifying water storage capacity needs to support Eutrophication BUI removal	BUI 8	Nonpoint	Assessment	Reporting	In Progress	06/01/2019	03/01/2019	$25,000.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Investigating Native Mussel Communities within Nearshore Habitats	BUI 3, BUI 14	Fish and Wildlife	Assessment	COMPLETED	Completed	2018	2019	$30,000.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Lower Fox River PCB Cleanup	BUI 1, BUI 3, BUI 4, BUI 5, BUI 6, BUI 7, BUI 9	Sediment	Remediation	Remedial Implementation	In Progress	2009	2019	$1,200,000,000.00	Responsible Party [Non-GLRI]	USEPA
Lower Fox tributary volunteer monitoring	BUI 8	Nonpoint	Assessment	COMPLETED	Completed	2014	2019	$150,341.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Lower Green Bay and Fox River AOC Habitat Restoration Plan and Path Toward Delisting	BUI 3, BUI 14	Fish and Wildlife	Assessment	COMPLETED	Completed	2014	2018	$464,052.00	U.S. Environmental Protection Agency [GLRI]	UWGB
Lower Green Bay-Fox River Benthic Community and Habitat Suitability Assessment	BUI 6	Fish and Wildlife	Verification Monitoring	Implementation	In Progress	2019	2021	$169,620.00	U.S. Environmental Protection Agency [GLRI]	WDNR
Nine Key Element Plan (9KE Plan) Development in Lower Fox River Basin	BUI 8	Nonpoint	Assessment	COMPLETED	Completed	07/01/2017	12/01/2019	$121,175.00	U.S. Environmental Protection Agency [GLRI]	
Point au Sable Wetland Restoration-Phase 1	BUI 14	Fish and Wildlife	Restoration	COMPLETED	Completed	2012	2013	$150,000.00	Sustain Our Great Lakes [GLRI]	UWGB
Point au Sable Wetland Restoration-Phase 2	BUI 14	Fish and Wildlife	Restoration	COMPLETED	Completed	2014	2016	$130,650.00	Sustain Our Great Lakes [GLRI]	UWGB
Sediment Budget and Sediment Source Apportionment Study for Apple Creek	BUI 8	Nonpoint	Assessment	Implementation	In Progress	07/01/2017	12/01/2019	$178,426.00	U.S. Environmental Protection Agency [GLRI]	USGS
Sediment Budget and Sediment Source Apportionment Study for Plum Creek	BUI 8	Nonpoint	Assessment	COMPLETED	Completed	06/01/2016	12/01/2019	$194,785.00	U.S. Environmental Protection Agency [GLRI]	USGS
Vegetation Monitoring and Assessment of the Cat Island Chain	BUI 3, BUI 14	Fish and Wildlife	Assessment	COMPLETED	Completed	2013	2015	$18,000.00	U.S. Environmental Protection Agency [Non-GLRI]	WDNR
Volunteer Monitoring of Aesthetics	BUI 11	Aesthetics	Assessment	COMPLETED	Completed	2011	2018	$16,900.00	U.S. Environmental Protection Agency [GLRI]	WDNR
WPS Green Bay Former Manufactured Gas Plant Superfund Alternative Site	BUI 3, BUI 4, BUI 6, BUI 7	Sediment	Remediation		In Progress	2014	2019	Unknown	Responsible Party [Non-GLRI]	USEPA

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Appendix D

Summary of Stakeholder Engagement in Revising the Loss of Fish and Wildlife Habitat and Degradation of Fish and Wildlife Populations BUIs

June 2015 – December 2017: UW-Green Bay and WDNR Lower Green Bay & Fox River Area of Concern Habitat Restoration Plan and Path Toward Delisting Project

UW-Green Bay project partners held 17 stakeholder meetings (see table below for meeting descriptions), three of which included presentations on overall project status updates. Fourteen meetings were interactive, in which we generated discussions with stakeholders and asked for specific feedback and information on various aspects of the project, including:

a) Compiling lists of current of historical AOC projects,
b) Gaining historical information on AOC fish and wildlife habitat and populations,
c) Identifying critical fish and wildlife habitats, populations, and areas of interest (i.e., "priority areas",
d) Evaluating the current condition or status of priority habitats and priority species/species groups
e) Reviewing AOC Fish and Wildlife Assessment Process and Tools, and
f) Reviewing proposed BUI removal targets for fish and wildlife habitat and populations.

Many of the stakeholders engaged throughout this process were active conservationists, environmentalists, scientists, biologists, natural resource managers, retirees, and engaged citizens who regularly work with fish and wildlife in the AOC and whose expertise is vital to the removal of both BUIs and the AOC as a whole.

Date	Location	Type	Audience	Purpose
23 Jun 2015	UW-Green Bay	Interactive	Local fish and wildlife experts	Introduction to the project; compile existing information on fish and wildlife from attendees
17 Dec 2015	WDNR	Presentation	AOC technical stakeholders	Status update on the project
06 Jan 2016	UW-Green Bay	Interactive	Fish experts	Get feedback on identifying priority fish species and potential projects
13 Jan 2016	UW-Green Bay	Interactive	Local expert Thomas Erdman	Gain historical information on the LGB&FR AOC and identify potential projects
19 Jan 2016	UW-Green Bay	Interactive	Local expert Thomas Erdman	Gain historical information on the LGB&FR AOC and identify potential projects
22 Jan 2016	UW-Green Bay	Interactive	Local expert Thomas Erdman	Gain historical information on the LGB&FR AOC and identify potential projects
19 Apr 2016	UW-Green Bay	Interactive	Green Bay Conservation Partners	Introduction to the project; compile existing information on fish and wildlife from attendees
30 Jun 2016	WDNR	Presentation	AOC technical stakeholders	Status update on the project
16 Dec 2016	UW-Green Bay	Interactive	Local fish and wildlife experts	Status update on the project; review draft lists of AOC priority areas and fish and wildlife species/species groups

27 Jan 2017	WDNR	Presentation	AOC technical stakeholders	Status update on the project; review draft assessment tools
25 Apr 2017	UW-Green Bay	Interactive	Green Bay Conservation Partners	Get feedback on the AOC Fish and Wildlife Habitat Assessment Tool and brainstorm potential habitat restoration projects
24 May 2017	UW-Green Bay	Interactive	Local fish and wildlife experts	Review the AOC Fish and Wildlife Habitat and Populations Assessment Tools, discuss BUI removal targets, and brainstorm potential projects
15 Jun 2017	UW-Green Bay	Interactive	Local fish experts	Identify priority fish groups, evaluate their current condition, and brainstorm potential projects
03 Aug 2017	WDNR	Interactive	AOC technical stakeholders	Get feedback on the AOC Fish and Wildlife Habitat and Populations Assessment Tools and setting BUI removal targets
28 Sep 2017	UW-Milwaukee	Interactive	WDNR, USEPA, & USFWS staff	Overview of AOC fish and wildlife assessment process and get general feedback
01 Nov 2017	WDNR	Interactive	WDNR, USEPA, & USFWS staff	Overview of AOC fish and wildlife assessment process, discuss BUI removal targets and management action/project list
06 Dec 2017	UW-Green Bay	Interactive	Local fish and wildlife experts	Review the AOC Fish and Wildlife Habitat and Populations Assessment Tools, discuss BUI removal targets and potential projects

April 2018 - Present: UW-Green Bay and WDNR Development of Projects and Management Actions Necessary for Habitat & Populations BUI Removal in the Lower Green Bay & Fox River Area of Concern

UW-Green Bay and WDNR held 12 TAC, 14 Focus/Working Group, and 3 stakeholder meetings (see table below for meeting descriptions) of which interactive discussions and presentations on progress made toward the refinement of fish and wildlife habitat and population metrics and project ideas occurred.

Date	Location	Audience	Purpose
12 April 2018	UW-Green Bay	TAC Members	Introduction to TAC members on the process for developing management action list, overview of assessment process and recommended BUI removal targets, general discussion and feedback.
25 April 2018	WDNR	AOC Stakeholders	RAP Update meeting presenting process for developing management action list, overview of assessment process and recommended BUI removal targets, general discussion and feedback.
11 June 2018	UW-Green Bay	TAC Members	TAC unanimously recommends WDNR draft new BUI removal targets for the Loss of Fish and Wildlife Habitat and Degradation of Fish and Wildlife Populations BUIs based on the

			BUI Assessment Tools. Discussed restoration ideas on AOC Islands.
06 August 2018	UW-Green Bay	TAC Members	Continued to discuss restoration ideas on AOC Islands and activities that would benefit priority habitats and populations at those locations.
19 September 2018	UW-Green Bay	TAC Members	Continued to discuss restoration ideas on AOC Islands and activities that would benefit priority habitats and populations at those locations.
27 September 2018	UW-Green Bay	Colonial Waterbirds Working Group	Discussed considerations for developing colonial waterbirds IEC metric with regional experts.
11 October 2018	UW-Green Bay	Wet Meadow and Grasslands Focus Group	Discussed considerations for developing wet meadow and surrogate grasslands metrics and ideas for project activities that would benefit these habitats and associated populations in the AOC with regional experts.
26 October 2018	UW-Green Bay	Shoreline Fish Working Group	Discussed considerations for developing shoreline fish metric with regional experts.
29 October 2018	UW-Green Bay	Emergent and Submergent Marsh Focus Group	Discussed considerations for developing marsh metrics and ideas for project activities that would benefit these habitats and associated populations in the AOC with regional experts.
12 December 2018	UW-Green Bay	TAC Members	Updates to Assessment Tools and metric refinements, TAC unanimously recommends WDNR adopt a target condition score of 6.0 out of 10.0 for the Loss of Fish and Wildlife Habitat BUI, and 6.5 out of 10.0 for the Degradation of Fish and Wildlife Populations BUI. Group agrees that more discussion is needed on confidence intervals around those target scores and time period in which they must be observed to consider the target met.
5 February 2019	UW-Green Bay	Open Water and Fisheries Focus Group	Discussed considerations for developing open water and shoreline, tributary, and Fox River fish metrics. Developed ideas for project activities that would benefit these habitats and populations in the AOC with regional experts.
11 February 2019	Weyers-Hilliard Brown County Library	AOC Stakeholders	RAP Update meeting presenting process for developing management action list, overview of assessment process and recommended BUI removal targets, general discussion and feedback.
14 February 2019	UW-Green Bay	Mammal Working Group	Discussed considerations for developing mammal metrics with regional experts.
6 March 2019	UW-Green Bay	Turtles Working Group	Discussed considerations for developing turtle metrics with regional experts.
27 March 2019	UW-Green Bay	Native Freshwater Mussels Focus and Working Group	Discussed considerations for developing freshwater mussel metrics and ideas for project areas/activities that would benefit this population with regional experts.

2 April 2019	UW-Green Bay	Coastal Forests and Inland Waters Focus Group	Discussed considerations for developing forest and inland water metrics and ideas for project areas/activities that would benefit these habitats and associated populations with regional experts.
2 April 2019	UW-Green Bay	Stream Macroinvertebrate Working Group	Discussed considerations for developing stream macroinvertebrate metrics with regional experts.
23 April 2019	UW-Green Bay	Great Lakes Beach Focus Group	Discussed considerations for developing Great Lakes beach metrics and ideas for project areas/activities that would benefit this habitat and associated populations with regional experts.
29 April 2019	UW-Green Bay	Bird Working Group	Discussed considerations for developing breeding shorebirds, bald eagle/osprey, wetland terns, migratory shorebirds, migratory landbirds, and migratory waterfowl metrics with regional experts.
20 May 2019	UW-Green Bay	Terrestrial Macroinvertebrate Working Group	Discussed considerations for developing coastal terrestrial macroinvertebrate metrics with regional experts.
23 May 2019	UW-Green Bay	Colonial Waterbirds Working Group	Continued to discuss considerations for developing colonial waterbirds IEC metric with regional experts.
June – December 2019	UW-Green Bay	Metrics Team Meetings	UW-Green Bay, USFWS, and WDNR met on several occasions to synthesize outcomes from previous meetings and refine priority habitat and population metrics and to draft the a metric and tracking BUI progress plan.
01 August 2019	UW-Green Bay	TAC Members	Discussed survey results for project areas and recommended activities generated from past TAC and Focus Group meetings for the east shore of the bay of Green Bay portion of the AOC. Identified 7 priority project areas located in this AOI to continue developing ideas and consideration for inclusion in the management action list.
25 September 2019	UW-Green Bay	TAC Members	TAC members presented and discussed project concepts for priority east shore project areas. Also discussed survey results for project areas and recommended ideas generated from past TAC and Focus Group meetings for the Fox River and southwest shoreline of the bay of Green Bay portion of the AOC.
22 October 2019	Southwest Brown County Library	TAC Members	TAC members presented and discussed project concepts for priority Fox River and southwest shoreline project areas. Also discussed project areas and ideas for the west shore of the bay of Green Bay portion of the AOC and metrics for Designated Conservation Area and Designated Conservation Area/Count Based Hybrid based fish and wildlife populations.
18 November 2019	WDNR	TAC Members	TAC members presented and discussed project concepts for priority west shore of Green Bay project areas. A total of 26 priority project areas for the AOC were initially ranked

			by TAC members by overall project importance. TAC also discussed non-condition score metrics and how to incorporate those considerations into overall project scoring. Metric refinements were discussed overall.
12 December 2019	WDNR	TAC Members	WDNR, UW-Green Bay, and USFWS presented overall structure of the metrics and BUI progress evaluation plan to the TAC and discussed. Continued discussion about formally recommending BUI removal target language to WDNR. Presented priority project ranking results and revisions to project concepts/areas. TAC reached consensus on the removal of the Malchow/Olson project due to difficulty in acquiring private land under AOC program, but stressed that still an important overall priority area for AOC for other programs and initiatives to focus effort on. TAC members individually scored priority areas, habitat activities, impacts to priority populations, cost, feasibility, and cobenefits for each project.
30 January 2020	WDNR	TAC Members	WDNR, UW-Green Bay, and UFWS reviewed chapters of metric and BUI progress evaluation plan to the TAC and discussed. TAC unanimously recommended WDNR adopt the revised BUI target language for both BUIs. WDNR proposed a final draft MAL with 18 project areas based on several months of priority project ranking and discussion. TAC gained consensus on recommending this list of 18 projects be included in the management action list.
31 March 2020	UW-Green Bay	TAC Members	TAC members recommended WDNR adopt the "Evaluating Progress Toward Removing Fish and Wildlife Beneficial Use Impairments in the Lower Green Bay & Fox River Area of Concern" plan and continued to refine and develop the 18 projects recommended for inclusion in the management action list.
7 May 2020	Zoom Virtual Meeting	AOC Stakeholders	WDNR will present the revised BUI removal target language and 18 project concepts the TAC has recommended for inclusion in the management action list to AOC stakeholders in the 2019 RAP Update Meeting for feedback.

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Appendix E

Investigation native mussel communities within nearshore habitats in the Lower Green Bay & Fox River. WDNR Natural Heritage Conservation Program 2020 Final Report

Investigating native mussel communities within nearshore habitats in the Lower Green Bay & Fox River

Project Period:
Project duration: June 1, 2018 through December 31, 2019

Principle Investigators
Jesse Weinzinger
Lisie Kitchel

Acknowledgements

Investigating native mussel communities within nearshore habitats in the Lower Green Bay & Fox River would not have been completed without the dedicated effort and commitment of the individuals acknowledged below. Funding for this project was provided by the Great Lakes Restoration Initiative.

Contributors: Jesse Weinzinger, Lisie Kitchel, Jacob Winkler, Terrell Hyde, Shari Koslowsky, Brenton Butterfield, Brianna Kupsky, Vic Pappas, Donalea Dinsmore, Ana Lindborg, Jay Watson, Andrew Hudak, Amy Wolf, Dan Graf, Sarah Bartlett, Brandon Falish, Cadie Olson, Sam Hoffman, Lisa Gaumnitz, and Jack Silverberg.

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Abstract

A total of 25 species of native unionid mussels (Bivalvia: Unionidae) are now catalogued within the Lower Green Bay & Fox River Area of Concern (AOC) and its adjacent waterbodies. During 2018 and 2019 field surveys, 14 species were cataloged at 34 sites from Ashwaubenon Creek, Duck Creek, Dutchman Creek, Fox River, Green Bay, Suamico River, and Wequiock Creek. We implemented initial timed sampling at 30 sites to provide an inventory on species presence-absence, demographics, and habitat associations. We also applied a semi-quantitative survey design at four sites where 2018 initial sampling found the highest abundance of living mussels. Among all searches, we identified and recorded 257 living individuals, representing eight species. An additional six species were identified as dead shell only. *Pyganodon grandis* and *Quadrula quadrula* were the most common species found and comprised nearly 67% of living individuals collected during the study. At semi-quantitative sites, mussel densities were lowest at Point au Sable (0.01m^2) and highest near Renard Island (0.18m^2). Similarly, we noted high mortality near Point au Sable and the East Shore by observing an abundance of dead shells from native mussels. The site near Renard Island had a replacement ratio of 3.11, suggesting the mussel population may be expanding in that area. Using random forest classification on our semi-quantitative sites, we modelled the presence-absence of mussels as a group (68.9% accuracy) to 16 habitat variables. Substrates comprised of sand, gravel, and silt were the most influential predictors of native mussel presence at a site. Although we did not quantify the abundance of dreissenid mussels, we suspect soft, silt-sand sediments allow burrowing by native freshwater mussels which discourages infestation and physically removes attached dreissenid mussels. Results of this study provide evidence of small, but stable populations of native mussels occurring in the AOC, primarily in soft and stable sediments. We also include a list of current contaminant levels in the AOC that are known to negatively affect species of native mussels. Lastly, we recommend management actions to better understand native mussel communities in the AOC and how to improve their current condition.

Introduction

Developing a fish and wildlife management and restoration plan for the Lower Fox River and Green Bay Area of Concern (AOC) requires synthesizing a variety of sources of background information. When the existing information needed for the conservation of biological diversity is not considered adequate for planning, a “biotic inventory” is conducted. The scope and intensity of biotic inventory efforts vary according to the size and ecological complexity of the properties involved, as well as the amount of existing information available. The inventory efforts in this project focused on rare species and high-quality examples of native mussel communities and included field surveys, as well as data collection, synthesis, and interpretation.

Knowledge of the suitable habitat and distribution of unionid mussels within the Lower Green Bay and Fox River AOC is lacking, which hinders the ability to manage their populations. An assessment on the status and distribution of native mussels provides much needed information on the following beneficial use impairments (BUIs): 1) Degradation of Fish and Wildlife Populations, 2) Degradation of Benthos, and 3) Loss of Fish and Wildlife Habitat. Information provided from this study provides stakeholders information to develop implementable habitat projects to sustain and recover unionid mussels within the Green Bay and Lower Fox River AOC.

Due to their varied life histories, sedentary nature, and relatively poor dispersal mechanisms, native mussel populations are susceptible to numerous biotic and abiotic stressors. For example, mussels are now recognized as the most sensitive organisms ever tested to the effects of ammonia (Augspurger et al. 2007, USEPA 2013). Limited occurrence of many unionid mussel species in the Lower Fox River and Green Bay may be partly related to chronic, low-level exposure to ammonia, toxic metals, and other contaminants. The Lower Fox River and Green Bay Area of Concern is contaminated with several lethal contaminants as a result of human activities. As benthic filter-feeding organisms, mussels are exposed to contaminants that are dissolved in water, associated with suspended particles and deposited in bottom sediments.

As native mussels continue to suffer from anthropogenic impacts, procedures will need to be implemented to protect and augment current populations. Models of mussel presence can inform best practices for land use and water quality to help preserve current populations and guide restoration efforts where mussels are known to have been negatively impacted. The goals of this study are: 1) Catalog the diversity and density of native mussels in the Lower Green Bay and Fox River Area of Concern, where a lack of published data exists; 2) Determine what, if any, hydrologic and habitat variables structure mussel communities in this area; and 3) Prioritize species, sites, and activities for conservation and management efforts, which will aid managers in restoring populations and communities within the Lower Green Bay & Fox River AOC. We also included a list of current water quality contaminant levels in waters of the AOC that are known to negatively affect species of native mussels.

Methods

Prior to fieldwork, a records search was conducted to determine if historical unionid mussel information exists for the Lower Green Bay & Fox River AOC. During the historical search, information was gathered from the Natural Heritage Conservation (NHC) invert atlas database and from contacts in the DNR - Bureau of Water Quality, US Fish and Wildlife Service (FWS), and UW-Green Bay (UWGB), to document further historical mussel records. Additionally, UW-Stevens Point (UWSP) MUSSELp database provided several additional presence records forthe project area. The museum records from the MUSSELp are primarily from the Academy of Natural Sciences, Illinois Natural History Survey, Milwaukee Public Museum (MPM) Mathiak specimens database, Museum of Comparative Zoology, Smithsonian, Ohio State Museum, and the University of Michigan. Since quantitative historical survey information is limited, the available data was used as an indicator of mussels that have been found in past surveys and not as an indicator of species abundance or species absence.

Mussel sampling was conducted at 34 sample sites throughout the AOC in 2018 and 2019 (Figure 1). Sampling occurred during summer and early fall (September and into October) when water temperatures were sufficient for surveys and mussels were still active. This period allowed mussels that were disturbed during sampling to re-establish themselves into the substrate.

Low water levels in Green Bay can expose nearshore mussels and increase their mortality. At the start of this survey, water levels in the bay were above their long-term average level and about 137 centimeters above the January - 2013 record low gage-heights. To maximize detectability in nearshore environments, we targeted survey locations with depths of least 152 centimeters within the bay or perennial stream reaches.

Initial 30-minute timed searches using SCUBA were first completed to assess suitability and presence of unionid mussels. Where habitat was determined suitable and contained living unionid mussels, we employed a semi-quantitative sampling procedure using transects (10 per site, 60 m in length). Based on the principle of spatially balanced sampling, a 600 m^2 search area helped maximize our probability of detecting species presence within a site (Smith 2006). Four semi-quantitative sites were selected for surveys. 16 additional timed searches were implemented in 2019 to compliment existing data.

Habitat parameters were collected at each timed and transect survey to establish mussel habitat associations within the AOC. Water depths, substrate types for detritus, clay, silt, sand, gravel, cobble/rubble, boulder and bedrock were recorded to the nearest 5%. Substrate types are visual or tactile estimates of substrate composition within the search area. Vegetation coverage of macrophytes (emergent and submergent) were recorded to the nearest 5%. Mean average water depth, water clarity, and mesohabitat was also estimated during searches. Definitions for each variable are defined under the guidelines for Sampling Freshwater Mussels in Wadable Streams (Piette 2005).

Once in place, divers tactically swept a transect width to remove fine substrates and reveal buried mussels. All transects were excavated up to a depth of 5cm to expose buried mussels. All unionid mussels found inside transect area were placed in a mesh bag numbered with the corresponding transect. Numbered bags were then handed to topside personnel for identification, and measurements for length, age, and shell wear noted.

To help determine what, if any, hydrologic and habitat variables structure mussel communities in the Lower Green Bay & Fox River, we developed and assessed a predictive habitat model. Specifically, we assessed whether a living mussel can be predicted at a given location based on substrate composition and other habitat variables. We chose a Random Forest with Classification (RF) for its ability to handle data sets with higher dimensionality. Further, the model outputs the importance of each habitat variable, which can help identify where mussels may occur elsewhere within the study area. Using an RF approach, many decision trees were created through bootstrapping. The model was run with a variety of trees grown. We settled to 401 decision trees to ensure that every variable gets simulated and predicted several times. We set the number of variables randomly sampled at each split to four to minimize our estimate of error. Data was split 60:40 into training data and test data. Each time a decision tree was produced, a random observation from our training data (n=24) was used to estimate the presence or absence of a freshwater mussel given the randomly selected four predictor variables. We evaluated the importance of a specific predictor by computing the increase of mean standard error (MSE) in prediction after the values of the variables in the samples used for testing were randomized. A higher increase in MSE indicates more importance. Each decision tree was randomly tested on 40% of observations (n=16). The response of mussel presence to a predictor was described with a partial-dependence plot. RF modelling was implemented using randomForest in R environment (RDevelopment Core Team 2018).

Our review of unionid mussel sensitivities from contaminants focused on available data on toxicity tests from mussel species that occur within the Lake Michigan Basin. Published results of testing on bioaccumulation, tissue distribution, uptake, elimination, detoxification and ecotoxicological effects of certain contaminants on juvenile and glochidia of native mussels were included in this report. We obtained water quality data from Northeast Wisconsin Water's Aquatic Monitoring Program (AWQMP) (Green Bay Metropolitan Sewerage District 2019) to examine current levels and trends of contaminants known to negatively affect species of native mussels found in Northeast Wisconsin. Of the 24 water quality parameters measured, we reviewed current levels of Ammonia, Chlorine, Cadmium, Copper, Mercury, and Zinc. Statistics on Ammonia and Chlorine represent average values during 1986 -2018 monitoring years from NEW Water AWQMP stations 16 and 22. Cadmium, Copper, Mercury, and Zinc measurements represent average concentrations during 1986 - 2015 monitoring years from NEW Water AWQMP stations 5, 13, 16, 41, and 51. All samples used for review were sampled one meter above the bottom of the AOC. Annual contaminant concentration results were averages among all stations sampled. Metal samples are taken twice a year and other contaminants were sampled May through October.

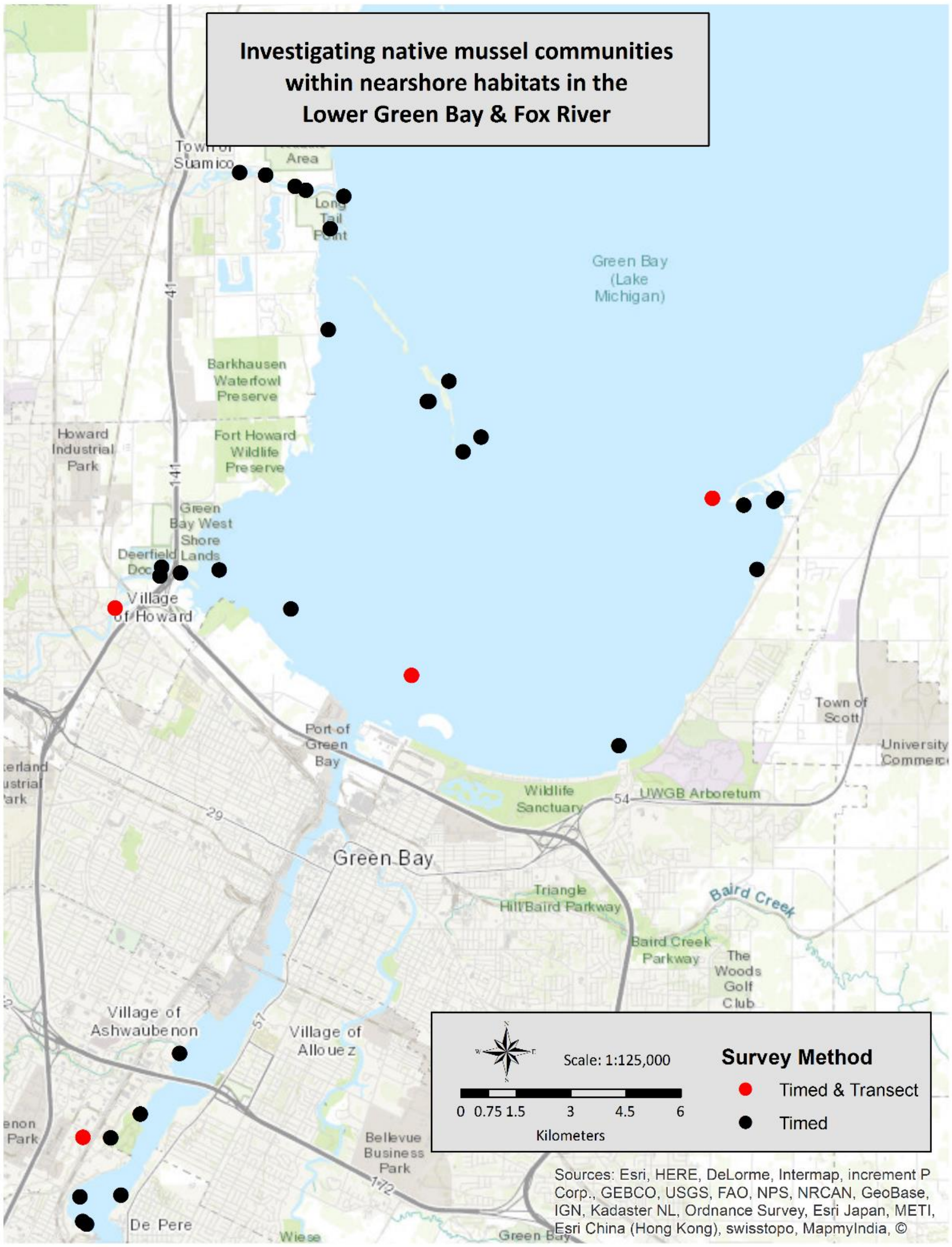

Figure 1. Freshwater mussel survey sites from 34 initial timed survey sites and four semi-quantitative transect survey sites within or near the Lower Green Bay & Fox River AOC project boundary, 2018 and 2019.

Results

Previous Mussel Work

Several surveys limited in scope and extent have been done in the Lower Fox River and Green Bay, but no known quantifiable surveys have ever been completed. Known historical records starting from 1924 up to this study, recorded 21 native unionid species found within or near the Lower Fox and Green Bay AOC. Most notably, a 1920's assessment observed *C. tuberculata* (purple wartyback) in the Lower Fox River (Baker 1928). This species was again recorded more recently, upstream on the Fox River near Kaukauna (EA Engineering 2006). Historically, the Fox River recorded the highest species diversity of living and dead individuals (16 species), followed by Green Bay, Duck Creek, Suamico River, Ashwaubenon Creek, East River, and Wequiock Creek (Table 1). No information was available for other tributaries of the AOC such as Mahon Creek, Baird Creek, or Dutchman Creek. Of the 21-mussel species documented historically, one species is considered state endangered, *C. tuberculata*, one species is threatened, *A. viridis* (slippershell), and two species of special concern, *A. marginata* (elktoe) and *Q. quadrula* (mapleleaf).

2018-19 Field Survey Results

During 2018-19 surveys, we visited 34 sites within the AOC. Thirty sites were surveyed following initial survey methodology and four sites were re-sampled using the semi-quantitative transect approach (Figure 1). We identified and recorded 257 living individuals, representing eight species (Table 2). An additional six species were identified as dead shell only; *E. dilatata* (spike), *L. cardium* (plain pocketbook), *L. recta* (black sandshell), *P. alatus* (pink heelsplitter), *T. truncata* (deertoe) and *U. imbecillis* (paper pondshell). *P. grandis* (giant floater) was the most commonly collected species by abundance with over 37% of the total catch followed by *Q. quadrula* (mapleleaf) at 29% of all observations (Table 2).

The three waterbodies intensively surveyed using transects held a unique species assemblage. Green Bay sites primarily consisted of *Q. quadrula*, *A. plicata* (threeridge), and *T. parvum* (lilliput). Whereas, Ashwaubenon Creek's mussel community primarily consisted of *P. grandis* and Duck Creek's most common mussel species was *L. fragilis* (fragile papershell) and *P. grandis*. Eleven of the 14 species recorded during all surveys were found in Green Bay, while seven species were recorded in Duck Creek and five mussel species in Ashwaubenon Creek (Table 3). All 26 specimens of *A. plicata* and 70 of the 75 *Q. quadrula* were found in Green Bay.

Sites on Dutchman and Wequiock Creeks, and Fox, and Suamico Rivers were added to 2019 timed searches. All four waterbodies had *P. grandis* present, while Suamico River documented three other living species (*L. siliquoidea*, *L. fragilis*, and *Q. quadrula*).

Four species*, L. cardium, T. parvum, T. Truncata,* and *U. imbecillis* found during these surveys have not been previously documented in the AOC or in adjacent tributaries. These newly-recorded species bring the total historical species richness of the area to 25 (Table 1).

Relative abundance comparisons through time can indicate shifts in community composition but give no information about absolute abundances. Estimates of population and total mussel density do provide measures of absolute abundance by supplying information on numbers of individuals per unit area that can be compared through time. Total mussel density was highest at the Renard Island site (Table 4). Of the four semi-quantitative sites, the total live/dead ratios were highest at Renard Island (3.11) followed by Duck Creek (1.84) and Ashwaubenon Creek (1.47). All three sites exceeded the replacement value of 1. Point au Sable was not included for this analysis, as we did not quantify dead shells at the site. However, we observed a high abundance of dead shell material at Point au Sable. Therefore, we hypothesize the live/dead ratio would be below one and the lowest of the semi-quantitative sites surveyed. Although we cannot confidently explain the high mortality near Point au Sable, the coarse substrate and presence of dreissenid mussels may affect the survival of native mussel species. The four living *A. plicata* at the site were nearly encapsulated by dreissenid mussels.

During 2018-19 surveys, Ashwaubenon, Duck Creek, and Green Bay sites provided evidence of recruitment with the presence of living juvenile mussels. During semi-quantitative surveys at Ashwaubenon Creek, 29% of observed living mussels were less than four years old (Table 4). This suggests current water quality at this site can help sustain a reproducing population of native mussels. Although all juveniles in Ashwaubenon Creek were *P. grandis*, a species considered tolerant of poor water quality relative to other native mussel species, we also found a five-year-old *Q. quadrula* and a six-year-old *L. complanata* (white heelsplitter). Two of the 35 living mussels from Duck Creek were juveniles (Table 4). Three species of juvenile mussels were observed at sites within Green Bay, including *P. grandis, L. fragilis, and L. siliquoidea. Q. quadrula* and *T. parvum* were recorded at ages four and five, respectfully (Figure 2). Sizes ranged from a 24mm, four-year-old *Q. quadrula* to a 142mm, six-year-old *P. grandis*. The four most common species observed were plotted to analyze species growth patterns (Figure 3). We used a logarithmic trendline to illustrate predicted animal growth over time. Of the four species, *P. grandis* growth rates show significant growth in length during juvenile ages, but level out at an early age relative to *Q. quadrula, L. fragilis*, and *A. plicata,* which is typical of *P. grandis.* The maximum sampled age for *P. grandis* within the AOC was 10 years old, compared to *Q. quadrula* (17), *L. fragilis* (12), and *A. plicata* (28).

Habitat Model

For mussel presence-absence, the selected Random Forest (RF) model (mtry = 4) had an OOB error of 12.5%. Nearly 95% percent of the sample units where mussels were recorded during the field survey were correctly predicted. In comparison, 33.3% of the sampling units where no mussels were recorded were correctly predicted, likely due to a low sampling effort in the training model (n=24). The plot indicates that after 150 decision trees, there is not a significant reduction in error rate (Figure 4). Testing the model, our test data resulted in 68.8% accuracy, (41 - 89%, CI 95%), with a sample effort of n=16. P-value indicates a non-significant result, $p = 0.81$.

Multiple environmental variables appeared to contribute to presence–absence of mussels at a site. We focused on those ranked as the top three based on % Mean Standard Error (MSE) increase in the RF model. Substrate_Sand was the most important predictor to mussel presence in the AOC, followed by Substrate_Gravel and Substrate_Silt (Figure 5). Prediction power from RF was maximized when sand and silt each comprised of nearly 50% substrates (Figure 5). The presence of gravel also showed an importance at low percent cover.

Water Quality

There is scant information on the acute and chronic effects from several contaminants on unionid mussels. A literature review indicates that the early life-stages of freshwater mussels are acutely sensitive to copper and ammonia compared to other aquatic life (Wang et al. 2007). Of the water quality parameters evaluated for this study, copper and ammonia concentrations in the AOC are near acute negative concentrations for select mussels found in the Lake Michigan Basin when exposed to the toxins for extended time durations (Table 4). Prior to 1992, zinc concentrations within the water of the AOC regularly exceeded levels known to be lethal to *U. imbecillis* (paper pondshell). Average ammonia concentrations periodically exceed the LC50 concentration for *Villosa iris* (rainbow), most recently in 2012 (Figure 6). Although, *V. iris* is not expected to occur in the AOC, it occurs in Lake Michigan tributaries and may be representative of other mussel species in the AOC which have not been studied. Of the 6 water quality parameters reviewed, mercury, zinc and ammonia concentrations appear to be declining, while cadmium, copper, and chloride have not changed significantly since 1986 (Figure 6).

Table 1. Species richness of documented native mussels for the Lower Fox River and Green Bay AOC and some of its tributaries. H = historic references, prior to 2018, R = recent surveys, 2018 and 2019.

Species	State Status	Ashwaubenon Creek	Duck Creek	East River	Fox River	Green Bay	Suamico River	Wequiock Creek	Dutchman Creek
Actinonaias ligamentina			H			H			
Alasmidonta marginata	SC/P					H			
Alasmidonta viridis	THR		H				H		
Amblema plicata			H		H	H;R			
Anodontoides ferussacianus			H			H	H		
Cyclonaias tuberculata	END				H				
Elliptio dilatata			H;R		H	H;R	H		
Fusconaia flava			H;R		H	H;R	H;R		
Lampsilis cardium						R		R	
Lampsilis siliquoidea			H;R		H;R	H;R	H;R	R	
Lasmigona complanata		R	H;R		H	R	H;R		
Lasmigona compressa			H		H		H		
Lasmigona costata					H	H			
Leptodea fragilis		R	R		H;R	H;R	H;R	R	
Ligumia recta					H	R			
Obliquaria reflexa					H				
Pleurobema sintoxia						H	H		
Potamilus alatus					H;R	H	R		
Pyganodon grandis		H;R	H;R	H	H;R	H;R	H;R	H;R	R
Quadrula pustulosa					H	H			
Quadrula quadrula	SC/P	R	H;R		H;R	H	R		
Strophitus undulatus			H		H	H	H		
Toxolasma parvum			R			R	R		
Truncilla truncata							R		
Utterbackia imbecillis		R							
Richness		**5**	**14**	**1**	**16**	**19**	**15**	**4**	**1**

Table 2. List of unionid species and their relative live abundance found during AOC surveys during 2018 & 2019 field seasons.

Species	Rank	Total # Live Abundance	Proportion	Accumfreq
Pyganodon grandis	1	97	37.7	37.7
Quadrula quadrula	2	75	29.2	66.9
Leptodea fragilis	3	27	10.5	77.4
Amblema plicata	4	26	10.1	87.5
Toxolasma parvum	5	20	7.8	95.3
Lampsilis siliquoidea	6	9	3.5	98.8
Fusconaia flava	7	2	0.8	99.6
Lasmigona complanata	8	1	0.4	100
Elliptio dilatata	9	0	0	100
Lampsilis cardium	10	0	0	100
Ligumia recta	11	0	0	100
Potamilus alatus	12	0	0	100
Truncilla truncata	13	0	0	100
Utterbackia imbecillis	14	0	0	100

Table 3. List of unionid species and their relative abundance separated by waterbody during AOC surveys during 2018 and 2019 field seasons "x" represents individuals found by dead shell only.

Species	Ashwaubenon Creek	Duck Creek	Dutchman Creek	Fox River	Green Bay	Suamico River	Wequiock Creek
Amblema plicata					26		
Elliptio dilatata		x			x		
Fusconaia flava					2	x	
Lampsilis cardium					x		x
Lampsilis siliquoidea		3		x	5	1	x
Lasmigona complanata	1	x			x		
Leptodea fragilis	1	15		x	9	2	x
Ligumia recta					x		
Potamilus alatus				x		x	
Pyganodon grandis	64	14	1	5	5	7	1
Quadrula quadrula	3	1		x	70	1	
Toxolasma parvum		2			18	x	
Truncilla truncata						x	
Utterbackia imbecillis	x						

Table 4. Richness, abundance, and densities for each 2018 semi-quantitative site. Replacement ratio and % Juveniles observed includes all surveys within a given waterbody or site.

Site	Richness	Abundance	Density (m^2)	Replacement Ratio	% Juvenile
Ashwaubenon Creek	4	66	0.11	1.47	29
Duck Creek	2	12	0.02	1.84	5.7
GB - Kidney Island	7	109	0.18	3.11	0
GB - Point au Sable	1	4	0.01	NA	0

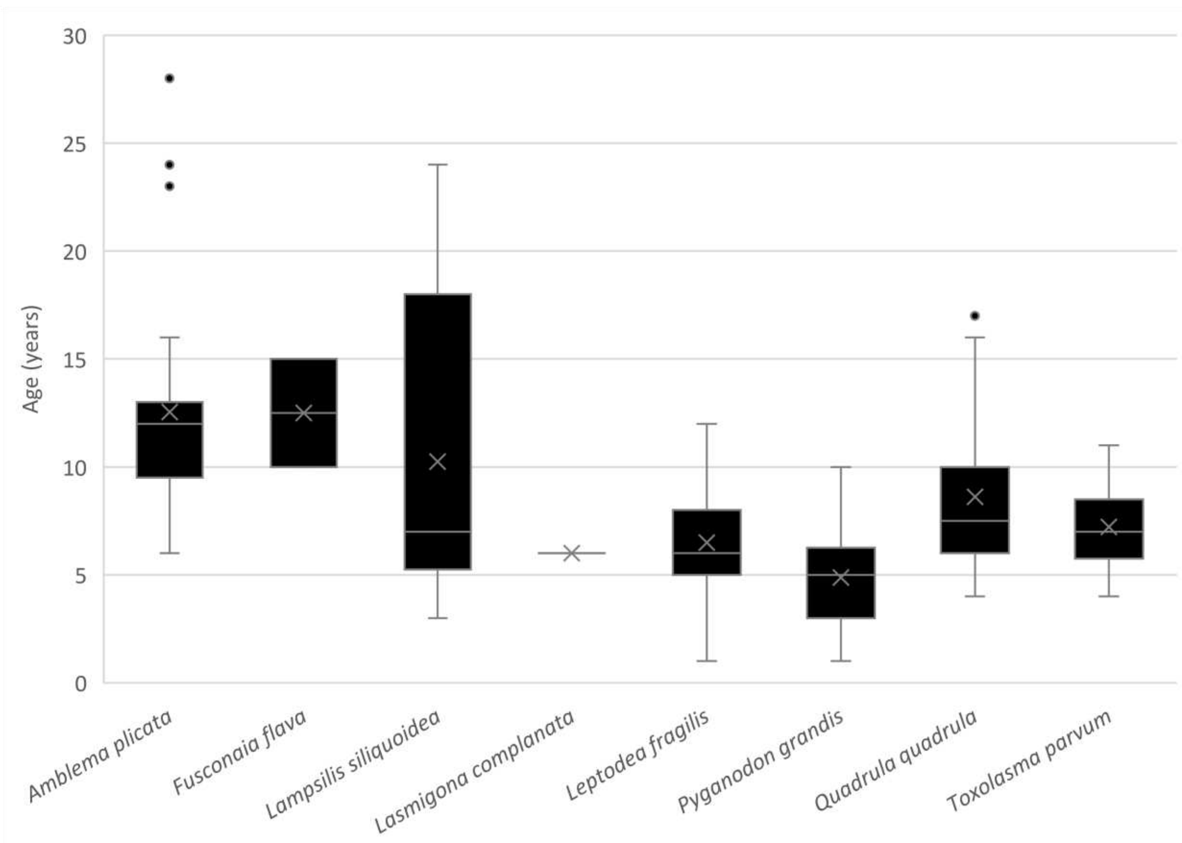

Figure 2. Box plots showing the age distributions of live unionid mussel species observed during AOC surveys during 2018-19 field seasons.

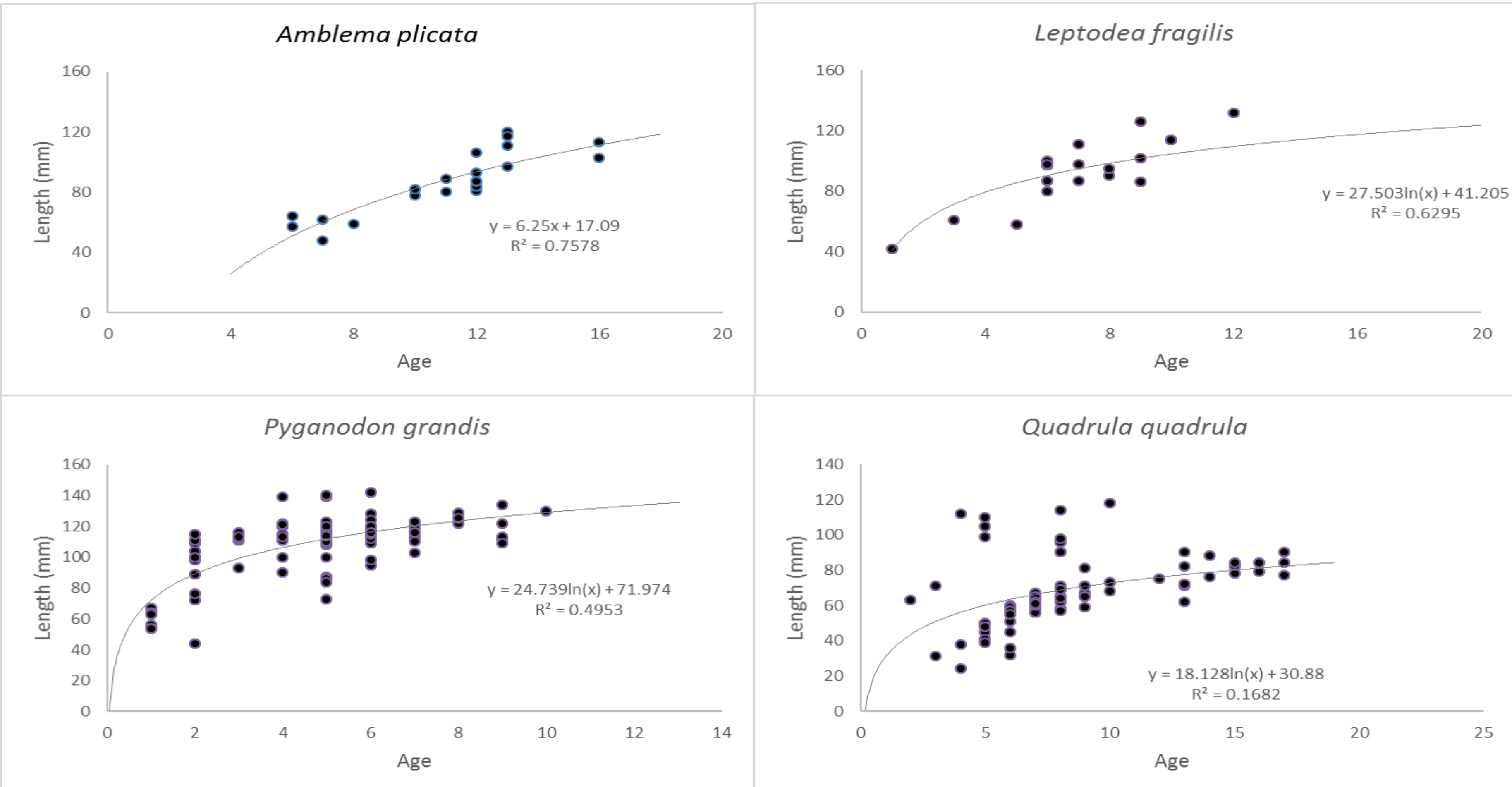

Figure 3. Scatter plots of length vs age for four species of mussels collected during 2018 and 2019 AOC sampling. All mussels were measured and externally aged in the field.

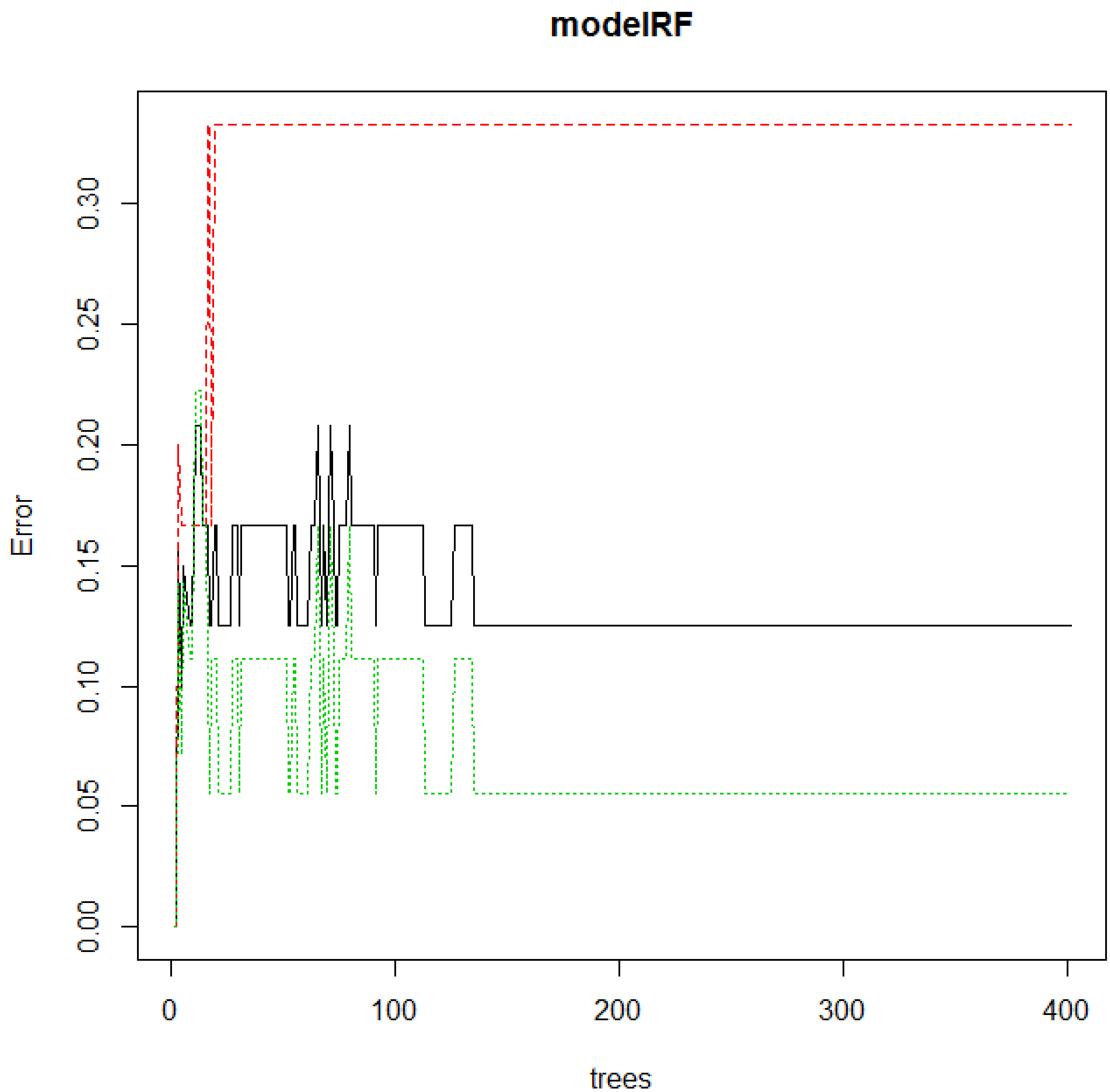

Figure 4. Random Forest Out-Of-Bag (OOB) error rate constructed after running 401 trees. The red curve is the error rate for predicting mussel absence and the green curve is the error rate for predicting mussel presence.

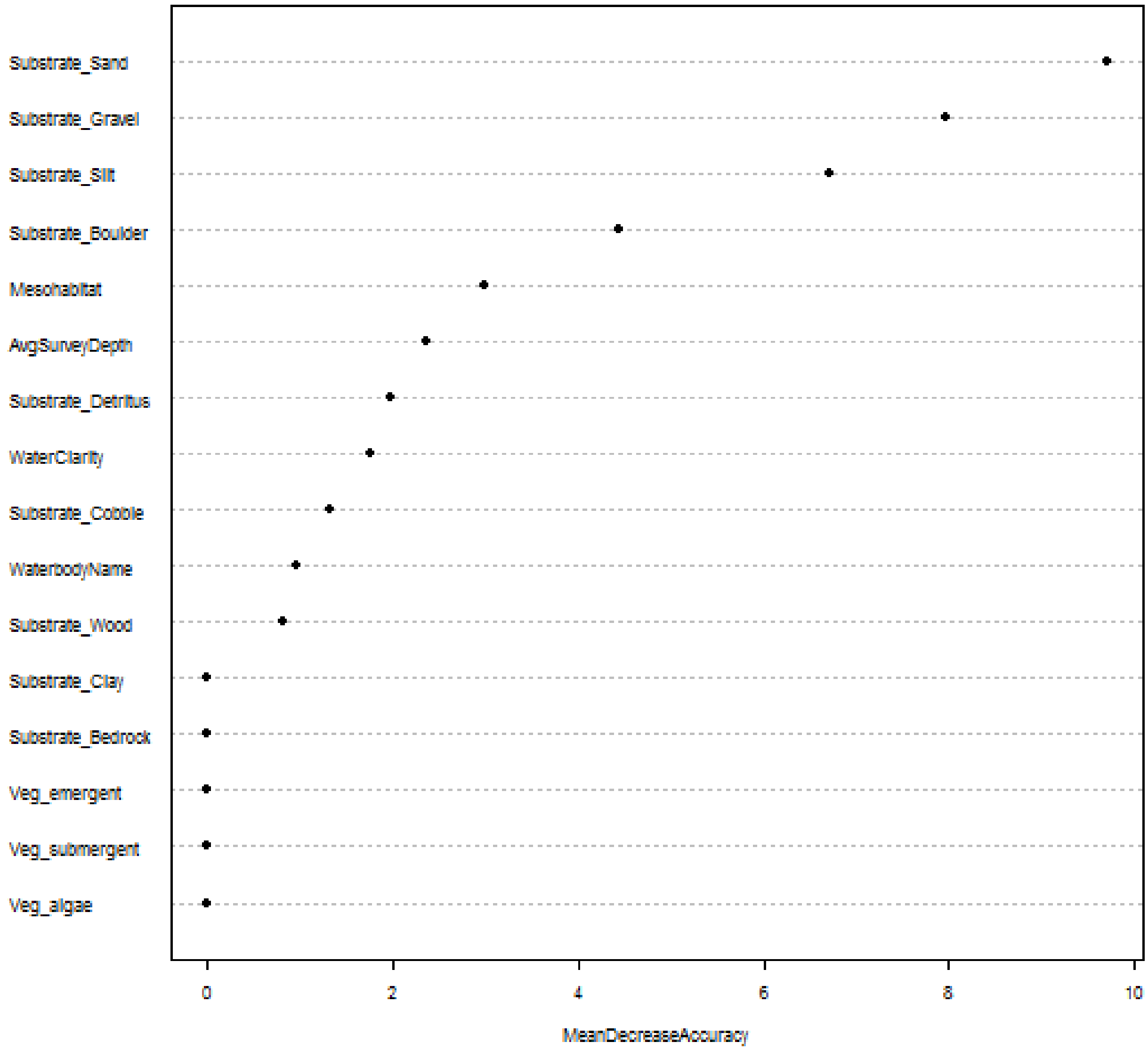

Figure 5. Importance values for the 16 environmental variables for predicting species presence in random forest classification estimated by Mean Standard Error.

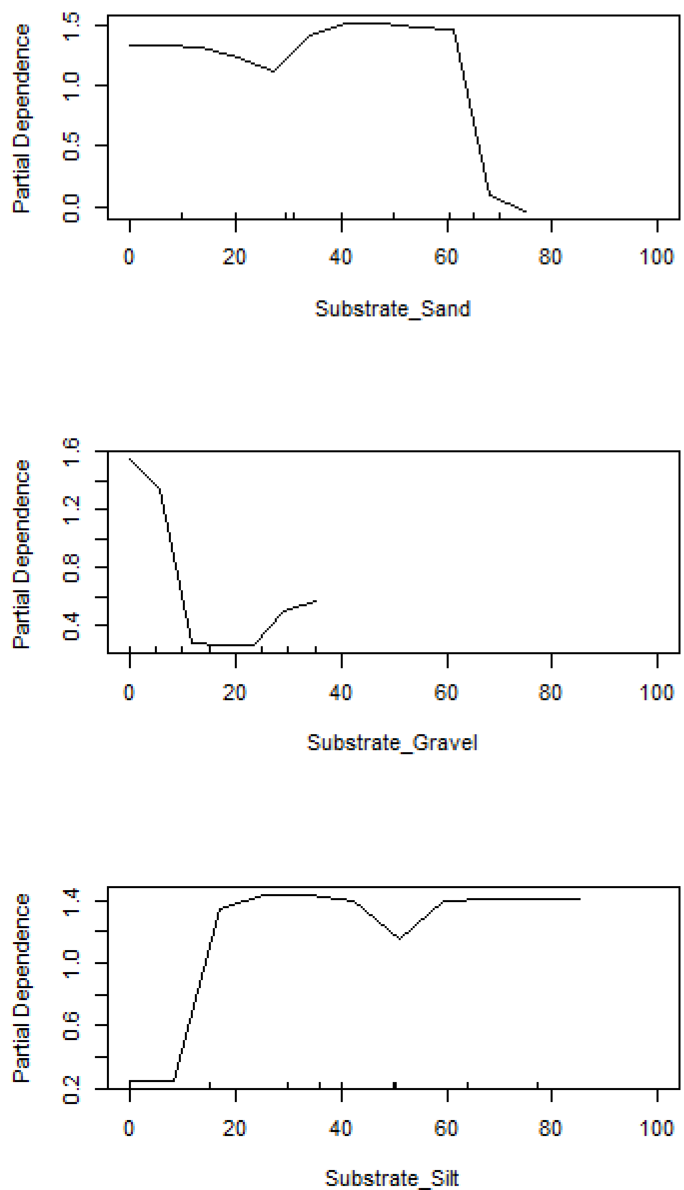

Figure 6. Partial dependence plots of the three most influential variables on predicting mussel presence with the random forest model for the Lower Fox River and Green Bay AOC.

Table 5. Results of acute toxicity studies exposing unionid mussels to various contaminants in the laboratory.

Species	Life Stage	Toxicant	Duration	LC/EC 50	Concentration	Unit	Reference
A. ligamentina	Glochidia	Ammonia	48 h	EC	7.7 - 8.3	mg/L	Wang et al. (2007)
L. siliquoidea	Juvenile	Ammonia	10 d	EC	2.4 - 3.1	mg/L	Wang et al. (2007)
P. ohiensis	Glochidia	Ammonia	48 h	EC	7.0 - 7.6	mg/L	Wang et al. (2007)
V. iris	Juvenile	Ammonia	96 h	LC	0.11	mg/L	Mummert et al. (2003)
L. cardium	Juvenile	Cadmium	48 h	LC	345	µg/L	Lasee (1991)
L. cardium	Juvenile	Cadmium	48 h	LC	141	µg/L	Lasee (1991)
L. cardium	Juvenile	Cadmium	48 h	LC	166	µg/L	Lasee (1991)
L. siliquoidea	Glochidia	Copper	48 h	EC	14 - 15	µg/L	Wang et al. (2007)
L. siliquoidea	Juvenile	Copper	10 d	EC	7.3 - 8.9	µg/L	Wang et al. (2007)
P. grandis	Glochidia	Copper	24 h	LC	160	µg/L	Jacobson et al. (1997)
P. ohiensis	Glochidia	Copper	48 h	EC	12.0 - 13	µg/L	Wang et al. (2007)
V. iris	Glochidia	Copper	24 h	LC	32-107	µg/L	Jacobson et al. (1997)
V. iris	Glochidia	Copper	48 h	LC	33-69	µg/L	Jacobson et al. (1997)
A. imbecilis	Juvenile	Copper sulfate	48 h	LC	388	µg/L	Keller and Zam (1991)
A. imbecilis	Juvenile	Copper sulfate	96 h	LC	199	µg/L	Keller and Zam (1991)
P. grandis	Juvenile	Copper sulfate	24 h	LC	44	µg/L	Jacobson et al. (1993)
V. iris	Glochidia	Mercury	24 h	LC	107	µg/L	Valenti et al. (2005)
V. iris	Glochidia	Mercury	48 h	LC	39	µg/L	Valenti et al. (2005)
V. iris	Glochidia	Mercury	72 h	LC	14	µg/L	Valenti et al. (2005)
V. iris	Juvenile	Mercury	21 d	EC	8	µg/L	Valenti et al. (2005)
L. siliquoidea	Glochidia	Sodium chloride	24 h	EC	135-189	mg/L	Gillis (2011)
A. imbecilis	Juvenile	Zinc sulfate	48 h	LC	88	µg/L	Keller and Zam (1991)
A. imbecilis	Juvenile	Zinc sulfate	96 h	LC	438	µg/L	Keller and Zam (1991)

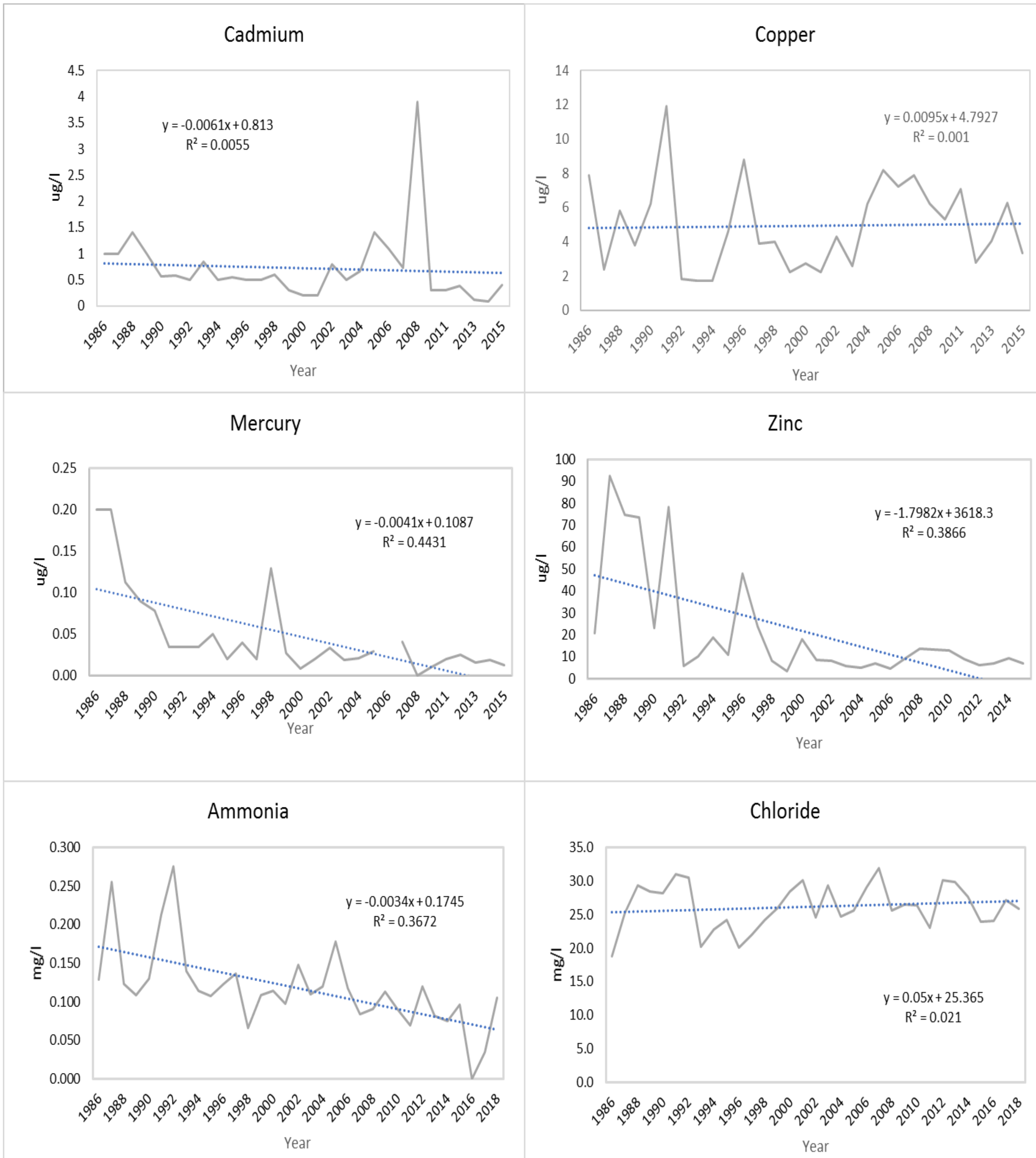

Figure 6. Annual average concentrations of six contaminants that are known to negatively impact unionid mussel populations. Data extracted from NEW Water's Aquatic Monitoring Program.

Discussion

Despite widespread freshwater mussel surveys throughout Wisconsin, there is little information on the presence of native mussels in the Lower Fox River and Green Bay Area of Concern (AOC). Previous records helped establish an inventory of which mussel species occured within the study area, but these records lack quantitative results to compare temporal trends. Though this study serves as a baseline assessment of native freshwater mussels in the AOC, it also provides the most comprehensive analysis of freshwater mussels to-date, providing a basis for examining further factors that may influence the distributions of this taxon at multiple scales.

Historical information gathered for the AOC and its adjacent waterbodies provides documentation on 21 species of freshwater mussels, including four state listed species. The lower Fox River and Green Bay contained 20 of the 21 species, with *A. viridis* (slippershell) only reported from tributaries. During 2018-19 surveys, we recorded 14 species of unionid mussels, eight of which were live specimens. The community structure within the AOC had a characteristically low evenness and typically was dominated by a few species. Overall, nearly 67% of the total abundance comprised of two species; *P. grandis* and *Q. quadrula*. However, this is not unusual as the Great Lakes Basin has low evenness characteristically compared to the Mississippian and Eastern Gulf regions of the U.S. (Haag 2012). Densities at our four semi-quantitative sites are similar and consistent with reported densities in the Great Lakes (McGoldrick et al. 2009, Crail et al. 2011). Reasons for one or two taxa dominance are unknown but could include a combination of factors including habitat preferences, availability of host organisms, physical and chemical factors, food availability and water temperature.

Although our random forest model does not significantly predict the presence-absence of unionid mussels in the AOC, results do provide some insights into mussel occurrence. Sites where live unionids occurred contained substrates composed primarily of sand and silt and these variables were most important to maximizing the predictability of occurrence model. Partial dependence plots showed the maximum dependence of sand and silt each when comprised of nearly 50% substrate cover at a given site. Gravel cover was also an important predictor of mussel presence. However, gravel and other course substrates may have once been a more significant predictor to mussel presence before the introduction of dressenid mussels. Previous habitat studies with both dreissenid and unionid mussels present describe soft benthic substrates as a key to unionid survival because these substrates act as a mechanism for unionids to avoid or remove dreissenid mussels via burrowing and prevent fouling (Bowers and de Szalay, 2004, Sherman et al. 2013). This may help explain why fouling was higher along east shore sites as the firm substrate composition may have inhibited unionids from burying themselves sufficiently to dislodge or suffocate dreissenid mussels. We did not quantify the presence of dreissenid mussels during our study, but we did note that dreissenid abundance appeared to be higher in areas with coarse substrates.

Studies suggest some unionid species are more likely to survive dreissenid fouling than others (Haag et al. 1993, Strayer and Smith 1996). In addition to burrowing capabilities, explanations for unionid tolerance to mortality caused by dressenid mussels include: high shell robustness, short brooding periods, high fecundity, early age of reproduction, and short life spans (Haag 2012). Robust shells and short-term brooding periods of *A. plicata, Q. quadrula,* and *F. flava* may give them some resilience to dreissenid fouling. While the high fecundity, early age of reproduction, and short life spans of *L. fragilis* and *P. grandis* may allow their populations to remain present in the AOC. Host-fish abundance may have contributed to their persistence as well; *P. grandis* is a host generalist and *L. fragilis* appears to be dependent on freshwater drum, a common species in the AOC (Watters et al. 2009).

Overall replacement ratios and juvenile presence within the study area suggests mussels are slowly recolonizing areas of the AOC where they may not have occurred recently. Reasons for the high replacement ratios in Ashwaubenon Creek, Duck Creek, and the semi-quantitative site at Renard Island cannot be fully determined. However, habitat suitability and gradual improvements in some water quality parameters may explain increased survival. Sites along the East Shoreline and Point au Sable, where coarse substrates occur, show an increase of dead shell material from native mussels.

Several contaminants known to negatively impact freshwater mussels are present within the AOC. While this study did not investigate the complex nature of exposure rates, some contaminants such as ammonia and copper are near concentrations known to be toxic to freshwater mussels. Historically the AOC had extremely high ammonia levels which may have limited reproduction in the mussels occurring there (WDNR 1993). For many other contaminants present in the AOC, chronic exposure rates are unknown as to their effects on native mussels. However, it is suspected waterborne contaminant levels have contributed to the decline of mussel populations in the past, as well as contaminated sediments (Sparks and Strayer 1998, Strayer and Malcom 2012). Further investigation into the sensitivity of mussels to long-term exposure of certain contaminants should be considered.

Management Recommendations

The most fundamental long-term goal of mussel conservation within the AOC is to increase the amount of occupied mussel habitat and mussel assemblage, and stream connectivity so species can sustain localized catastrophic events and adapt to more subtle but longer-term environmental changes. As such, water quality improvements, stream restoration and reintroduction of mussel assemblages should be the primary focus for management efforts to improve the occurrence and condition of native mussels. Below are recommended future management actions for native mussel populations within the AOC.

Define habitat requirements at multiple spatial scales in the AOC

This study associated mussel presence to habitats containing silt, sand, and detritus. Sonar habitat mapping to delineate variations in substrate bedforms would help identify suitable habitat for native mussels and other targeted aquatic animals. Managers could utilize resulting benthic maps to conduct a stratified mussel survey to assess mussel–habitat associations at multiple scales. By focusing on the delineation of habitat types, and then sampling for mussels within each habitat, we can map and quantify habitat types and assess mussel–habitat associations. Results would also allow managers to focus on highly suitable habitats for future augmentation or reintroduction efforts. Predicted mussel occurrence within the AOC favors substrates with a mixture of silt, sand, and the presence of detritus.

Dreissenid mussels are suspected to increase unionid mussel mortality in areas of coarse substrates within the AOC. Further studies identifying refuge sites are needed to better understand the factors responsible for unionid survival in the AOC. Such information can be used to predict the locations of natural sanctuaries and to guide their management for the preservation of the unionid fauna.

Research to aid conservation and management

The Lower Fox River & Green Bay AOC has a long history of high levels of toxic effluents and water quality and habitat degradation from a century of industrial use and waste disposal. Although there have been studies on the acute effects of metals on mussels, there is scant information on the chronic effects of metals on adult mussels to assess the threats of long-term stressors on mussel populations. Yet, the effects of metals and other contaminants on feeding, growth and reproduction could significantly affect mussel populations. The largest data gaps pertain to the effects of sublethal contaminant concentrations on processes such as reproduction and growth. An assessment of sediment samples from the AOC, including metals, organic pollutants, on un-ionized ammonia, dissolved oxygen, and other contaminants in the AOC are needed to determine if levels are acute or chronically toxic to freshwater mussels at all life stages and the benthic community.

Restore abundant and diverse mussel populations until they are self-sustaining

Freshwater mussels are generally long-lived, slow growing, with complex life-histories. Once populations have declined, it can take decades for species to recolonize in areas of restored habitat. Consequently, a species restoration strategy may be necessary to jump-start species recovery in the AOC. As a result, propagation can be a key conservation management strategy for restoration and recovery of freshwater mussels into the future.

Several contributing factors responsible for the decline of mussel diversity in the AOC have been addressed that include habitat loss and alteration, pollution, and loss of fish hosts. However, other impacts such as competition with invasive species and sediment toxicity still need to be investigated further before determining whether controlled propagation is a key restoration strategy. All goals, objectives, and impacts for a restoration strategy should be detailed in a Species Propagation and Restoration Plan and written by a dedicated planning team (Patterson et. al. 2018).

A clear set of criteria should be established for assessing habitat suitability for supporting all life stages of each species considered for propagation, including substrate conditions, the presence of suitable fish hosts, water quality, and food availability. This study suggests surviving mussels are more present in substrates with mixtures of silt and sand, and may be influenced by lack of dressenid mussels in this type of habitat. Areas of these substrate conditions should be considered for mussel recovery efforts, especially in areas with high concentrations of host fishes.

Assessment of survival at various life stages of native mussels is needed before the full potential for reintroduction of mussels to the AOC is pursued. Mussels have limited mobility, making them highly susceptible to toxic contaminants in the water column or sediment. A field bioassay using captive mussels in 'silos' or comparable structures can help determine if there is a difference in the survival and growth of the mussels in different defined areas of the AOC. Areas of silt, sand, and detritus should be targeted to allow for the best survival opportunity of propagated mussels. Managers should also consider silos in areas of the Fox River where dredge and cap activities have been completed, although 2019 searches noted widespread areas of sediment deposition on the Fox River below the De Pere Dam. Survival and growth at each silo can be monitored on a regular basis through a single growing season, or longer if necessary. If individuals survived and grew comparable to either a controlled sample or estimated length, then managers could conclude that water quality and habitat suitability is adequate to sustain a population of freshwater mussels and may support their reintroduction.

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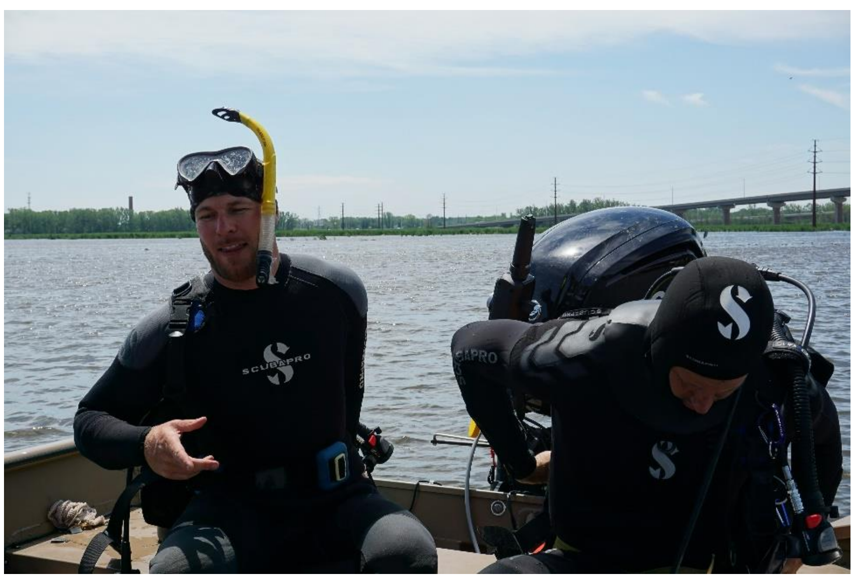
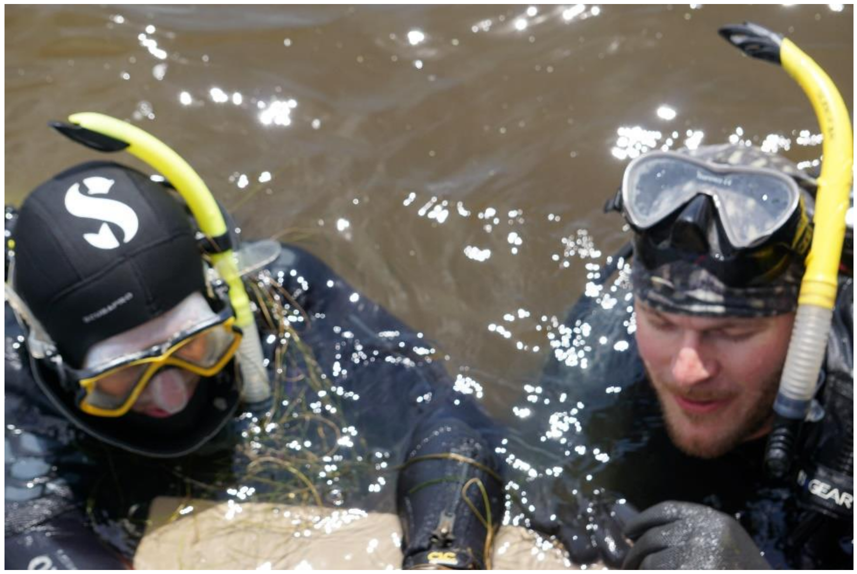
Appendix

Appendix A. Survey site locations given WGS84 map datum in decimal degree format.

Waterbody	Station	Year	Latitude	Longitude	Sampling Strategy
Ashwaubenon Cr.	Ashwaubenon Cr. 1	2018	44.46999	-88.05732	Timed
Ashwaubenon Cr.	Ashwaubenon Cr. 2	2018	44.46584	-88.06458	Timed
Ashwaubenon Cr.	Ashwaubenon Cr. 3	2018	44.46591	-88.07137	Timed & Transect
Duck Creek	Mouth	2018	44.56416	-88.05247	Timed
Duck Creek	Velp Bridge	2018	44.55855	-88.06347	Timed & Transect
Green Bay	East Shore 1	2018	44.53449	-87.93990	Timed
Green Bay	East Shore 2	2018	44.56529	-87.90598	Timed
Green Bay	East Shore 3	2018	44.57654	-87.90923	Timed
Green Bay	Renard Island	2018	44.54676	-87.99076	Timed & Transect
Green Bay	Long Tail Point 1	2018	44.59468	-87.98647	Timed
Green Bay	Long Tail Point 2	2018	44.59468	-87.98687	Timed
Green Bay	Long Tail Point 3	2018	44.58588	-87.97815	Timed
Green Bay	Long Tail Point 4	2018	44.58844	-87.97369	Timed
Green Bay	Long Tail Point 5	2018	44.59823	-87.98161	Timed
Green Bay	Point au Sable	2018	44.57775	-87.91692	Timed & Transect
Dutchman Creek	Mouth	2019	44.48060	-88.04768	Timed
Fox River	De Pere Dam 1	2019	44.45071	-88.07050	Timed
Fox River	De Pere Dam 2	2019	44.45551	-88.07213	Timed
Fox River	De Pere Dam 3	2019	44.45581	-88.06207	Timed
Fox River	De Pere Dam 4	2019	44.45117	-88.07148	Timed
Green Bay	Deadhorse Bay 1	2019	44.62487	-88.01075	Timed
Green Bay	Deadhorse Bay 2	2019	44.60720	-88.01123	Timed
Green Bay	Peats Lake 1	2019	44.56570	-88.05208	Timed
Green Bay	Peats Lake 2	2019	44.56469	-88.04748	Timed
Green Bay	Peats Lake 3	2019	44.56523	-88.03799	Timed
Green Bay	Peats Lake 4	2019	44.55839	-88.02038	Timed
Green Bay	Point au Sable	2019	44.57775	-87.91692	Timed
Suamico River	Suamico River 1	2019	44.63467	-88.03297	Timed
Suamico River	Suamico River 2	2019	44.63421	-88.02655	Timed
Suamico River	Suamico River 3	2019	44.63227	-88.01938	Timed
Suamico River	Suamico River 4	2019	44.63156	-88.01667	Timed
Suamico River	Suamico River 5	2019	44.63049	-88.00741	Timed
Wequiock Creek	Wequiock Bridge 1	2019	44.57722	-87.90189	Timed
Wequiock Creek	Wequiock Bridge 2	2019	44.57769	-87.90115	Timed

Appendix B. Photos taken by Jack Silverberg during mussel surveys on Lower Green Bay, June 25, 2019.



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Appendix F

Non-Point Source Runoff Storage Capacity Opportunities for Sediment and Nutrient Reduction in the Lower Fox River Basin. Outagamie County Land Conservation Department 2020 Final Report.

Non-Point Source Runoff Storage Capacity Opportunities for Sediment & Nutrient Reduction in the Lower Fox River Basin

Project Summary

Photo Credit: James Wochos

March 2020

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Non-Point Source Runoff Storage Capacity Opportunities for Sediment & Nutrient Reduction in the Lower Fox River Basin

Project Summary

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March 2020

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Executive Summary

The Lower Fox River Basin is a 638 square mile basin located in Northeast Wisconsin. It encompasses Brown, Calumet, Outagamie and Winnebago Counties. The Lower Fox River empties the Wolf River and Upper Fox River basins which drain approximately 6,349 square miles.

The Lower Green Bay & Fox River were designated as a Great Lakes Area of Concern (AOC) in 1987. The Lower Green Bay-Fox River AOC was identified as facing the Eutrophication or Undesirable Algae beneficial use impairment (BUI) due to land use changes in the Fox-Wolf Basin that have resulted, in part, in a significant nutrient and sediment loading to the AOC. In addition to the land use change from woodlands and oak savannah to agriculture and urbanization, several of the watersheds in the region have experienced substantial conversion of wetlands and as such, these watersheds have lost the associated water storage capacity services these wetlands historically provided, leading to an increase in sediment and nutrient runoff, the flashiness of streams, and streambank erosion.

The water storage capacity analysis quantifies the amount of water storage capacity needed to return to pre-settlement land use runoff conditions. This analysis data will guide the implementation of conservation practices that will permanently restore water storage capacity while trapping sediment and phosphorus. Additionally, the data will help site other conservation practices on the landscape to where they will have the best benefit.

The main takeaways of the analysis are described below:

- The Stage II Remedial Action Plan identified 11 confirmed and 2 suspected BUIs out of the list of 14. Nutrient and sediment pollution stemming from point and nonpoint sources and transported to the AOC contributed to the listing of 8 of the 13 BUIs
    - Eutrophication or Undesirable Algae
    - Beach Closings
    - Degradation of Aesthetics
    - Restrictions on Drinking Water Consumption, or Taste and Odor Issues
    - Degradation of Phytoplankton and Zooplankton Populations
    - Degradation of Benthos
    - Degradation of Fish and Wildlife Populations
    - Loss of Fish and Wildlife Habitat
- Given the magnitude of impact water quality plays on the ability to make progress and eventually delist the Area of Concern, WDNR has spent several years working with AOC stakeholders to identify how to make a meaningful contribution to ameliorate the eutrophication issues in the basin consistent with the scope of the program.
- Preliminary results from the Plum Creek Sediment Fingerprinting study have shown that streambank erosion is a significant source of total phosphorous and total suspended solids in Plum Creek (Fitzpatrick et al. 2019), indicating that a combination of practices that increase water holding capacity and streambank stabilization are necessary in the Lower Fox River Basin to realize meaningful improvements in water quality.

- In 2016, WDNR and USEPA determined that a set of 5 structural best management practices (BMPs) had characteristics consistent with other AOC management actions. The 5 BMPs include: Agricultural Runoff Treatment Systems (ARTS), Wetland Creation/Enhancement/Restoration, Streambank Protection/Stabilization, Two-Stage Ditches, and Saturated Buffers.
    - ARTS provide the most opportunity to store water and reduce downstream flow rates, thereby also reducing streambank erosion and the need for streambank stabilization practices. An Agricultural Runoff Treatment system is similar to a storm water pond in that it will be designed to retain water and settle out sediment. ARTS are designed with wetland cells that mimic wetland functions.
- From 2017-2018, WDNR and technical experts estimated the total amount of opportunity in the basin to implement the 5 AOC-like practices and found that implementation could result in significant reductions in sediment and nutrient runoff.
- In 2019, WDNR partnered with Outagamie County to better refine where the structural practices were most needed by analyzing the water storage capacity needs for 17 of 20 subwatersheds in the basin.
- This analysis identified that 2/3 of historically present wetlands in the basin have been converted to urban or agricultural land uses. An estimated 1.6 billion gallons of water storage capacity based on the MSE4 2-year rainfall event has been lost in the analyzed areas due to land use changes and loss of wetlands.
- If Agricultural Runoff Treatment Systems were implemented in each subwatershed analyzed to create water storage to mitigate the impacts of land use change and lost wetlands for the 2-year rainfall event, it would contribute to a 29% reduction in total phosphorus and 47% reduction in sediment in the Lower Fox Basin for a total estimated cost of $184,968,637.
- An acreage efficiency factor for ARTS was developed based on the estimated costs, phosphorus reduction, and ARTS area needed. This efficiency factor can be used to rank priority catchments within a HUC12 watershed to implement the ARTS practice.
- Going forward, additional methods of prioritization will be considered and conversations with WDNR, USEPA, and AOC stakeholders will occur to determine the order of magnitude of AOC-sponsored implementation of structural practices as part of a broader watershed implementation and funding strategy plan.

1.0 Introduction

The Lower Green Bay-Fox River Area of Concern (AOC) was identified as facing the Eutrophication or Undesirable Algae beneficial use impairment (BUI) due to land use changes in the Fox-Wolf Basin that have resulted, in part, in a significant nutrient and sediment loading to the AOC. In addition to the land use change from woodlands and oak savannah to agriculture and urbanization, several of the watersheds in the region have experienced substantial conversion of wetlands and as such, these watersheds have lost the associated water storage capacity services these wetlands historically provided, leading to an increase in sediment and nutrient runoff, the flashiness of streams, and streambank erosion. This transport of sediment and nutrients through the tributaries located in the Lower Fox River Basin (LFRB) to the Lower Fox River has also caused significant and persistent algal blooms that pose an aesthetic and human health risk in the AOC, resulting in large part to the listing of the Degradation of Aesthetics and Beach Closings BUIs in the Stage II Remedial Action Plan along with impacting 8 of the 11 confirmed and 2 suspected BUIs in Green Bay.

While a variety of best management practices are being implemented throughout several of the HUC12 watersheds in the LFRB, a need exists to implement BMPs that will permanently restore water storage capacity to 1) capture and store water during storm events, slowly releasing water to the streams, thus reducing flood events and flashiness of streams leading to reduced downstream streambank erosion and 2) capture sediment and phosphorus from upstream fields.

Preliminary results from the Plum Creek Sediment Fingerprinting study have shown that streambank erosion is a significant source of total phosphorous and total suspended solids in Plum Creek (Fitzpatrick et al. 2019), indicating that a combination of practices that increase water holding capacity and streambank stabilization are necessary in the LFRB to realize meaningful improvements in water quality. This is important because the aforementioned nutrient and sediment loads that were determined to be emanating from “Natural Areas” were attributed to the “agriculture” reduction in the LFRB Total Maximum Daily Load (TMDL). This combination of sources hides the fact that the water conveyance system in the LFRB is just as important to stabilize as the agriculture land. Therefore, the theme of this report is, if we can store and slowly release water from strategic subwatersheds of the LFRB, we have an opportunity to both capture and treat nutrient and sediment from non-point sources as well as reduce the erosive force of runoff on downstream receiving streams. What remains unclear is how much storage capacity each HUC12 watershed needs and where the greatest reduction in downgradient streambank erosion is needed in each watershed to have the biggest impact on water quality, as each watershed is unique and needs to be analyzed according to its particular attributes. This study attempts to clarify the subwatersheds that would see the most beneficial response to restoring pre-settlement hydrology.

In 2016, WDNR and USEPA explored how AOC Great Lakes Restoration Initiative (GLRI) funding might be applied toward nutrient management practice implementation, with consideration for the project attributes that previous AOC GLRI-funded projects have shared and arrived at a set of five “AOC-like” practices for nutrient management that could be installed on the landscape including:

- Agricultural runoff treatment systems (constructed/treatment wetlands)
- Wetland creation/enhancement/restoration
- Streambank protection/stabilization
- Two-stage ditches
- Saturated buffers

Agricultural runoff treatment systems (ARTS) provide the most opportunity to store water and reduce downstream flow rates. Wetland restoration and creation on the landscape also provides water storage but will have a larger footprint than ARTS for same storage capacity and are not meant for treatment of runoff or to regulate flows artificially. This analysis will provide insight on how much storage is needed and where ARTS and wetland restoration/creation practices will be most beneficial in nutrient and sediment reduction. In 2017 and 2018, WDNR convened technical experts to estimate the total opportunity on the landscape to implement these practices, and how much phosphorus and sediment reduction would potentially be realized. The group found that these practices have the potential to contribute significantly to nutrient and sediment reductions in the Lower Fox Basin if implemented.

2.0 Watershed Characteristics

The Lower Fox River Basin is a 638 square mile basin located in Northeast Wisconsin. It encompasses Brown, Calumet, Outagamie and Winnebago Counties. The Lower Fox River empties the Wolf River and Upper Fox River basins which drain approximately 6,349 square miles. The Lower Fox River flows northeast from the outlet of Lake Winnebago to the bay of Green Bay.

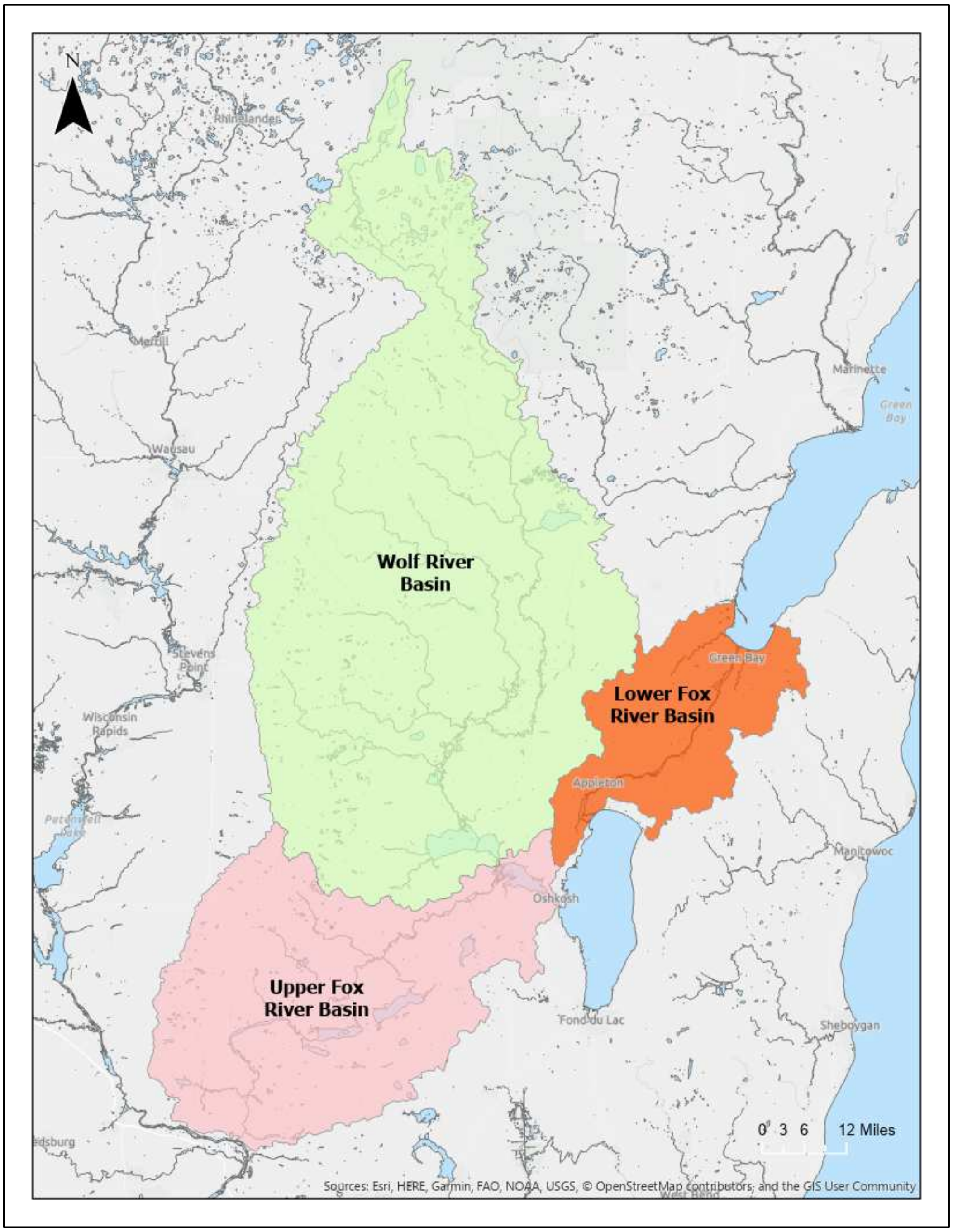


Figure 1. Map of Lower Fox River Basin drainage.

Historic Land Use

In 1990, the Wisconsin Department of Natural Resources digitized original vegetation cover data from a 1976 map that was created from land survey notes written in the mid-1800's when Wisconsin was first surveyed. The original pre-settlement land cover in the Lower Fox Basin was mostly hardwood forest consisting of Beech, Sugar Maple, Basswood, Red Oak, White Oak, and Black Oak. There were also large areas of Swamp conifers (white cedar, black spruce, tamarack, hemlock) present. Other vegetation communities found in the basin are shown in Table 1 & Figure 2.

Table 1. Pre-settlement vegetation summary by area in Lower Fox River Basin.

Vegetation Type	Area (Acres)
Beech, sugar maple, basswood, red oak, white oak, black oak	137,061
Sugar maple, basswood, red oak, white oak, black oak	125,704
Swamp conifers - white cedar, black spruce, tamarack, hemlock	35,583
Oak - white oak, black oak, bur oak	32,802
Oak openings - bur oak, white oak, black oak	22,193
Hemlock, sugar maple, yellow birch, white pine, red pine	9,667
Beech, hemlock, sugar maple, yellow birch, white pine, red pine	8,548
Lowland hardwoods - willow, soft maple, box elder, ash, elm, cottonwood, river birch	8,049
Marsh and sedge meadow, wet prairie, lowland shrubs	7,012
Water	5,700
Area with vegetation cover type not interpreted on the source map	5,234
White pine, red pine	4,696
Jack pine, scrub (hill's), oak forest and barrens	4,445
Brush	4,245
Prairie	2,595
Aspen, white birch, pine	378

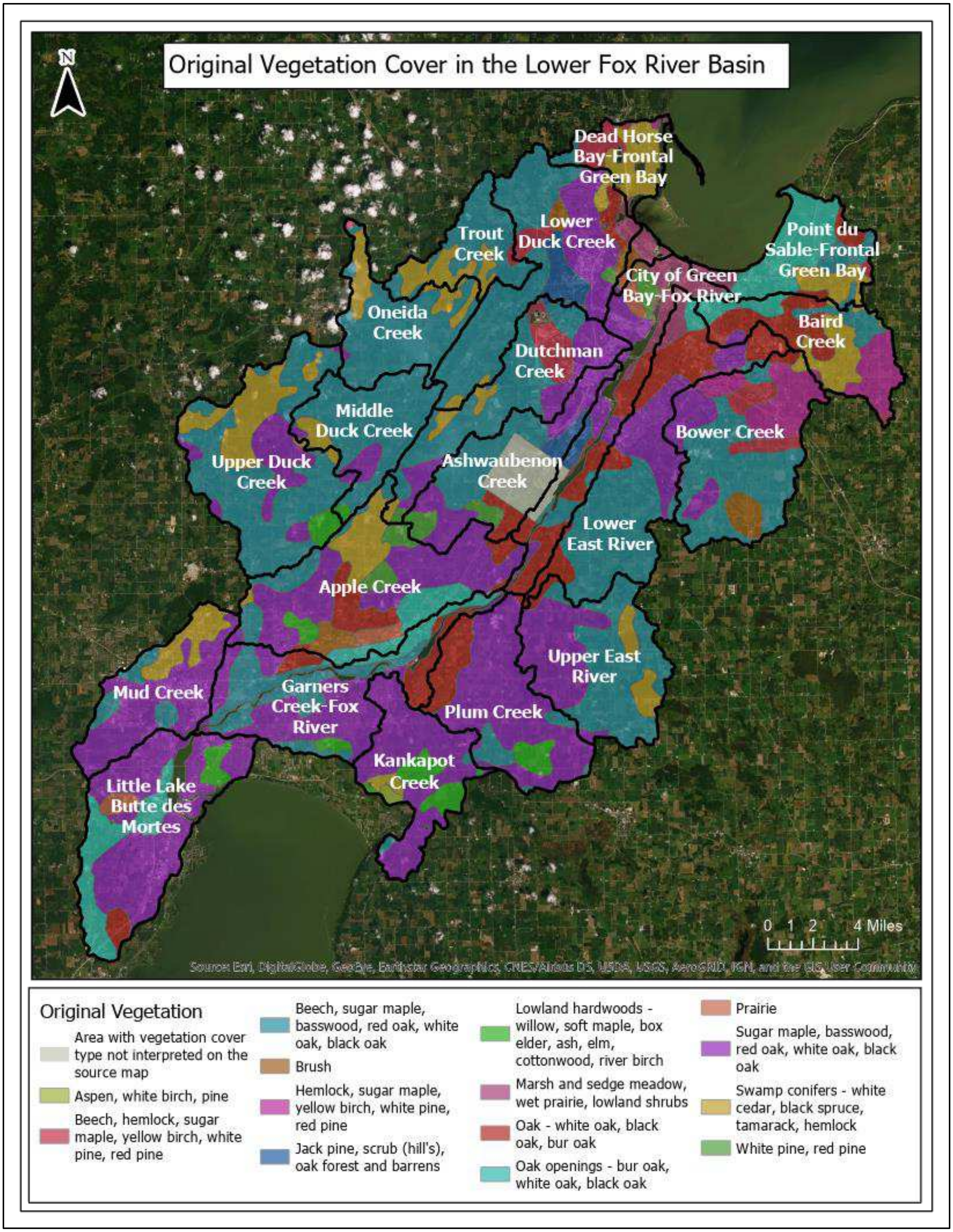


Figure 2. Map of pre-settlement vegetation cover in Lower Fox River Basin.

Wetlands

The amount of existing wetlands and potentially restorable wetlands was determined using WDNR GIS data. There are approximately 32,078 acres of existing wetlands in the Lower Fox Basin and an estimated 62,688 acres of potentially restorable wetlands (historic/lost wetlands) in the basin (Figure 3). A summary of existing wetland and potentially restorable wetland acreage is shown in Table 2. The majority of the historic wetlands in the basin have been filled for urban development, are currently farmed through, or have been artificially drained for farming. The loss of wetlands in the basin has likely contributed to significant changes in hydrology since pre-settlement times.

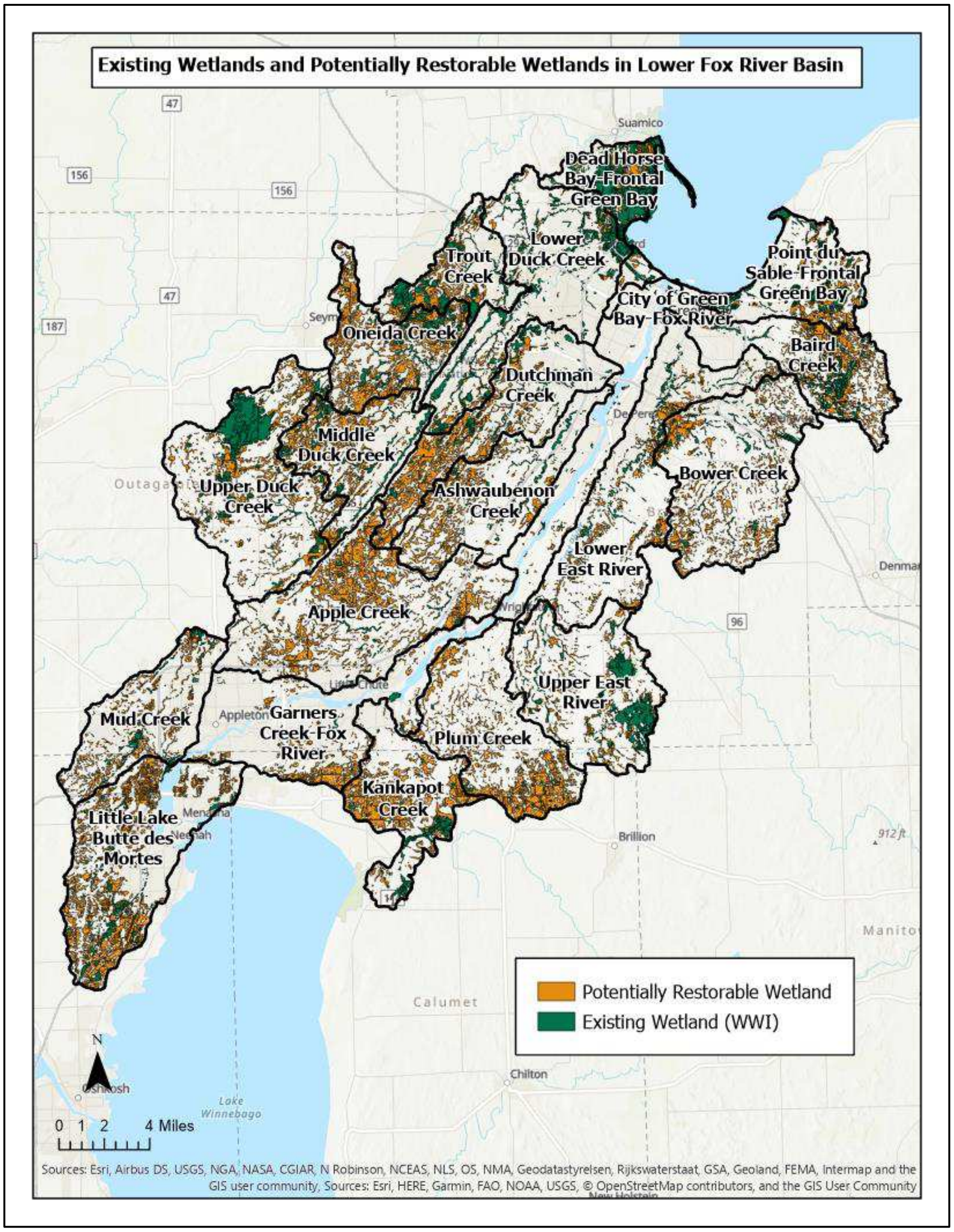


Figure 3. Existing and potentially restorable (lost) wetlands in the Lower Fox River Basin.

Table 2. Existing and potentially restorable (lost) wetlands in Lower Fox River Basin subwatersheds.

Watershed (HUC 12)	Watershed Area	Existing Wetlands (WWI)		Potentially Restorable (lost) Wetlands (PRW)	
	acres	acres	percent	acres	percent
Apple Creek	33,190	608	1.8%	7,090	21.4%
Upper Duck Creek	30,851	3,857	12.5%	4,298	13.9%
Plum Creek	22,322	250	1.1%	4,621	20.7%
Oneida Creek	14,939	1,542	10.3%	4,609	30.9%
Bower Creek	26,991	1,126	4.2%	3,750	13.9%
Little Lake Butte des Mortes	27,918	1,427	5.1%	6,505	23.3%
Kankapot Creek	16,386	957	5.8%	4,023	24.6%
Ashwaubenon Creek	18,984	797	4.2%	2,680	14.1%
Dutchman Creek	19,741	1,287	6.5%	4,366	22.1%
Upper East River	22,997	2,670	11.6%	1,969	8.6%
Lower East River	28,696	1,155	4.0%	2,429	8.5%
Middle Duck Creek	14,780	1,231	8.3%	3,165	21.4%
Baird Creek	15,695	1,623	10.3%	2,959	18.9%
Point du Sable-Frontal Green Bay	13,686	2,319	16.9%	1,889	13.8%
Trout Creek	10,182	1,954	19.2%	1,863	18.3%
Lower Duck Creek	27,623	3,601	13.0%	1,217	4.4%
Mud Creek	16,359	702	4.3%	2,047	12.5%

Current Land Use

Existing land use and cover was determined for the watersheds using the United States Department of Agriculture (USDA) 2018 Cropland Data Layer. Table 3 summarizes land use data for the subwatersheds analyzed in the Lower Fox River Basin. A map of current land use/cover is shown in Figure 4. Approximately 50% of the basin is agricultural land, 30% is urban/developed and 15% is natural area (forest and wetlands). Most of the urban areas are concentrated near the main stem of the Lower Fox River near Lake Winnebago and Bay of Green Bay.

Table 3. Current land use summary of analyzed subwatersheds.

Watershed (HUC 12)	Watershed Area	Land Use							
		Agriculture		Urban/Developed		Natural Background		Water	
	acres	acres	percent	acres	percent	acres	percent	acres	percent
Apple Creek	33,190	20,715	62.4%	9,761	29.4%	2,551	7.7%	112	0.3%
Upper Duck Creek	30,851	13,464	43.6%	10,396	33.7%	4,674	15.2%	113	0.4%
Plum Creek	22,322	17,592	78.8%	2,064	9.2%	2,642	11.8%	18	0.1%
Oneida Creek	14,939	10,216	68.4%	1,129	7.6%	3,557	23.8%	20	0.1%
Bower Creek	26,991	18,314	67.9%	5,210	19.3%	3,417	12.7%	157	0.6%
Little Lake Butte des Mortes	27,918	6,446	23.1%	15,908	57.0%	2,731	9.8%	1,534	5.5%
Kankapot Creek	16,386	11,730	71.6%	3,745	22.9%	2,327	14.2%	24	0.1%
Ashwaubenon Creek	18,984	12,685	66.8%	4,687	24.7%	1,571	8.3%	36	0.2%
Dutchman Creek	19,741	10,641	53.9%	6,861	34.8%	2,218	11.2%	17	0.1%
Upper East River	22,997	16,761	72.9%	1,459	6.3%	4,756	20.7%	16	0.1%
Lower East River	28,696	13,464	46.9%	10,396	36.2%	4,674	16.3%	16	0.1%
Middle Duck Creek	14,780	10,081	68.2%	1,049	7.1%	3,542	24.0%	18	0.1%
Baird Creek	15,695	10,347	65.9%	3,969	25.3%	3,417	21.8%	157	1.0%
Point du Sable-Frontal Green Bay	13,686	7,702	56.3%	4,819	35.2%	2,663	19.5%	94	0.7%
Trout Creek	10,182	5,270	51.8%	1,163	11.4%	3,722	36.6%	22	0.2%
Lower Duck Creek	27,623	6,903	25.0%	12,413	44.9%	7,958	28.8%	157	0.6%
Mud Creek	16,359	4,034	24.7%	11,029	67.4%	1,335	8.2%	66	0.4%

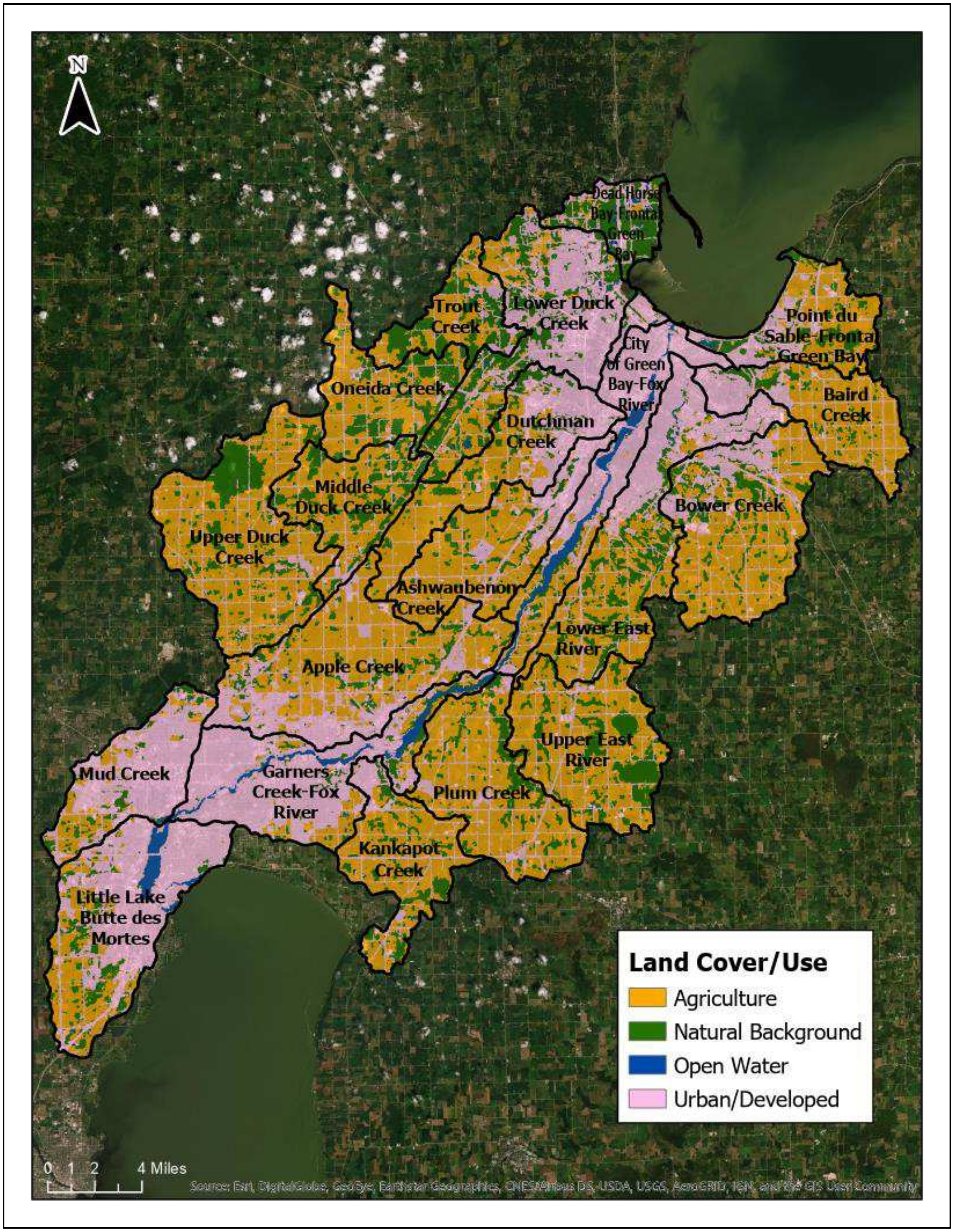


Figure 4. Map of land use/cover in Lower Fox River Basin.

3.0 Methods

The purpose of this analysis was to estimate current flow rates and pre-settlement flow rates for catchments of subwatersheds (HUC12) in the Lower Fox River Basin. The amount of storage needed can be calculated based on the difference between the flow rates. The analysis was completed using ESRI 10.7 ArcGIS tools/models and the NRCS EFH2 Spreadsheet. Outagamie County Land Conservation consulted with Robert D. Givens, P.E., P.H., C.F.M from OMNNI Associates on methods used to conduct the analysis described in this section.

ESRI Arc Hydro[1] is a water resource data model that contains a set of tools to support water resources analyses. Arc Hydro was used to condition the digital elevation model (DEM), generate flow lines, delineate catchments of each subwatershed (HUC12), and to characterize slope and watershed length. A DEM and a Culvert Polyline layer are needed to run Arc Hydro. The majority of the HUC 12 watersheds in the Lower Fox Basin already had a 3-meter resolution DEM created and a culvert polyline layer created for prior GIS analysis that had been done for 9 Key Element Plan creation. DEM and culvert polyline files for those watersheds that had not already been done were provided by Tom Simmons of the Wisconsin Department of Natural Resources.

The focus of this analysis was on agricultural dominant headwater drainages. Outlets for catchment delineation were selected if the majority land use was agricultural land and that the topography of the catchment was suitable for agricultural runoff treatment system.

Once the hydrologic parameters of each subwatershed were determined, the EFH2 runoff method was used to estimate runoff volume and peak discharge for each catchment. It is a single event rainfall-runoff model for small watersheds (<2,000 acres) where urban land use is less than 10%. Inputs into the EFH2 model include drainage area, runoff curve number, watershed length, and watershed slope. The EFH2 spreadsheet model uses NRCS storm distributions MSE3 and MSE4 from NOAA Atlas 14, Volume 8. The Lower Fox River Basin is in the MSE4 rainfall region.

Runoff curve number is a parameter used in hydrology for predicting runoff or infiltration from rainfall. Runoff curve number is calculated based on hydrologic soil group, land use, treatment, and hydrologic condition. Runoff curve number for current conditions was calculated using gSSURGO soils data and cropland data layers from 2014-2018 in the EVAAL Create Curve Number Raster tool. To calculate a curve number for pre-settlement conditions the land cover was assumed to be woods in good condition based on Wisconsin Land Survey data from the mid-1800s.

EFH2 runoff and peak discharge (flow rate) data was then used to calculate storage volumes needed and area required to return to pre-settlement conditions. Current and historic flow rates from the EFH2 were adjusted based on the amount of wetlands in a catchment. The adjustment factor for pond and swamp areas from Technical Release 55-Urban Hydrology for Small Watersheds was used to adjust the flow rates. The maximum adjustment factor is 0.72 for 5% pond and swamp areas in a catchment. The WDNR GIS Potentially Restorable Wetlands

[1] For additional information on Arc Hydro: https://www.esri.com/library/fliers/pdfs/archydro.pdf

(Historic) and Wisconsin Wetland Inventory (WWI) data sets were clipped by catchment boundaries in GIS to determine acres in each catchment.

Baseline phosphorus and sediment loads from the Lower Fox River TMDL were used to estimate reductions. An area weighted average lbs/ac baseline load was calculated for nonpoint sources (urban non-regulated, agriculture and natural background) for each TMDL subwatershed (Appendix A). The load for each catchment was then calculated using the area weighted average times the catchment acres. The reduction efficiency used for Agriculture Runoff Treatment Systems was 60% for TP and 80% for TSS. This efficiency was chosen by the AOC technical advisory team based on the fact that the open water components of the ARTS systems would be designed to the WI DNR Technical Standard 1001 Wet Detention Pond. Therefore, they would be able to achieve similar reduction efficiencies as a wet detention basin does.

4.0 Analysis Results Summary

The hydrologic analysis was completed for 17 out of 20 subwatersheds (HUC12) in the Lower Fox River Basin (Figure 5). Subwatersheds that were mostly urban were not analyzed (Garners Creek-Fox River, City of Green Bay- Fox River, Dead Horse Bay-Frontal Green Bay). A partial analyses was completed for the agricultural portion of the Mud Creek and Little Lake Butte des Mortes subwatersheds.

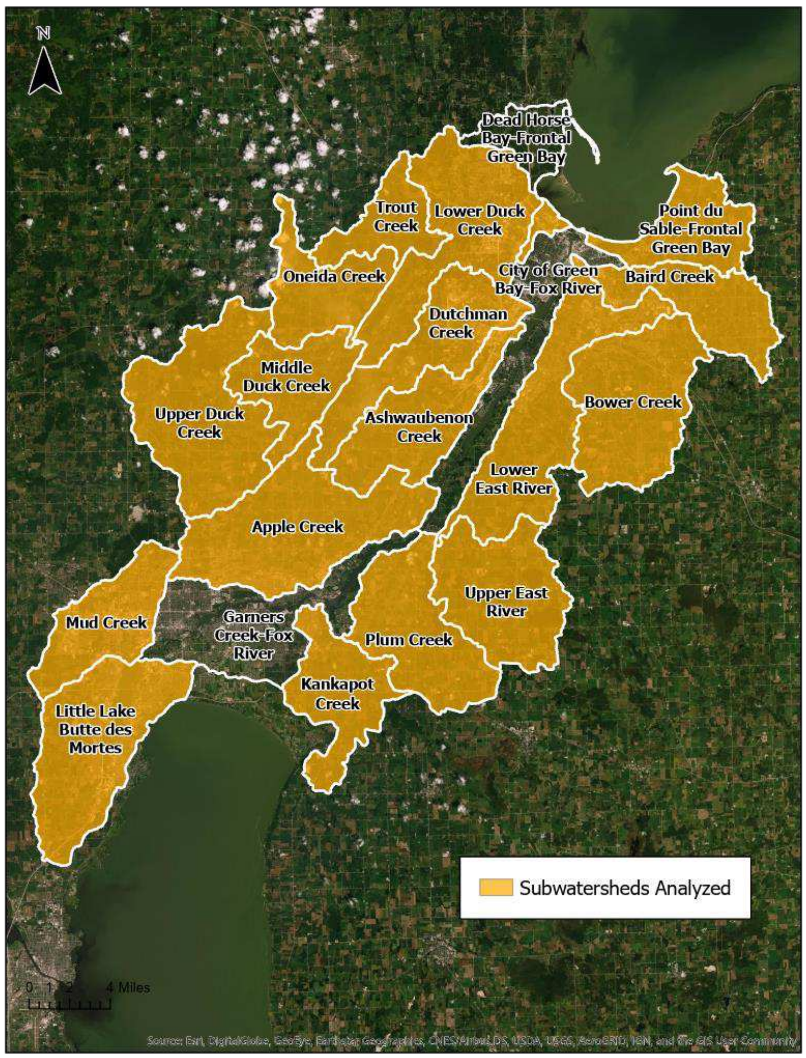
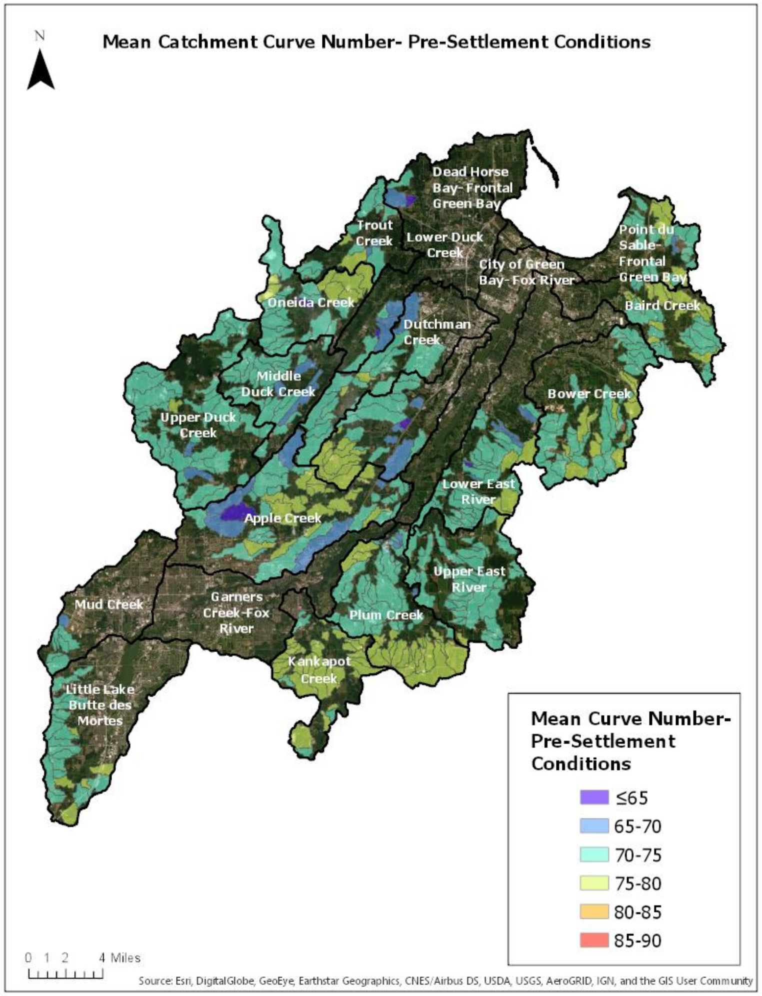


Figure 5. Subwatersheds analyzed.

Curve numbers are used to characterize runoff properties for a particular soil type and ground cover. Figure 6 shows the mean estimated curve number for pre-settlement land use conditions and for current land use conditions for the catchments analyzed in each subwatershed. The mean curve number for current conditions for all catchments was 83 while the mean curve number for pre-settlement conditions for all catchments was 73.



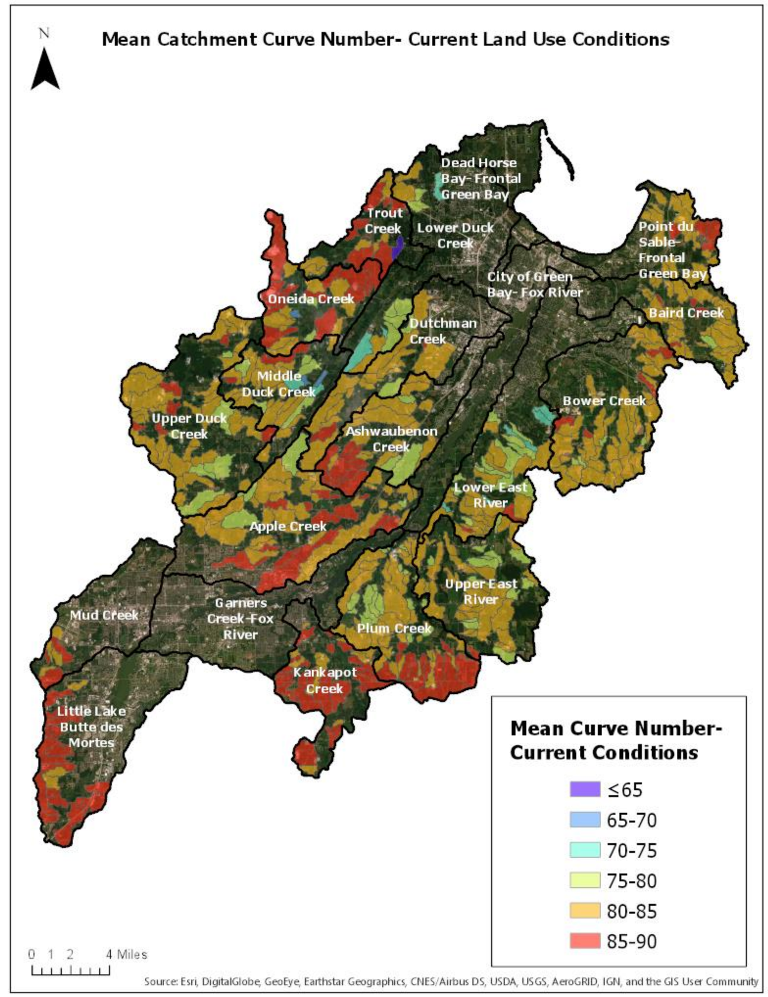


Figure 6. Pre-settlement mean curve number by catchment (left) and current mean curve number by catchment (right).

Water Storage Needed

The hydrologic analysis modeled runoff and storage needs for the 1-yr, 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, and 100-yr MSE-4 rainfall events. Current and historic flow rates for the analyzed area of each watershed using EFH2 are shown in Table 4. Table 5 shows the storage volume in millions of gallons needed to restore hydrology to pre-settlement conditions for analyzed areas for all storm events. It is commonly accepted that peak discharge control on the 2-yr design storm will help control stream bank erosion (Donovan et al. 2000). Because streambank erosion is also a significant source of nutrients and sediment, controlling the rate of erosion is important. Therefore, the 2-yr rainfall event was chosen as the basis for the volume needed to be retained in the subwatersheds to restore hydrology. Figure 7 shows the acres needed, assuming a 2 ft storage depth, to meet required volume retention and Figure 8 shows what percent of each catchment is required. Detailed maps of results for each subwatershed are shown in Appendix B.

Table 4. Current and historic flow rates for analyzed area of each watershed.

Watershed (HUC 12)	Watershed Area (acres)	Total Area Analyzed (Acres)	Percent of Watershed Analyzed	Current Flow Rate (cfs)							Historic Flow Rate (cfs)							Percent Change in Flow Rate						
				1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Apple Creek	33,190	20,379	61.4%	4,545	5,916	8,583	11,114	14,940	18,198	21,728	1,135	1,677	2,821	3,983	5,867	7,575	9,499	75%	72%	67%	64%	61%	58%	56%
Upper Duck Creek	30,851	16,417	53.2%	3,812	4,997	7,323	9,546	12,935	15,832	18,964	906	1,393	2,466	3,561	5,321	6,931	8,756	76%	72%	66%	63%	59%	56%	54%
Plum Creek	22,322	16,756	75.1%	4,018	5,323	7,860	10,306	14,187	17,545	21,227	1,258	1,870	3,143	4,436	6,596	8,566	10,806	69%	65%	60%	57%	54%	51%	49%
Oneida Creek	14,939	10,839	72.6%	2,333	2,998	4,279	5,482	7,272	8,799	10,454	627	920	1,536	2,152	3,146	4,045	5,055	73%	69%	64%	61%	57%	54%	52%
Bower Creek	26,991	13,590	50.4%	3,161	4,239	6,337	8,355	11,551	14,292	17,245	949	1,454	2,505	3,552	5,308	6,916	8,718	70%	66%	60%	57%	54%	52%	49%
Little Lake Butte des Mortes	27,918	7,554	27.1%	2,387	3,033	4,263	5,419	7,193	8,731	10,407	605	883	1,458	2,040	3,012	3,903	4,911	75%	71%	66%	62%	58%	55%	53%
Kankapot Creek	16,386	8,655	52.8%	2,869	3,712	5,315	6,832	9,259	11,358	13,697	852	1,235	1,997	2,775	4,110	5,321	6,712	70%	67%	62%	59%	56%	53%	51%
Ashwaubenon Creek	18,984	10,319	54.4%	1,775	2,347	3,460	4,528	6,175	7,598	9,137	467	701	1,202	1,716	2,569	3,349	4,229	74%	70%	65%	62%	58%	56%	54%
Dutchman Creek	19,741	9,255	46.9%	1,422	1,879	2,769	3,622	4,940	6,067	7,284	424	644	1,119	1,602	2,401	3,132	3,957	70%	66%	60%	56%	51%	48%	46%
Upper East River	22,997	11,327	49.3%	2,282	3,121	4,773	6,386	8,990	11,276	13,734	690	1,095	1,980	2,884	4,401	5,806	7,396	70%	65%	59%	55%	51%	49%	46%
Lower East River	28,696	10,829	37.7%	2,117	2,918	4,495	6,033	8,513	10,688	13,046	699	1,103	1,973	2,860	4,347	5,720	7,267	67%	62%	56%	53%	49%	46%	44%
Middle Duck	14,780	8,742	59.1%	1,569	2,095	3,131	4,123	5,653	6,974	8,411	453	698	1,242	1,819	2,763	3,636	4,627	71%	67%	60%	56%	51%	48%	45%
Baird Creek	15,695	7,308	46.6%	1,588	2,130	3,188	4,207	5,822	7,210	8,701	591	897	1,526	2,151	3,198	4,154	5,222	63%	58%	52%	49%	45%	42%	40%
Point du Sable-Frontal Green Bay	13,686	5,581	40.8%	1,224	1,633	2,426	3,187	4,379	5,406	6,510	371	575	1,005	1,438	2,163	2,830	3,579	70%	65%	59%	55%	51%	48%	45%
Trout Creek	10,182	4,551	44.7%	990	1,287	1,863	2,404	3,237	3,951	4,724	242	367	634	904	1,351	1,762	2,226	76%	72%	66%	62%	58%	55%	53%
Lower Duck	27,623	5,135	18.6%	578	804	1,256	1,698	2,412	3,043	3,735	118	197	387	601	976	1,333	1,744	80%	75%	69%	65%	60%	56%	53%
Mud Creek	16,359	1,828	11.2%	659	844	1,202	1,540	2,060	2,511	3,004	119	182	320	463	701	923	1,176	82%	78%	73%	70%	66%	63%	61%

Table 5. Water storage needed to return flow rates back to pre-settlement conditions.

HUC 12 NAME	HUC 12 Area (Acres)	Million Gallons of Storage Needed (1 yr)	Million Gallons of Storage Needed (2 yr)	Million Gallons of Storage Needed (5 yr)	Million Gallons of Storage Needed (10 yr)	Million Gallons of Storage Needed (25 yr)	Million Gallons of Storage Needed (50 yr)	Million Gallons of Storage Needed (100 yr)	Total Area Analyzed (Acres)	Percent of Watershed Analyzed
Apple Creek	33,190	146.0	175.9	230.5	279.7	351.5	410.9	473.8	20,379	61.4%
Upper Duck Creek	30,851	144.2	172.8	224.8	272.8	344.3	403.4	465.8	16,417	53.2%
Plum Creek	22,322	133.4	162.4	216.0	267.0	344.6	409.7	479.7	16,756	75.1%
Oneida Creek	14,939	103.5	122.7	158.0	190.1	236.1	274.1	314.2	10,839	72.6%
Bower Creek	26,991	101.3	123.9	166.1	206.0	266.8	317.4	370.7	13,590	50.4%
Little Lake Butte des Mortes	27,918	85.0	99.7	126.6	151.3	187.7	218.3	250.7	7,554	27.1%
Kankapot Creek	16,386	84.1	100.9	132.3	161.0	205.5	243.0	283.9	8,655	52.8%
Ashwaubenon Creek	18,984	83.6	102.2	136.0	166.9	213.2	251.9	292.9	10,319	54.4%
Dutchman Creek	19,741	75.4	91.3	120.0	146.5	186.1	218.9	253.3	9,255	46.9%
Upper East River	22,997	74.9	92.2	123.9	154.0	201.4	241.5	283.5	11,327	49.3%
Lower East River	28,696	66.6	82.7	112.4	140.5	184.5	221.7	260.9	10,829	37.7%
Middle Duck Creek	14,780	64.7	77.7	101.3	122.9	154.9	181.5	209.5	8,742	59.1%
Baird Creek	15,695	47.6	58.1	78.0	96.8	125.4	149.1	173.8	7,308	46.6%
Point du Sable-Frontal Green Bay	13,686	42.5	51.4	67.6	82.8	105.8	124.8	144.6	5,581	40.8%
Trout Creek	10,182	41.8	49.9	64.6	78.0	97.8	114.2	131.4	4,551	44.7%
Lower Duck Creek	27,623	35.9	44.9	60.5	74.4	95.3	112.9	131.6	5,135	18.6%
Mud Creek	16,359	22.1	26.2	33.4	40.0	49.9	58.2	66.9	1,828	11.2%
Total	361,340	1,352.4	1,634.8	2,152.2	2,630.8	3,350.8	3,951.3	4,587.3	169,065	46.8%

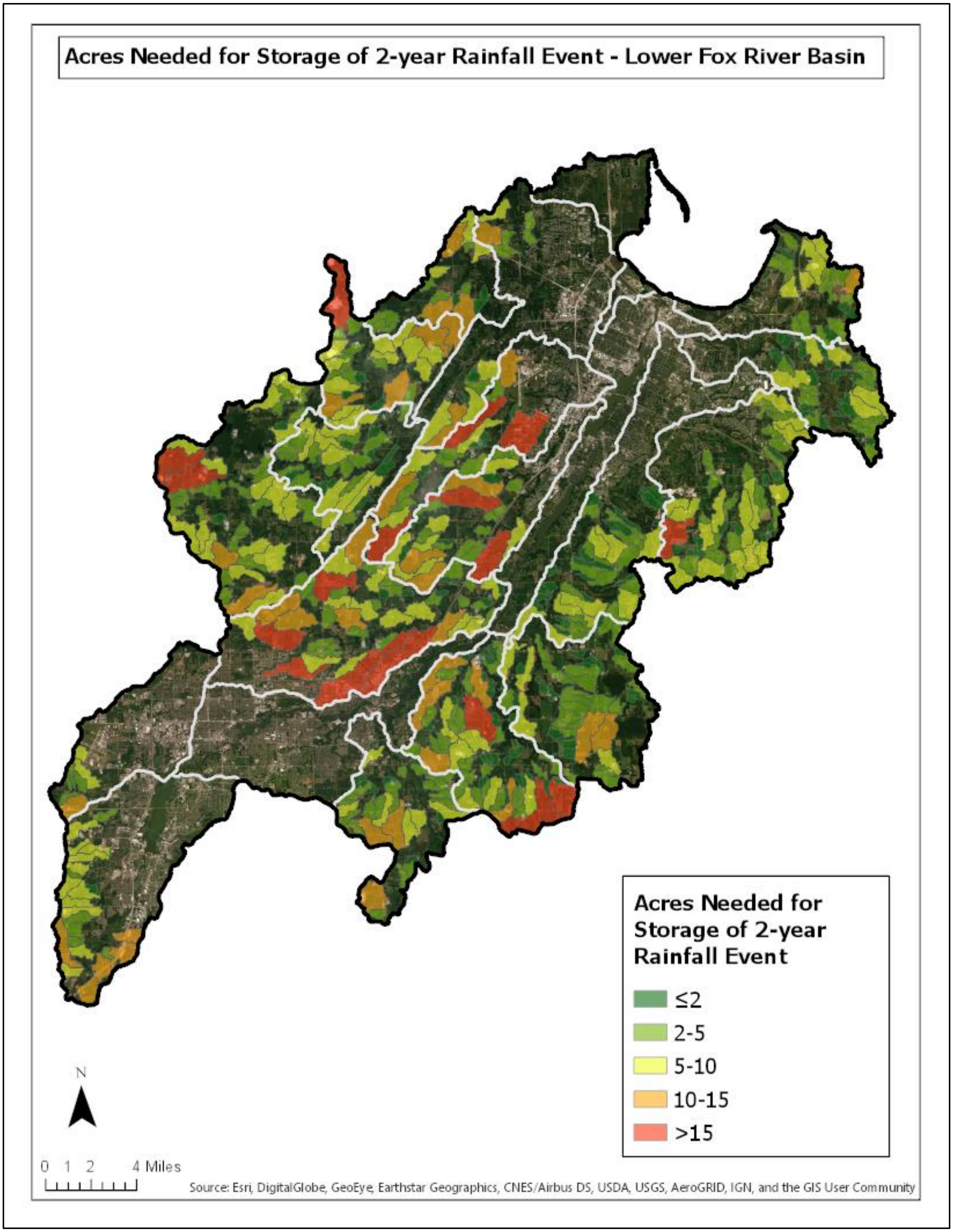


Figure 7. Map of acres needed for storage of 2- year rainfall event for catchments analyzed.

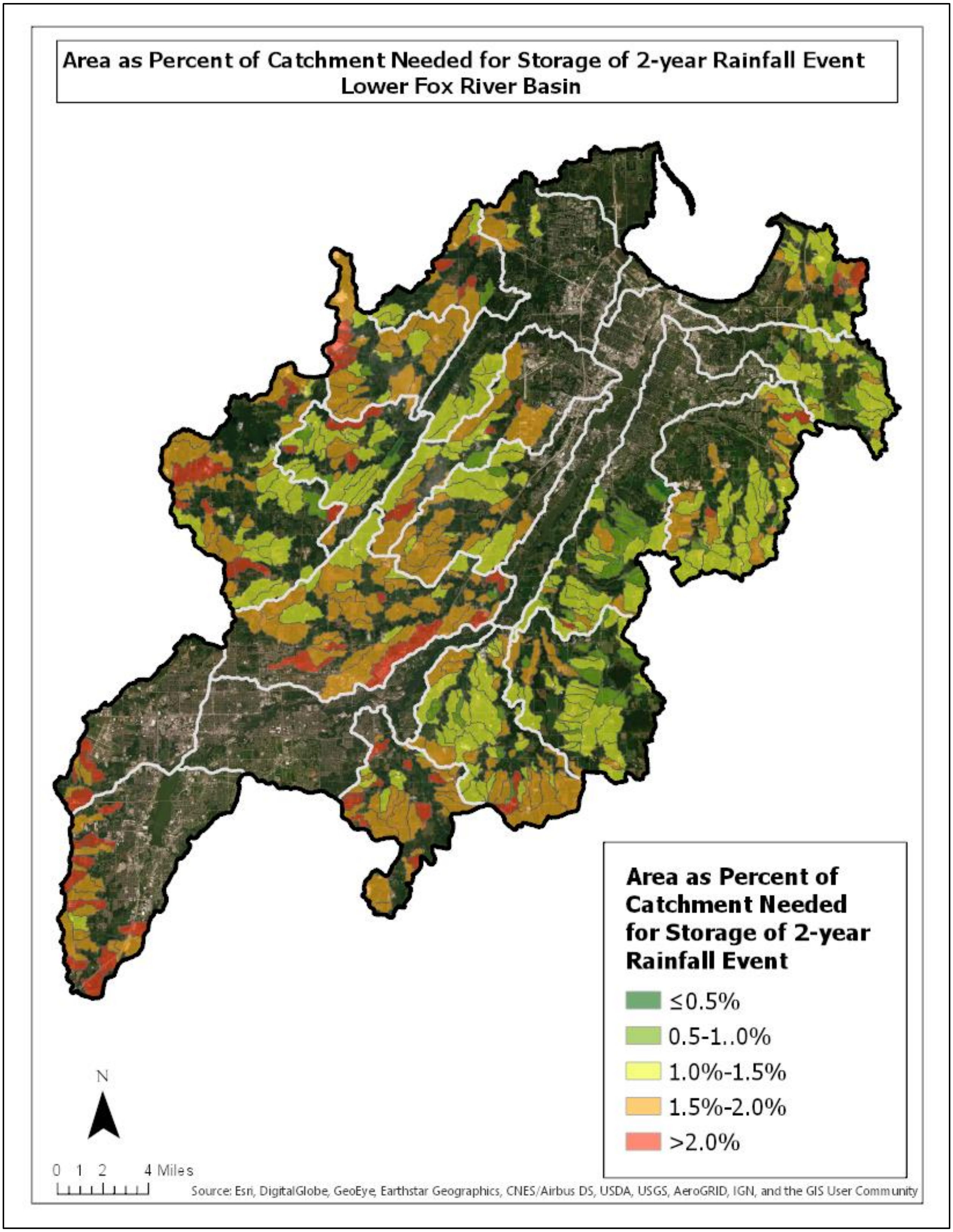


Figure 8. Map of area as a percent of catchment needed for storage of 2-year rainfall event.

Flood Control

This study focuses on the 1 and 2-yr MSE-4 24-hour rainfall event for the purpose of identifying and determining the need for increasing water storage capacity to improve water quality by reducing nutrient and sediment load reductions for the BUIs. This study includes numbers for larger storm events as well with the potential to help mitigate regional flooding issues. The analysis data from the other rainfall events such as the 25-yr, 50-yr and 100-yr can also be used by local communities and other local entities looking for ways to reduce the impact of flooding. Local communities can use this data to identify priority watersheds for potential downstream storm water practices (detention basins) and to identify opportunities to work with upstream communities or agriculture producers to reduce runoff rates from headwaters of priority watersheds. Communities may also want to partner with local land conservation departments to provide additional funding to increase the storage capacity of a potential ARTS system from a 2-yr rainfall to a 10-yr or 25-yr rainfall capacity if it benefits them downstream. The data can also be used to better plan urban development as communities in the Lower Fox Basin continue to expand by designing regional treatment that provides for both future development and create storage needed for this analysis.

Nutrient and Sediment Load Reductions

Best management practices (BMPs) with the greatest potential to store significant volumes of water for agriculture land use include agricultural runoff treatment systems (ARTS) and wetland restoration/creation. An Agricultural Runoff Treatments system is similar to a storm water pond in that it will be designed to retain water and settle out sediment. ARTs are designed with wetland cells that mimic wetland functions. Phosphorus and sediment reductions were estimated based on the installation of ARTS to store water volumes at the 2-year rainfall event level. For the purposes of this study a 60% TP and 80% TSS reduction efficiency was used for ARTS. Table 6 shows the reductions that could be achieved if all the volume of the 2-yr rainfall event were to be stored for all catchments analyzed using the ARTS practice. Wetland restoration and creation in the watershed will also help to achieve water storage goals and thus reduce downstream flow rates and erosion impacts. Due to the variety in wetland types it is difficult to estimate phosphorus and sediment reductions from wetland restoration/creation from currently available data. Restored wetlands and created wetlands don't allow for regular maintenance or regulation of flow which also affects the phosphorus and sediment retention ability. However, ARTS will offer new opportunities to restore adjacent wetlands and provide them with a cleaner source of water.

Table 6. Estimated total phosphorus and total suspended sediment reductions if all storage required was implemented using ARTS.

Watershed (HUC12)	TP Reduction (lbs)	TSS Reduction (tons)
Apple Creek	13,083	2,993
Upper Duck Creek	7,092	1,886
Plum Creek	12,969	3,477
Oneida Creek	4,682	1,245

Watershed (HUC12)	TP Reduction (lbs)	TSS Reduction (tons)
Bower Creek	8,562	2,072
Little Lake Butte des Mortes	4,261	965
Kankapot Creek	6,335	1,511
Ashwaubenon Creek	5,758	1,115
Dutchman Creek	4,276	795
Upper East River	7,068	1,860
Lower East River	6,757	1,779
Middle Duck Creek	3,776	1,004
Baird Creek	3,288	507
Point du Sable-Frontal Green Bay	2,177	438
Trout Creek	1,338	305
Lower Duck Creek	2,218	590
Mud Creek	1,020	226
Total	94,662	22,770

Discussion

Assuming all the storage needed for the 2-year rainfall event was implemented using ARTS in the analyzed subwatersheds significant phosphorus and sediment reductions would be achieved. The total area needed for storage practices (ARTS or Wetland Restoration/Creation with an assumed storage depth of 2 ft) is less than 1% of the total watershed area in most watersheds (Table 7). The estimated cost to install all ARTS needed to restore the 2-yr hydrology is $184,968,637 (Table 8). This cost takes into account the following costs: land acquisition, outreach, administration, design, survey, construction/construction oversight and operation and maintenance. The average upfront cost to reduce a pound of phosphorus is $2,195 and $9,684 to reduce a ton of sediment. It should be noted that these practices will be designed to achieve annual reductions for 10-20 years before needing maintenance to remove accumulated sediment.

In comparison, it is estimated that the upfront cost to reduce a pound of phosphorus is $1,960 for implementing conservation cover on a farm field, this includes using no-till, cover crops, and low disturbance manure injection. This cost assumes 7 years of cost sharing at $280/acre is needed for a farmer to adopt these practices for the long term. Current proposals include farmers agreeing to use the practices for another 14 years in order to receive the 7 years of funding.

When comparing the ARTS upfront cost to the upfront cost of conservation cover they are very similar; however, the cost of ARTS does not include the cost benefit of reduced downstream flooding and streambank erosion. Additionally, ARTS once constructed are a permanent structure, while full adoption of conservation cover would be an entirely new way of farming and may not be fully resilient to change in climate. However, encouraging adoption of conservation cover is still an important strategy in meeting reduction goals in the basin.

Table 7. Summary of acres of storage needed for 2-year rainfall event.

HUC 12 NAME	HUC 12 Area (Acres)	Acres of storage needed for 2-year rainfall event. (2 yr)	Total Area Analyzed (Acres)	Percent of Watershed Analyzed	Percent of Watershed Needed for Storage (2 yr)
Apple Creek	33,190	355.2	20,379	61.4%	1.1%
Upper Duck Creek	30,851	265.2	16,417	53.2%	0.9%
Plum Creek	22,322	249.2	16,756	75.1%	1.1%
Oneida Creek	14,939	188.3	10,839	72.6%	1.3%
Bower Creek	26,991	190.1	13,590	50.4%	0.7%
Little Lake Butte des Mortes	27,918	152.9	7,554	27.1%	0.5%
Kankapot Creek	16,386	154.8	8,655	52.8%	0.9%
Ashwaubenon Creek	18,984	156.8	10,319	54.4%	0.8%
Dutchman Creek	19,741	140.0	9,255	46.9%	0.7%
Upper East River	22,997	141.5	11,327	49.3%	0.6%
Lower East River	28,696	126.9	10,829	37.7%	0.4%
Middle Duck Creek	14,780	119.2	8,742	59.1%	0.8%
Baird Creek	15,695	89.2	7,308	46.6%	0.6%
Point du Sable-Frontal Green Bay	13,686	78.8	5,581	40.8%	0.6%
Trout Creek	10,182	76.6	4,551	44.7%	0.8%
Lower Duck Creek	27,623	68.9	5,135	18.6%	0.2%
Mud Creek	16,359	40.1	1,828	11.2%	0.2%

Table 8. Estimated costs for full implementation of ARTS practice for 2-year rainfall event storage needs.

Watershed (HUC12)	Cost	Cost/Pound of Phosphorus	Cost/ Ton of Sediment
Apple Creek	$22,295,474.23	$1,704.15	$7,448.69
Upper Duck Creek	$18,606,803.49	$2,623.55	$9,865.72
Plum Creek	$18,137,341.51	$1,398.52	$5,216.16
Oneida Creek	$11,738,490.03	$2,507.01	$9,427.49
Bower Creek	$15,458,663.09	$1,805.53	$7,459.89
Little Lake Butte des Mortes	$9,720,592.67	$2,281.48	$10,077.98
Kankapot Creek	$11,953,905.64	$1,886.87	$7,908.78
Ashwaubenon Creek	$11,625,209.21	$2,018.95	$10,423.52
Dutchman Creek	$8,683,831.46	$2,030.83	$10,919.99
Upper East River	$11,234,795.29	$1,589.54	$6,039.18
Lower East River	$11,155,962.27	$1,650.92	$6,272.36
Middle Duck Creek	$8,342,442.99	$2,209.12	$8,307.27
Baird Creek	$7,986,083.25	$2,428.50	$15,737.66
Point du Sable-Frontal Green Bay	$5,482,676.68	$2,518.94	$12,517.68
Trout Creek	$5,116,331.67	$3,823.73	$16,748.77
Lower Duck Creek	$4,631,217.22	$2,087.71	$7,850.73
Mud Creek	$2,798,816.63	$2,743.72	$12,410.81
Total	$184,968,637.32		

An acreage efficiency factor for ARTS was developed based on the estimated costs, phosphorus reduction, and ARTS area needed. This efficiency factor can be used to rank priority catchments within a HUC12 watershed to implement the ARTS practice. Implementation of ARTS will reduce the need for other practices such as streambank stabilization/restoration downstream of ARTS projects or conservation cropping practices in the contributing area to ARTS to achieve reduction and eutrophication BUI goals. In catchments where ARTS can't be implemented to the extent needed or at all, there still exists opportunity to install the other AOC like practices (streambank restoration, two-stage ditches, wetland restoration, and saturated buffers). Estimated reductions and cost estimates for the area of opportunity determined by AOC technical group for the other AOC like practices are shown in Table 9. Additionally, implementing conservation practices such as cover crops, reduced tillage, and buffers in drainage area to an ARTS should extend the amount of time needed before sediment is needed to be cleaned out.

Table 9. Estimate reductions and costs for other AOC like practices.

Practice	Estimated Opportunity Area	Units	Estimated TP Reduction (lbs)	Estimated TSS Reduction (tons)	Estimate Cost ($)
Wetland restoration/creation	5,745	ac	TBD*	TBD*	$6,894,000
Two-stage ditch	592,975	linear ft	3,730	1,248	$6,522,725
Streambank stabilization	284,189	linear ft	5,866	5,866	$17,051,340
Saturated buffer	151,745	linear ft	273	55	$1,062,215

*Due to the variation in natural wetlands (topography, vegetation, location) it is difficult to provide estimated phosphorus and sediment reductions. Overall wetlands would still provide the important service of water storage.

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Fitzpatrick, F.A., Blount, J.D., Kammel, L.E., Francart, S.A., Gellis, A.C. and Eickenberry, B.C. 2019. Stream Corridor Sources of Suspended Sediment and Phosphorus from an Agricultural Tributary to the Great Lakes. Proceedings of the Joint 11th Federal Interagency Sedimentation Conference and 6th Federal Interagency Hydrologic Modeling (SEDHYD) Conference.

United States Department of Agriculture Soil Conservation Service (USDA SCS). 1986. Urban Hydrology for Small Watersheds. Technical Release No. 55 (TR-55). USDA SCS, Washington, DC.

Appendices

Appendix A. Lower Fox River TMDL baseline total phosphorus and sediment loads.

Lower Fox TMDL Subbasin	Area					Total Phophorus						Total Suspended Sediment					
	Total (acres)	Agriculture (acres)	Urban (non-regulated) (acres)	Natural Background (acres)	Total (Agriculture + Urban (non-regulated) + Natural Background) (acres)	Total baseline (lbs/yr)	Agriculture Baseline (lbs/yr)	Urban (non-regulated) Baseline (lbs/yr)	Natural Background (lbs/yr)	Total (Agriculture + Urban (non-regulated) + Natural Background) (lbs/yr)	Total (Agriculture + Urban (non-regulated) + Natural Background) (lbs/ac/yr)	Total Baseline (tons/yr)	Agriculture Baseline (tons/yr)	Urban (non-regulated) Baseline (tons/yr)	Natural Background (tons/yr)	Total (Agriculture + Urban (non-regulated) + Natural Background) (tons/yr)	Total (Agriculture + Urban (non-regulated) + Natural Background) (tons/ac/yr)
East River	48,861	26,520	4,423	8,571	39,514	48,748	38,020	2,195	853	41,068	1.04	9,898	7,682	291	140	8,113	0.205
Baird Creek	16,372	8,633	1,437	3,149	13,219	12,748	9,018	588	263	9,869	0.75	1,896	1,073	54	20	1,148	0.087
Bower Cree	26,938	17,142	2,983	3,468	23,593	27,777	22,946	1,435	283	24,664	1.05	5,159	4,245	194	59	4,498	0.191
Apple Creek	34,232	20,613	5,378	2,343	28,334	35,088	27,297	2,837	255	30,389	1.07	6,368	4,725	443	34	5,203	0.184
Ashwaubenon Creek- State	14,408	8,220	454	1,276	9,950	11,887	8,797	154	113	9,064	0.91	1,871	1,278	28	12	1,318	0.132
Ashwaubenon Creek - Oneida	4,120	3,244	112	379	3,735	3,794	3,472	38	34	3,544	0.95	565	504	7	4	515	0.138
Dutchman Creek - State	7,454	1,809	398	1,459	3,666	4,791	1,890	156	122	2,168	0.59	913	268	17	10	294	0.080
Dutchman Creek - Oneida	11,732	7,888	634	379	8,901	10,489	8,240	248	32	8,520	0.96	1,604	1,167	27	3	1,197	0.134
Plum Creek	22,804	17,382	2,465	2,833	22,680	31,569	27,660	1,316	359	29,335	1.29	6,019	5,586	224	74	5,884	0.259
Kankapot Creek	16,401	11,367	1,120	2,172	14,659	20,050	17,195	493	269	17,957	1.22	3,627	3,072	96	31	3,200	0.218
Garners Creek	7,037	2,256	201	558	3,015	6,575	2,908	46	67	3,021	1.00	1,432	495	13	9	517	0.172
Mud Creek	9,585	1,474	335	532	2,341	6,594	1,884	245	49	2,178	0.93	1,462	340	18	4	361	0.154
Duck Creek - State	52,203	30,098	5,407	8,972	44,477	38,690	30,382	2,070	790	33,242	0.75	7,873	6,362	239	57	6,659	0.150
Duck Creek - Oneida	35,066	18,760	3,585	8,020	30,365	24,482	18,937	1,372	707	21,016	0.69	4,824	3,966	159	51	4,175	0.138
Trout Creek- Oneida	9,630	4,580	584	2,517	7,681	4,518	3,272	253	211	3,736	0.49	726	611	20	14	645	0.084
Neenah Slough	14,461	6,302	1,447	1,616	9,365	11,912	8,015	572	173	8,760	0.94	2,423	1,360	124	12	1,495	0.160
Lower Fox Mainstem	53,744	9,157	3,183	4,328	16,668	237,339	12,779	1,618	454	14,851	0.89	11,990	2,471	238	64	2,774	0.166
Lower Green Bay	18,609	7,135	809	6,677	14,621	12,652	8,670	324	575	9,569	0.65	2,151	1,345	54	34	1,434	0.098
Totals	**######**	**202,580**	**34,955**	**59,249**	**296,784**	**#####**	**251,382**	**15,960**	**5,609**	**272,951**		**70,801**	**46,551**	**2,246**	**632**	**49,429**	

Appendix B. Subwatershed analysis maps for 2-year rainfall event.

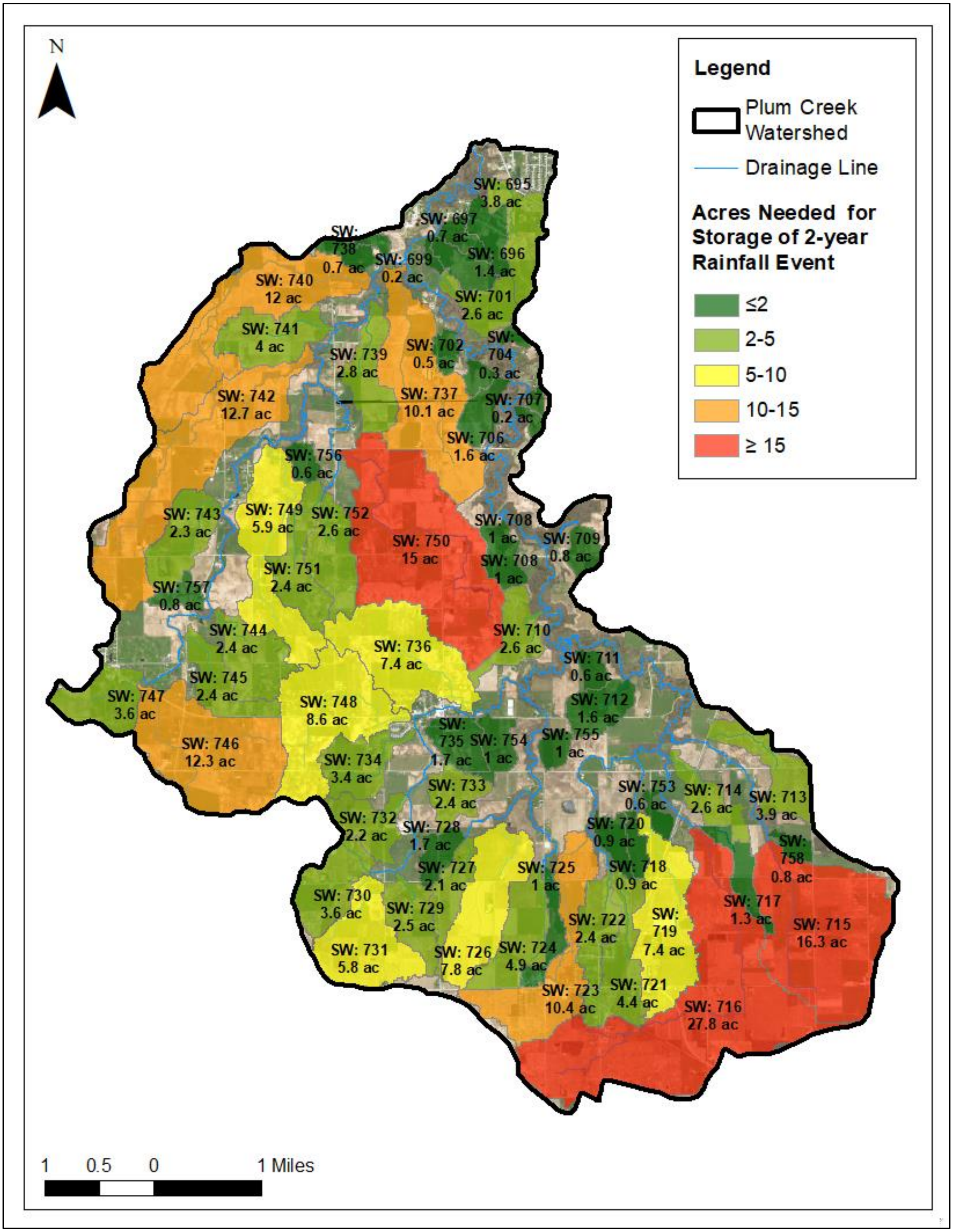

Figure B-1. Plum Creek acres of storage needed for 2-year rainfall event.

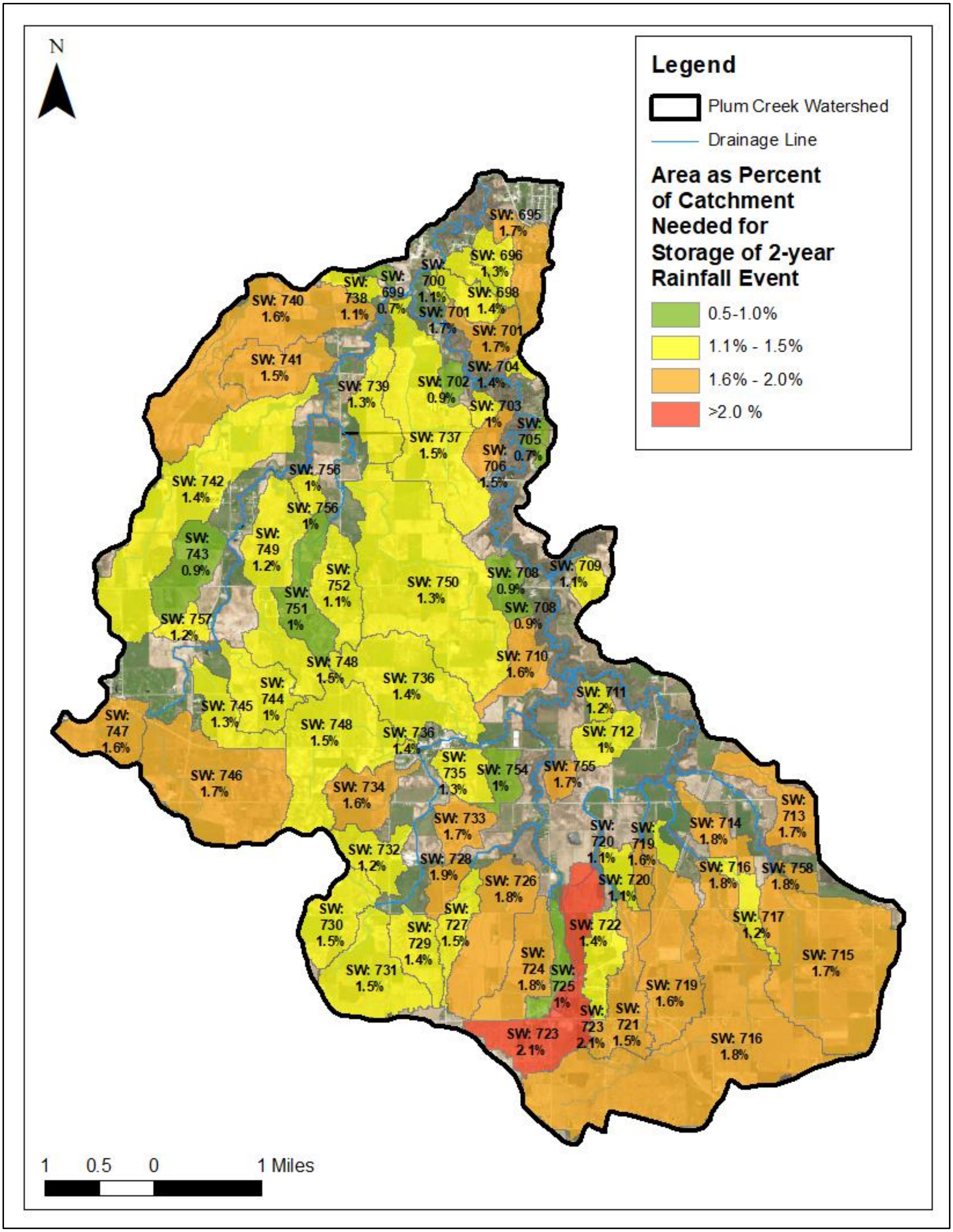

Figure B-2. Plum Creek percent of catchment needed for 2-year rainfall event.

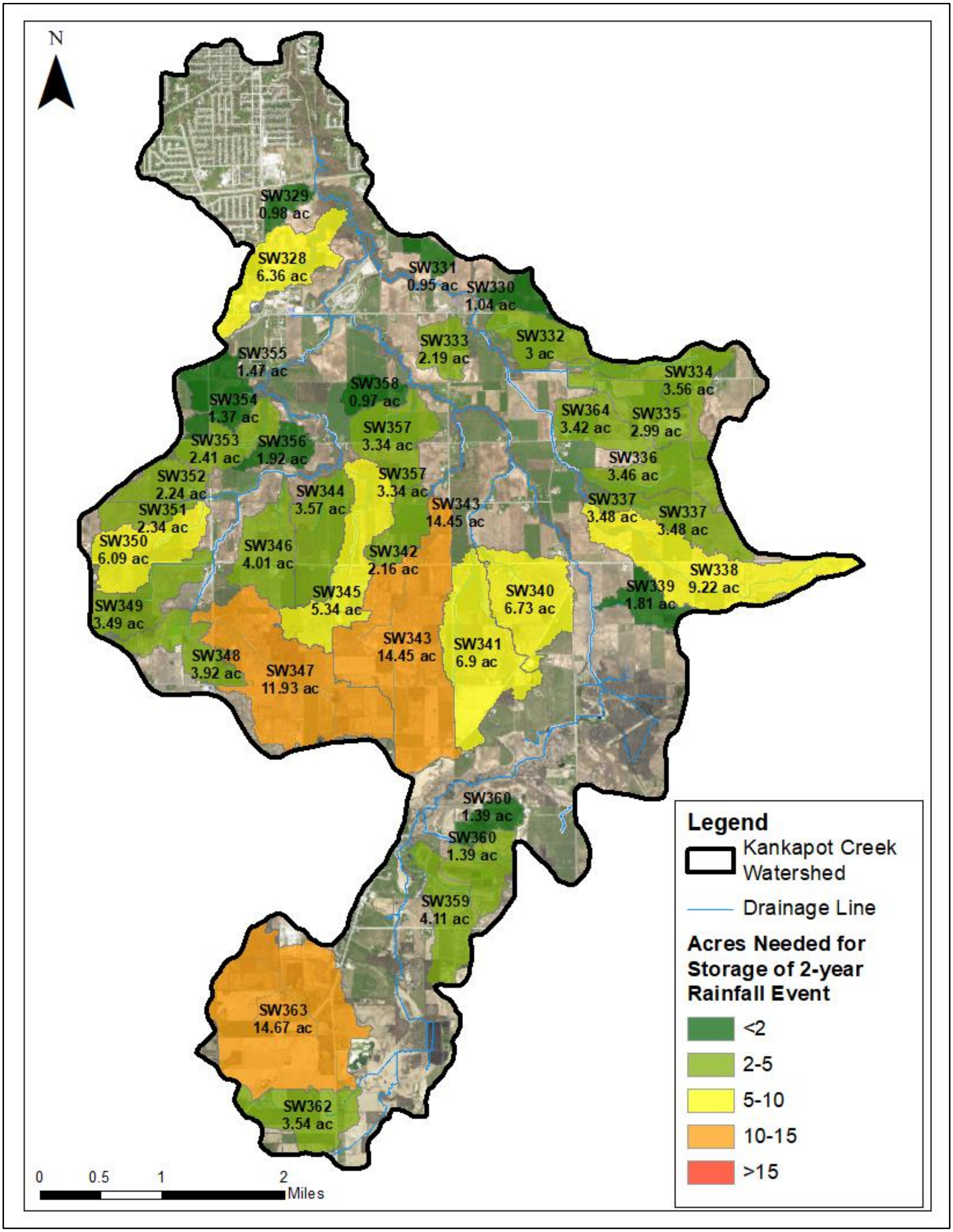

Figure B-3. Kankapot Creek acres of storage needed for 2-year rainfall event.

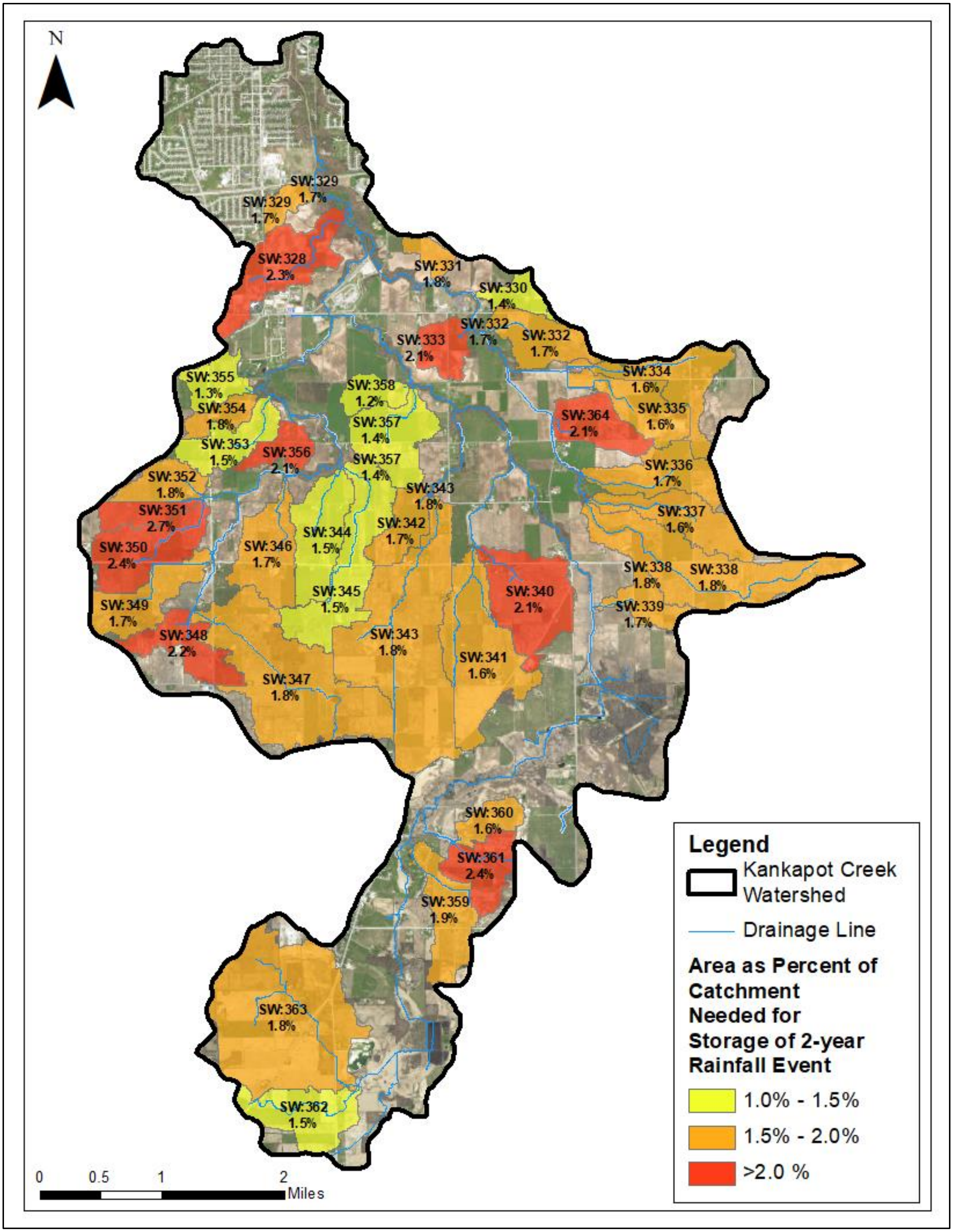

Figure B-4. Kankapot Creek percent of catchment needed for 2-year rainfall event.

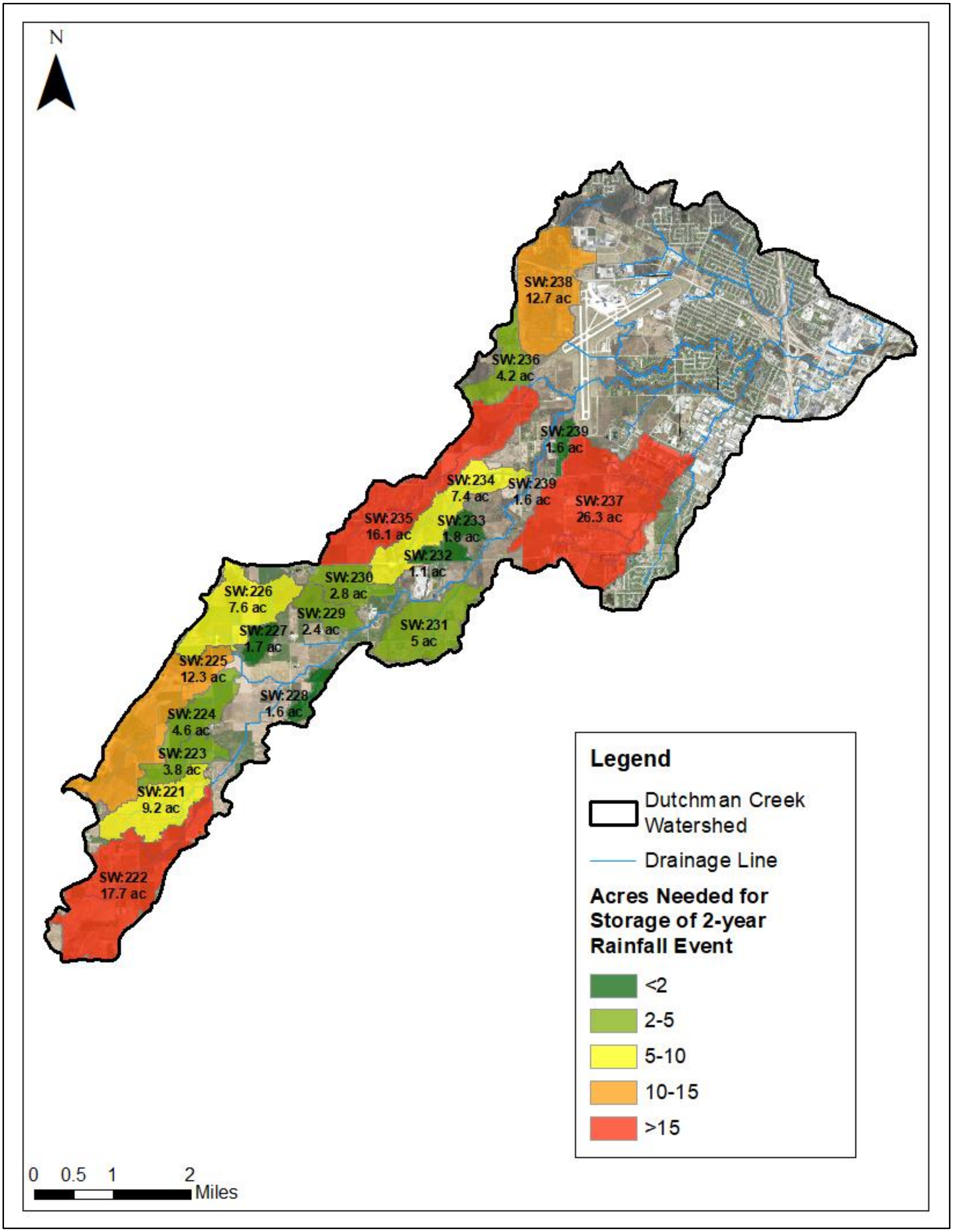

Figure B-5. Dutchman acres of storage needed for 2-year rainfall event.

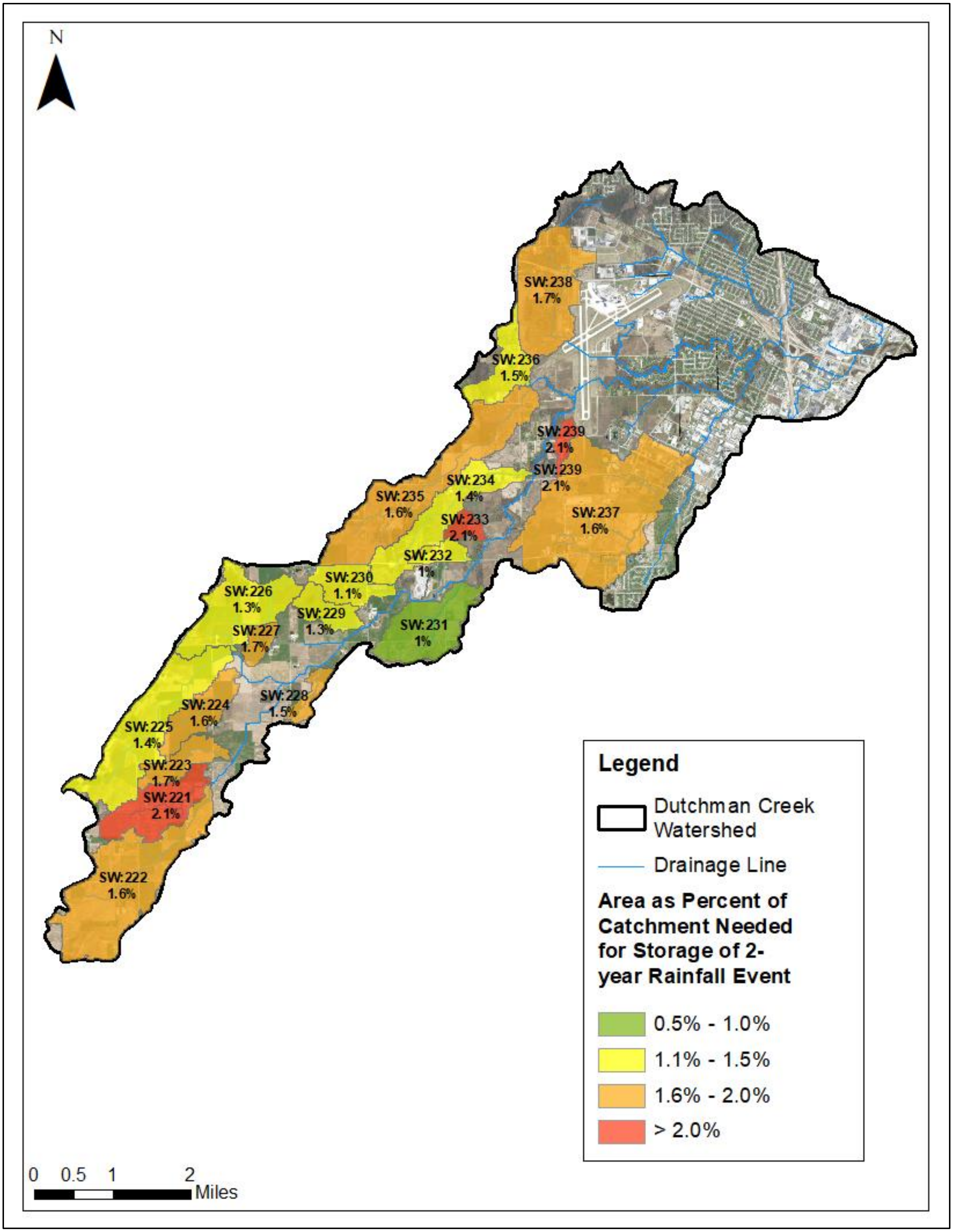

Figure B-6. Dutchman Creek percent of catchment needed for 2-year rainfall event.

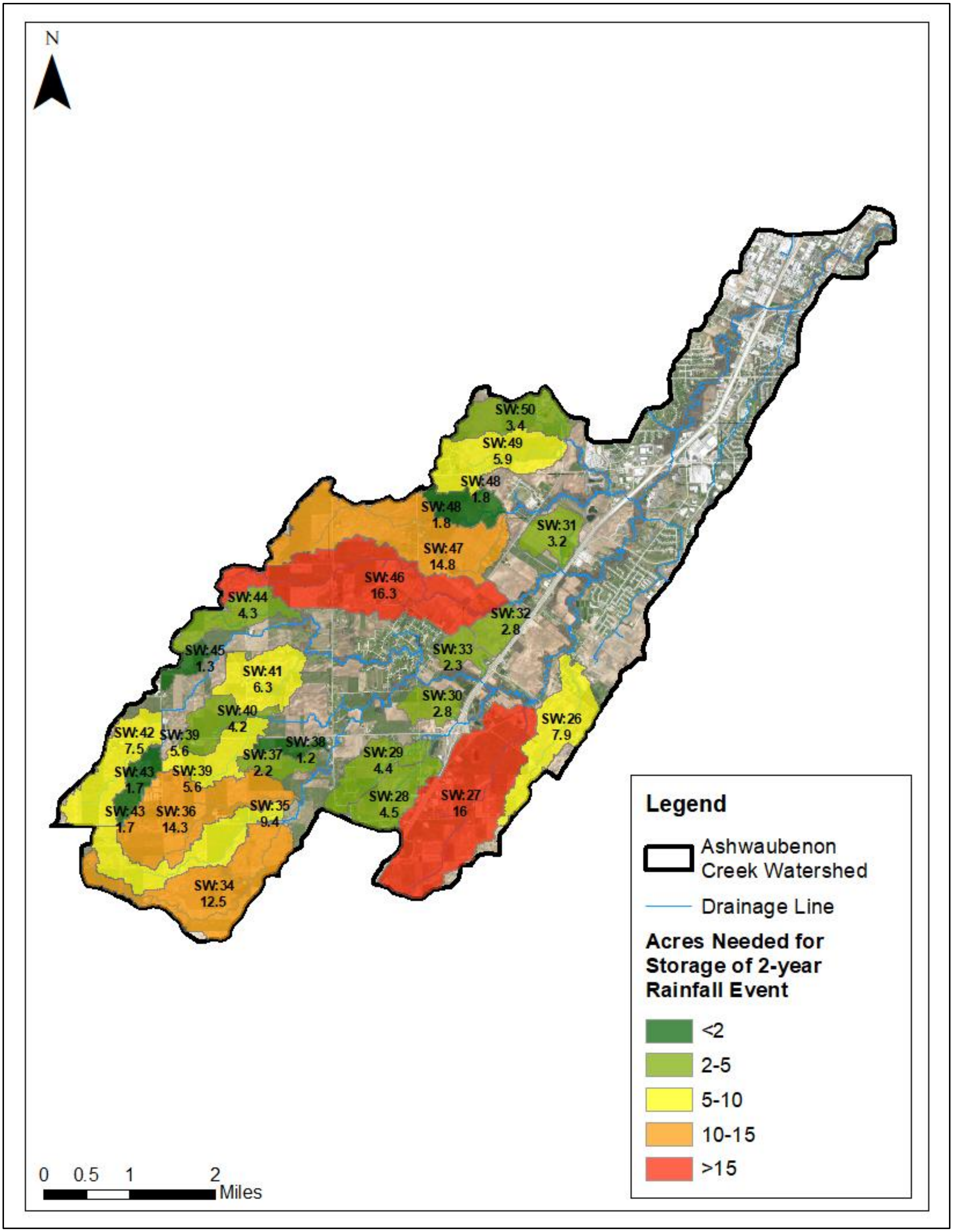

Figure B-7. Ashwaubenon Creek acres of storage needed for 2-year rainfall event.

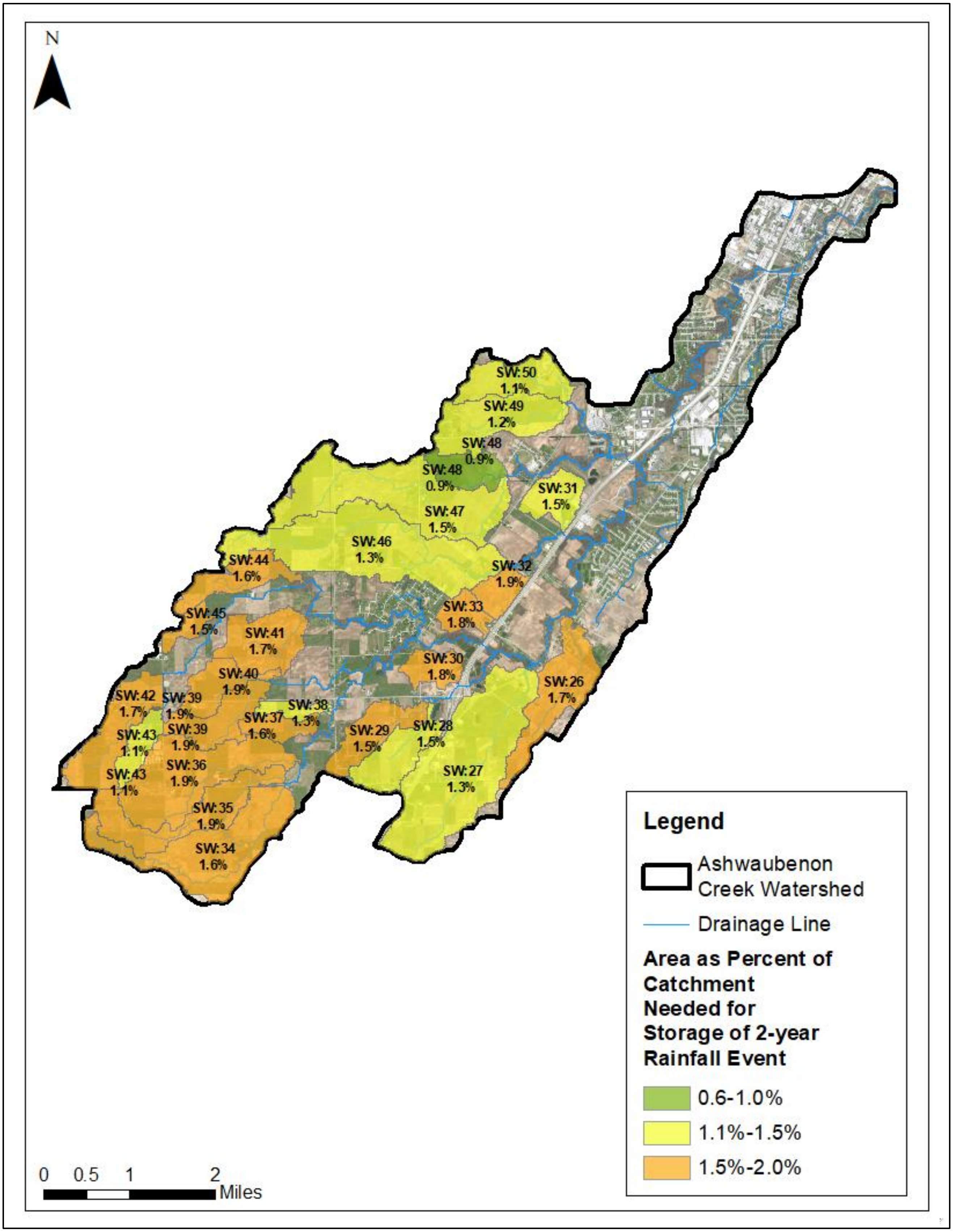

Figure B-8. Ashwaubenon Creek percent of catchment needed for 2-year rainfall event.

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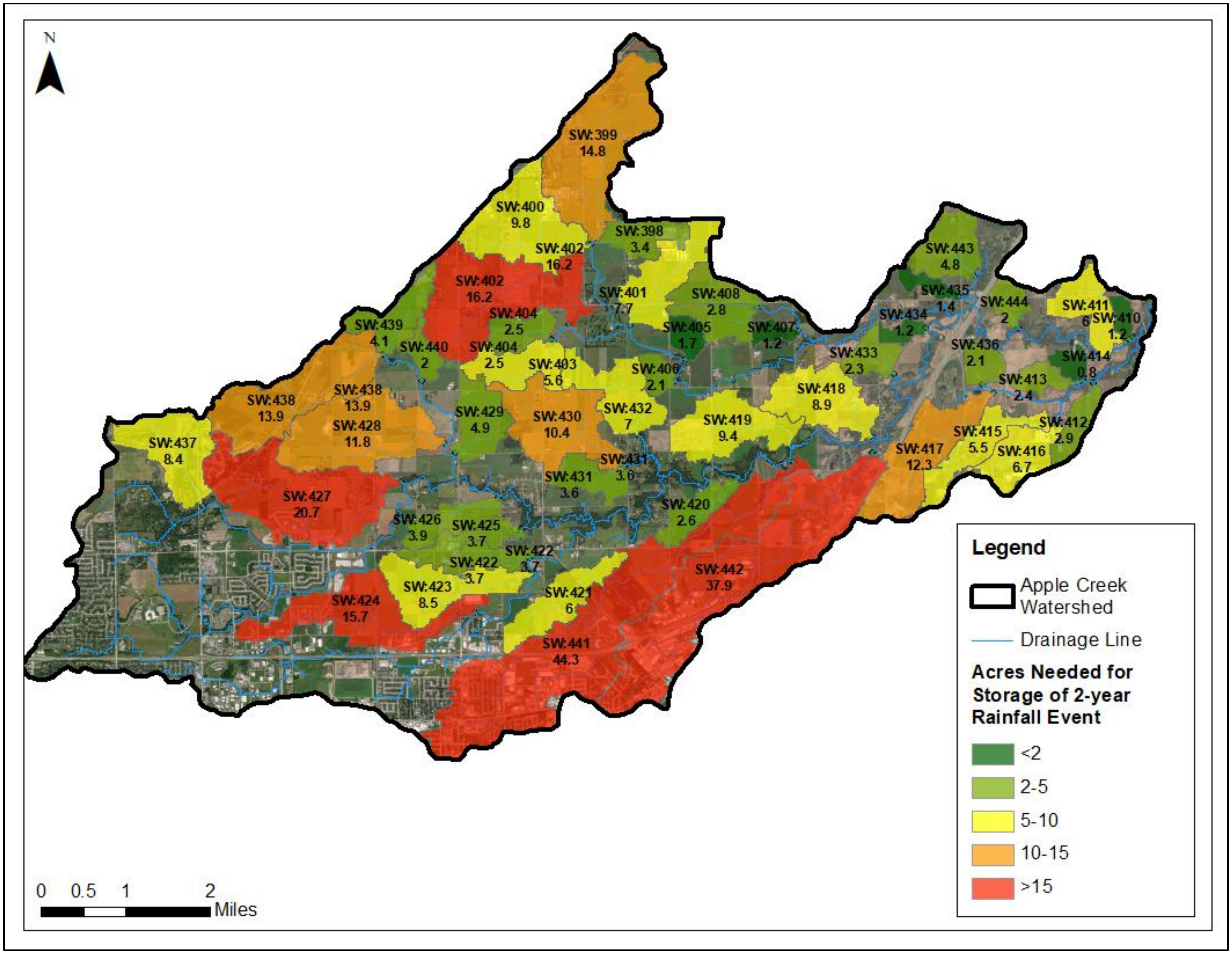

Figure B-9. Apple Creek acres of storage needed for 2-year rainfall event.

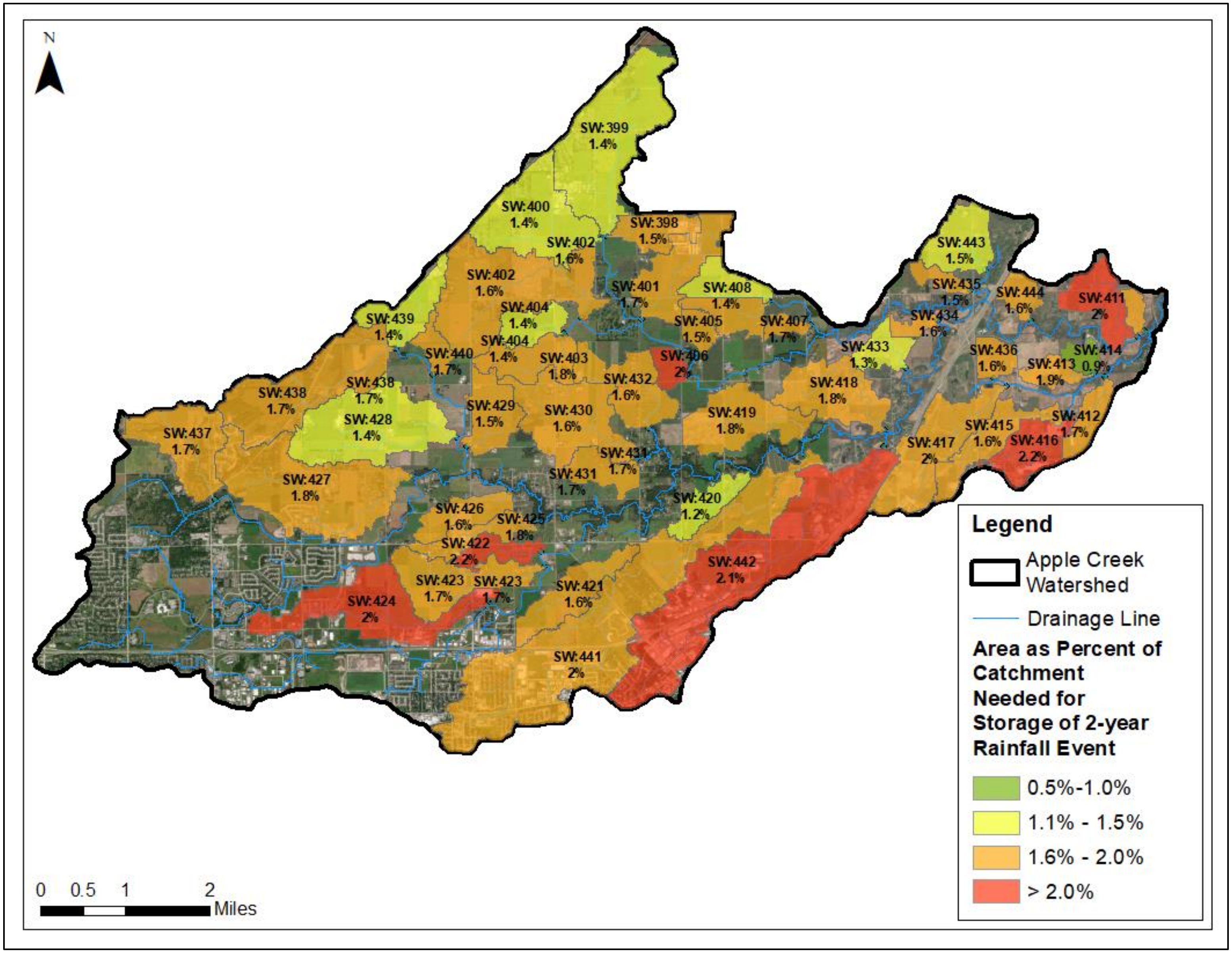

Figure B-10. Apple Creek percent of catchment needed for 2-year rainfall event.

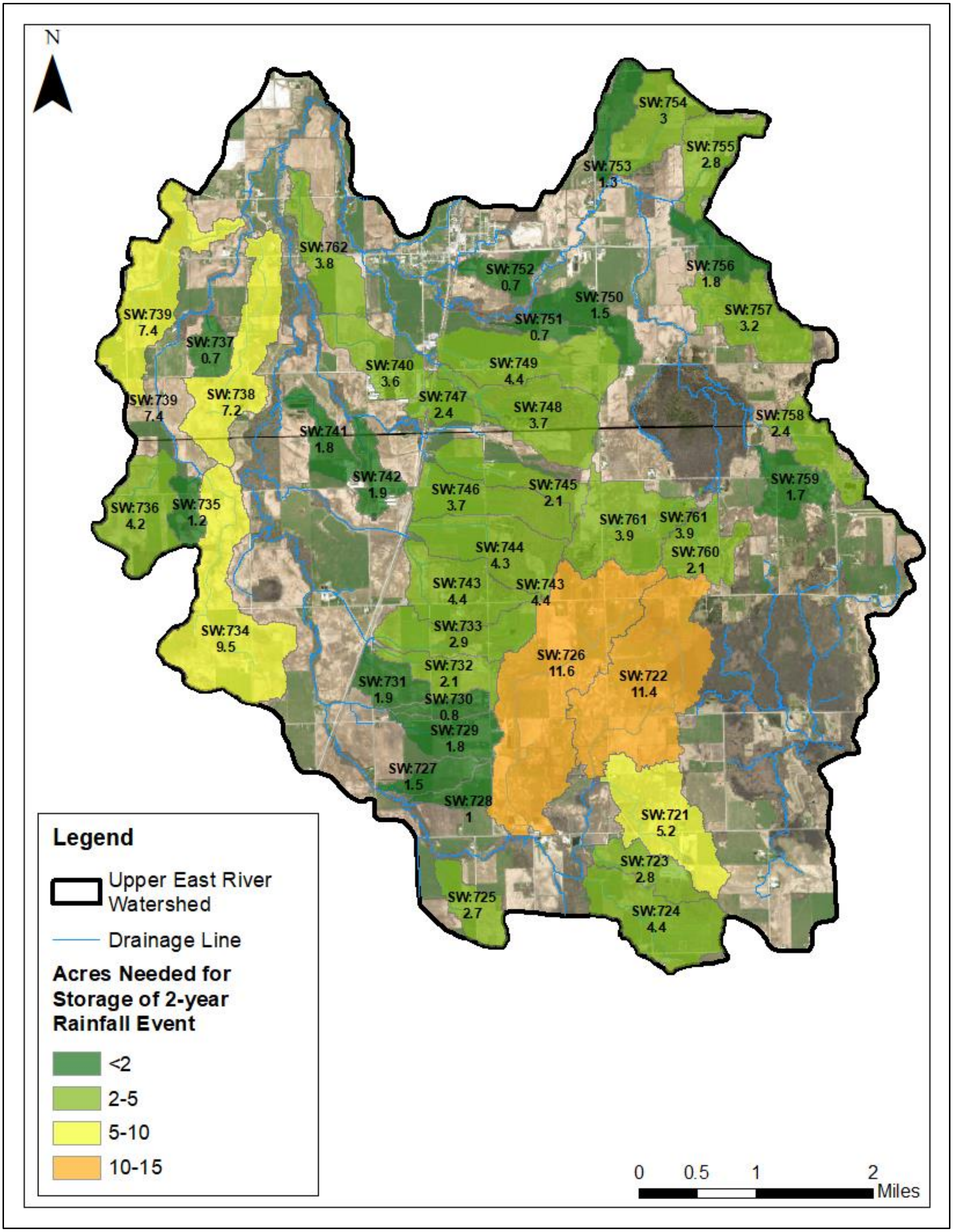

Figure B-11. Upper East River acres of storage needed for 2-year rainfall event.

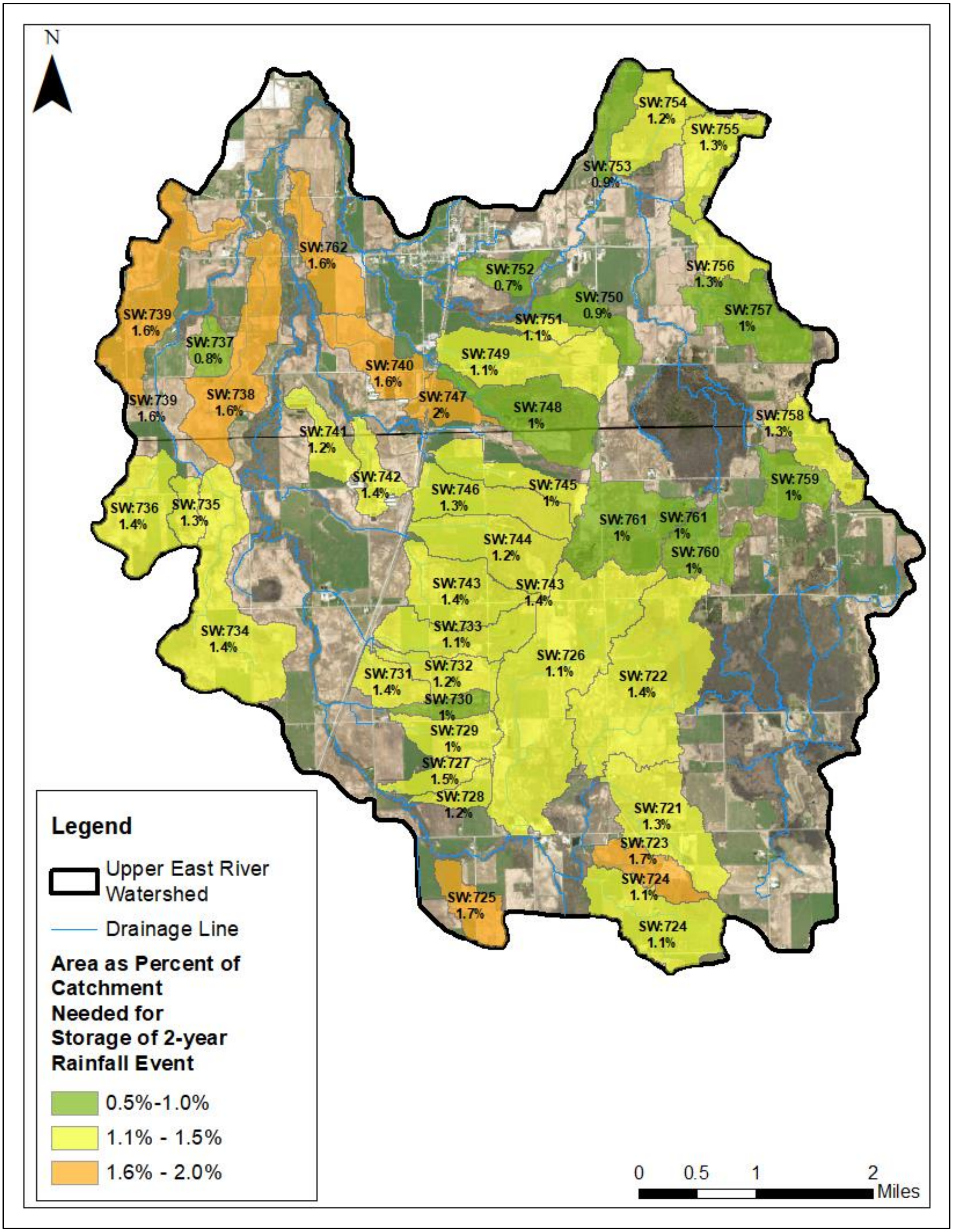

Figure B-12. Upper East River percent of catchment needed for 2-year rainfall event.

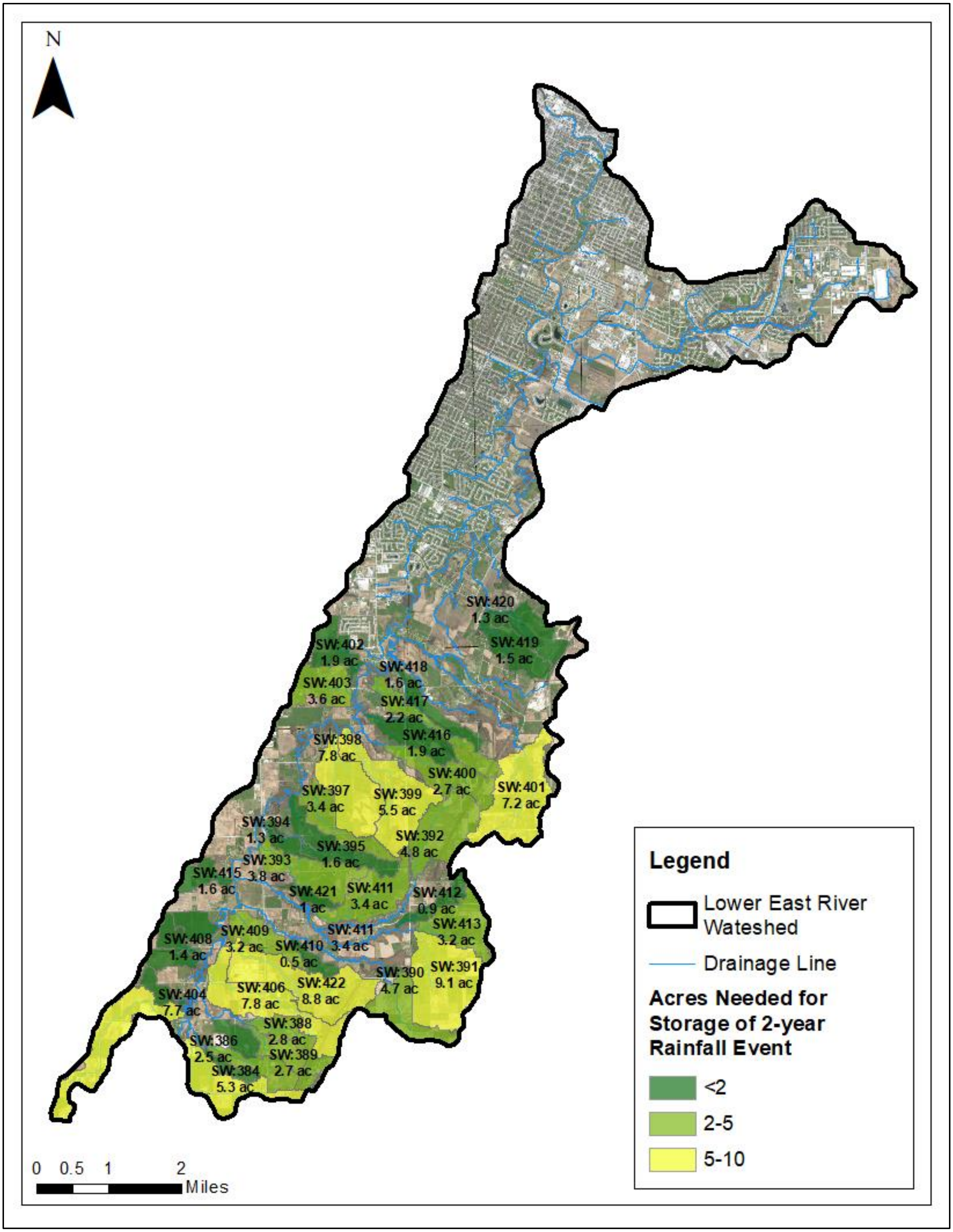

Figure B-13. Lower East River acres of storage needed for 2-year rainfall event.

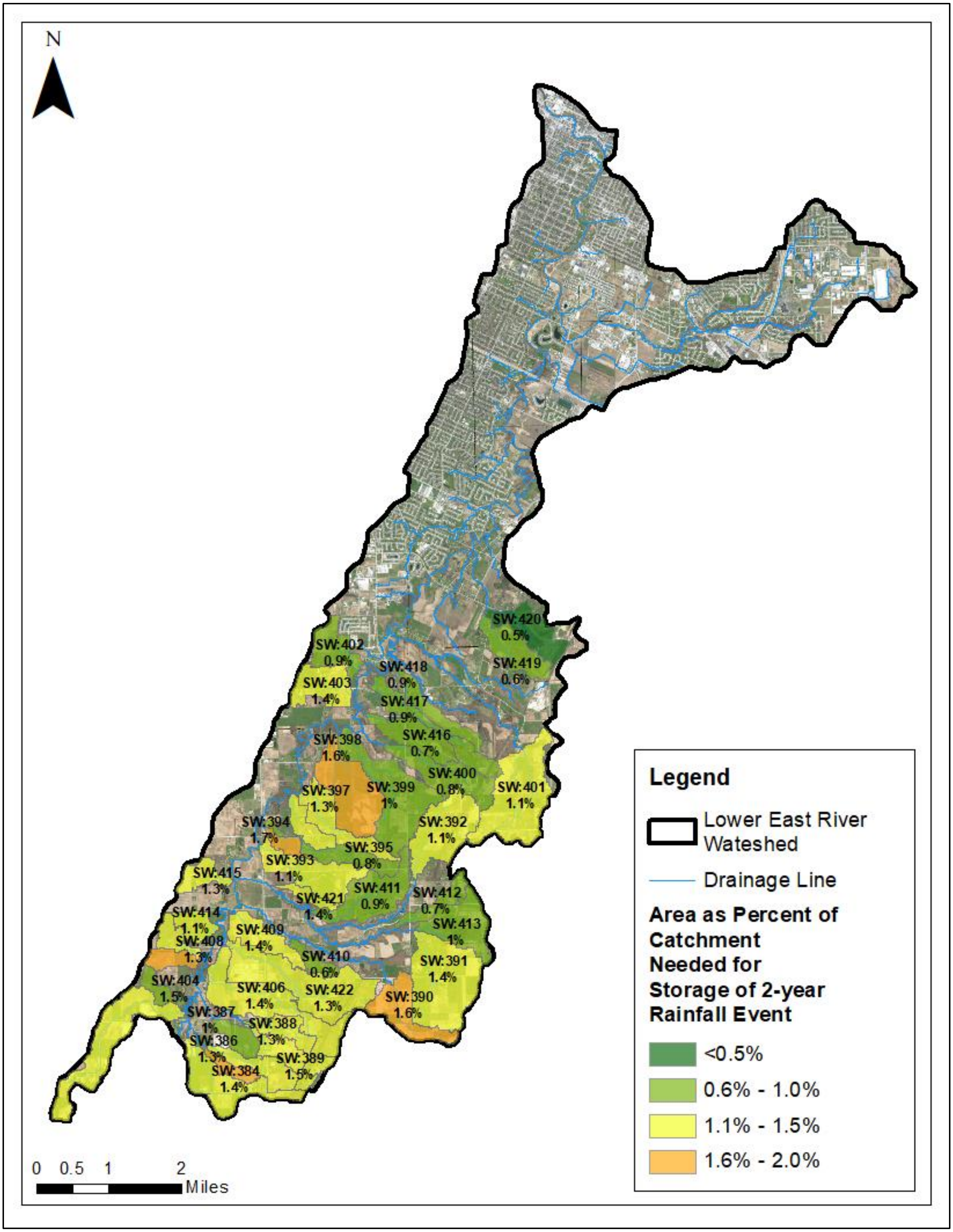

Figure B-14. Lower East River percent of catchment needed for 2-year rainfall event.

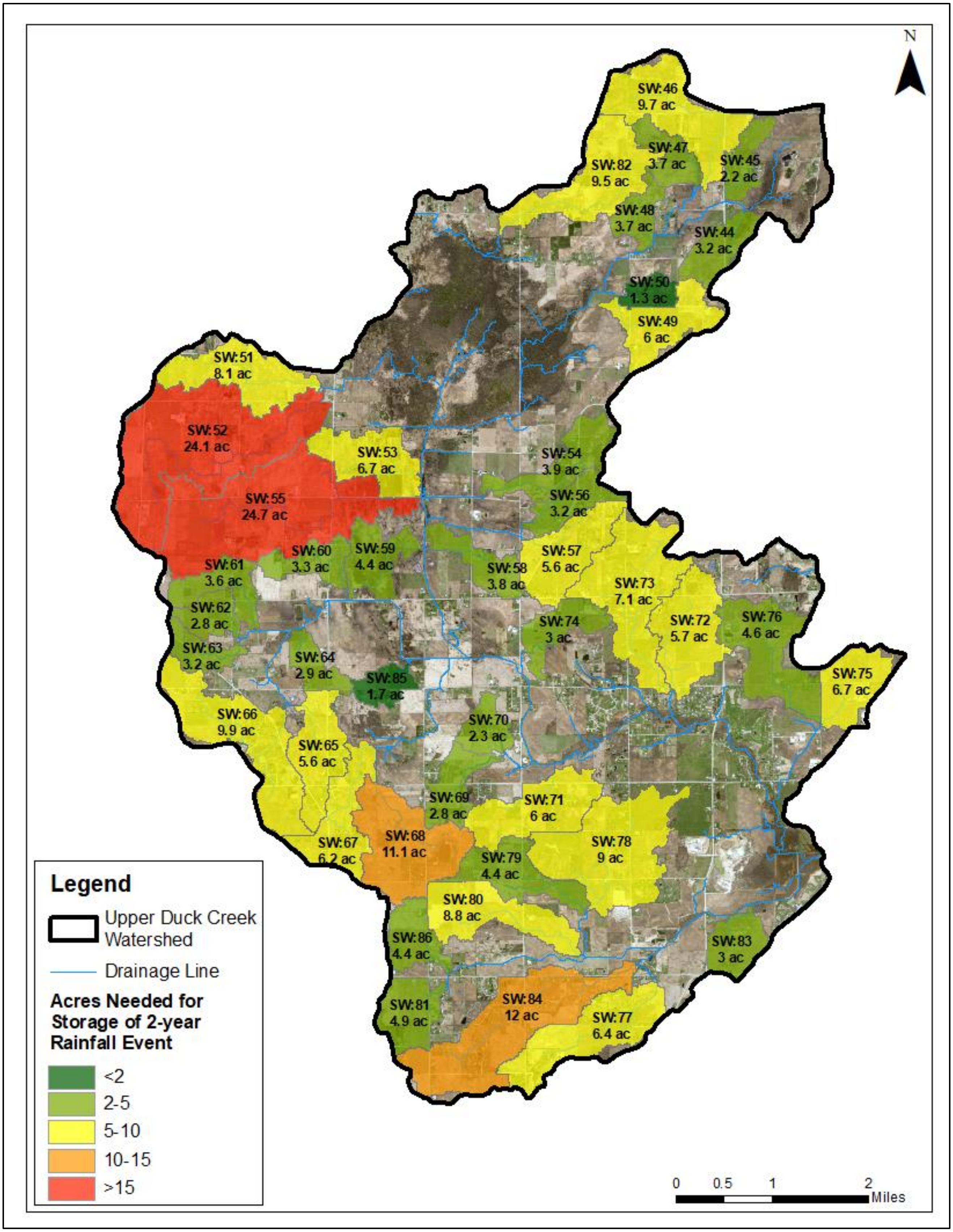

Figure B-15. Upper Duck Creek acres of storage needed for 2-year rainfall event.

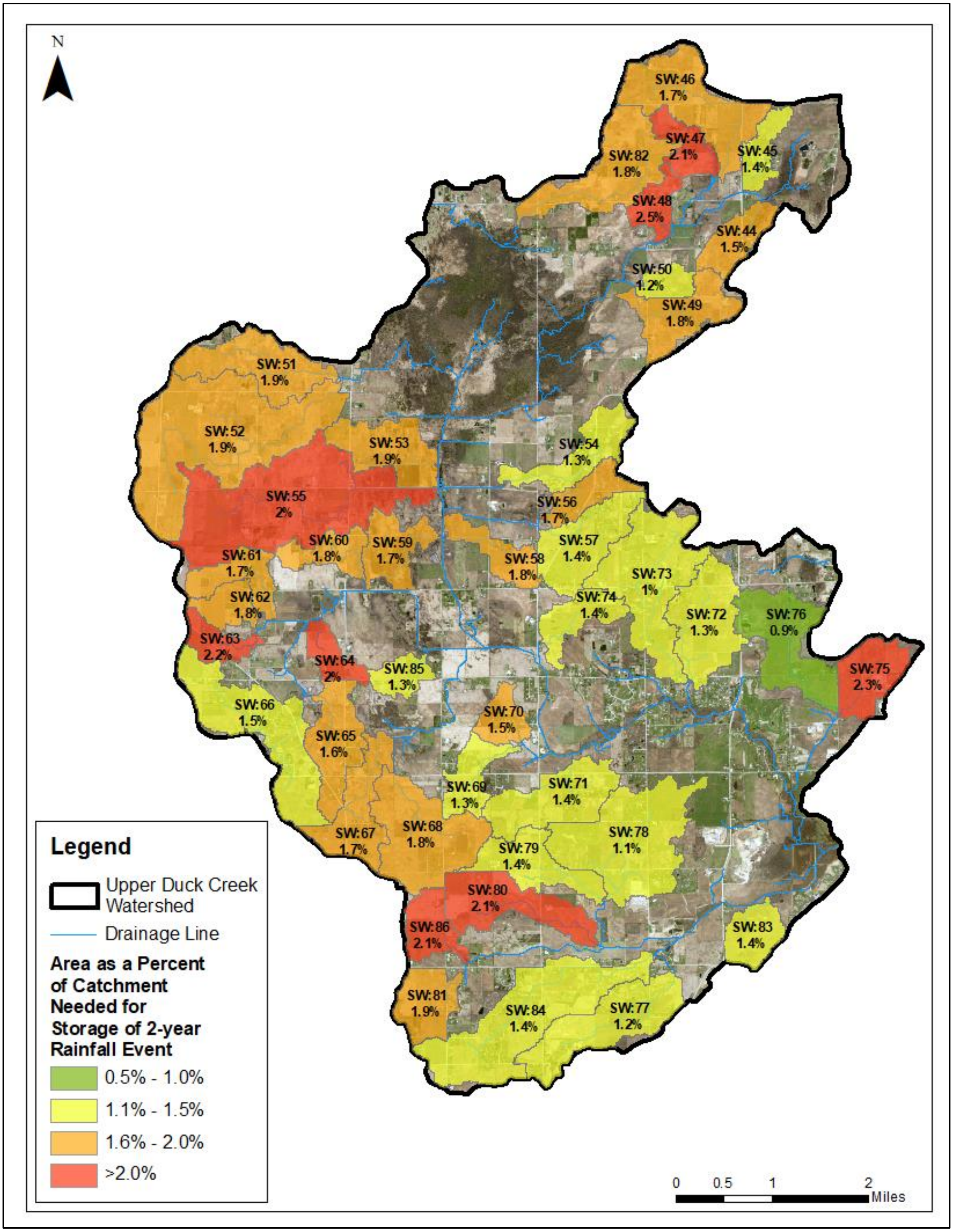

Figure B-16. Upper Duck Creek percent of catchment needed for 2-year rainfall event.

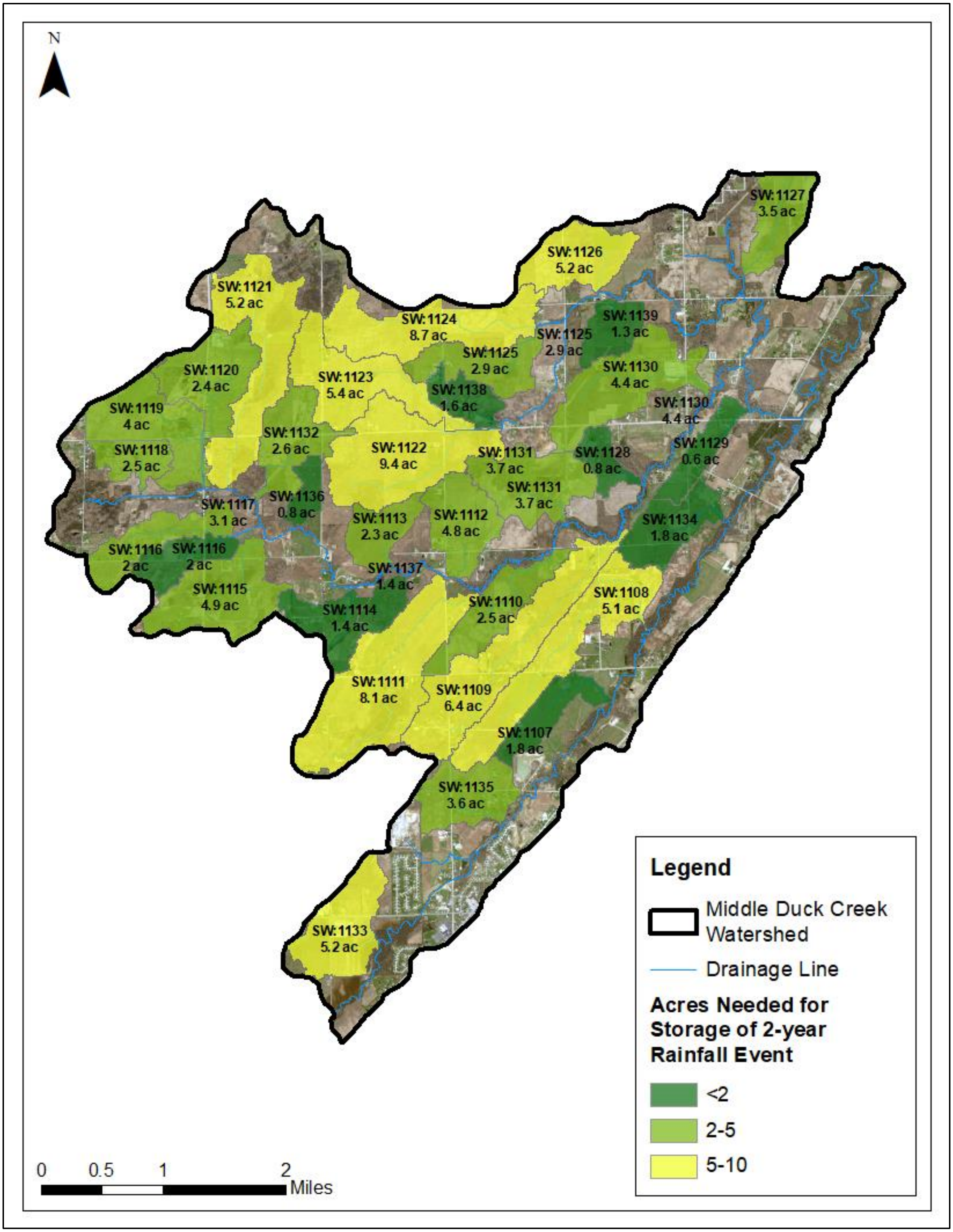

Figure B-17. Middle Duck Creek acres of storage needed for 2-year rainfall event.

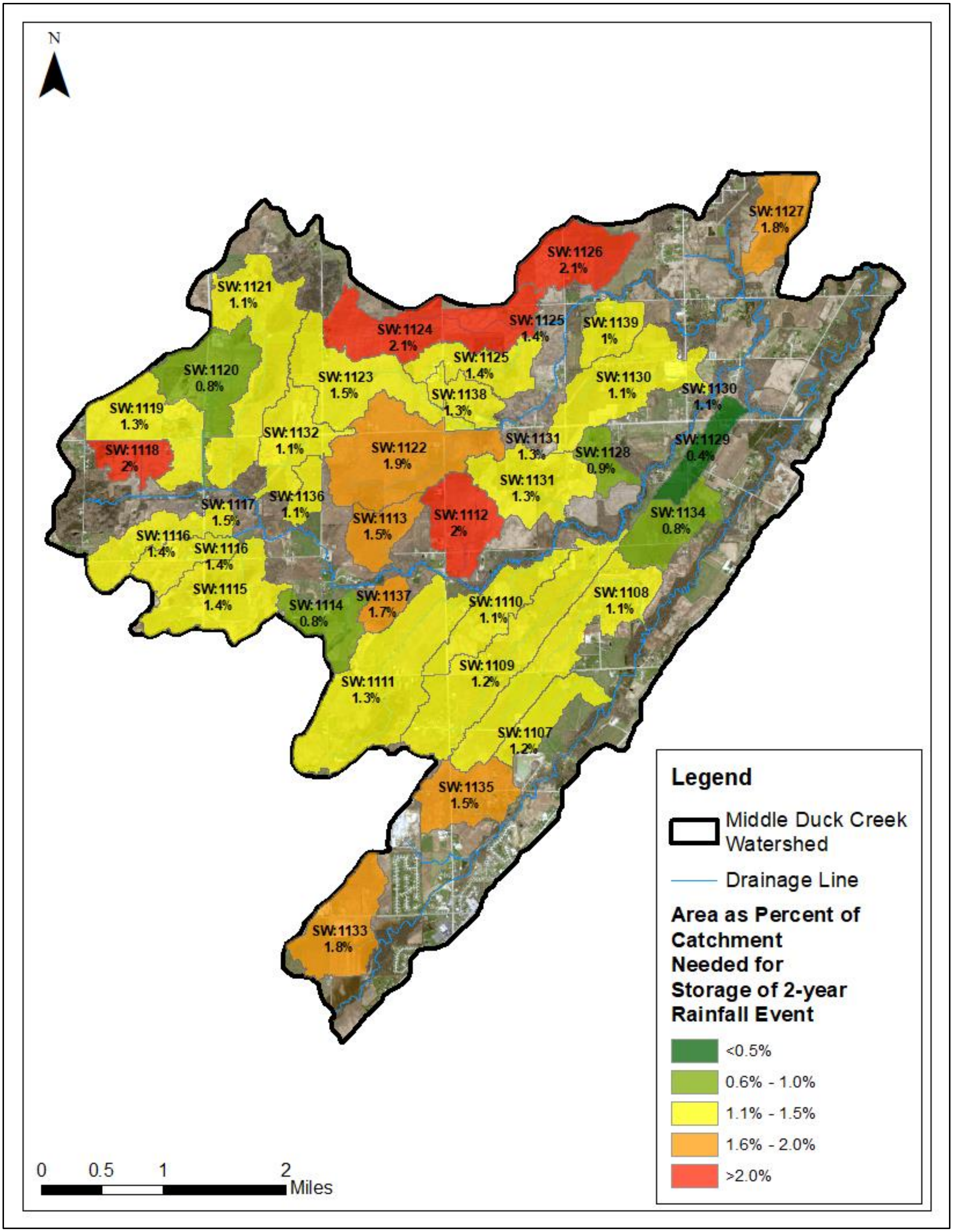

Figure B-18. Middle Duck Creek percent of catchment needed for 2-year rainfall event.

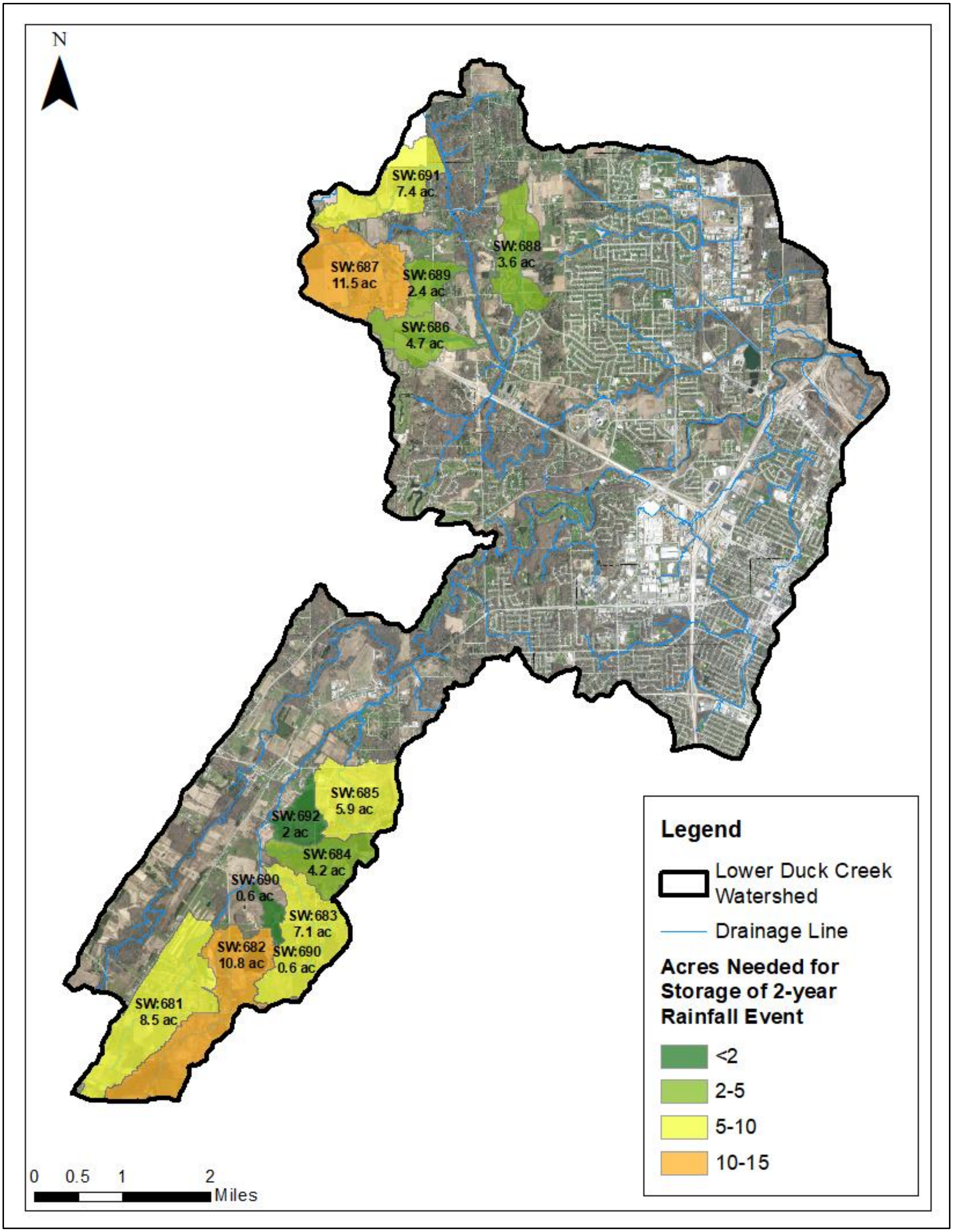

Figure B-19. Lower Duck Creek acres of storage needed for 2-year rainfall event.

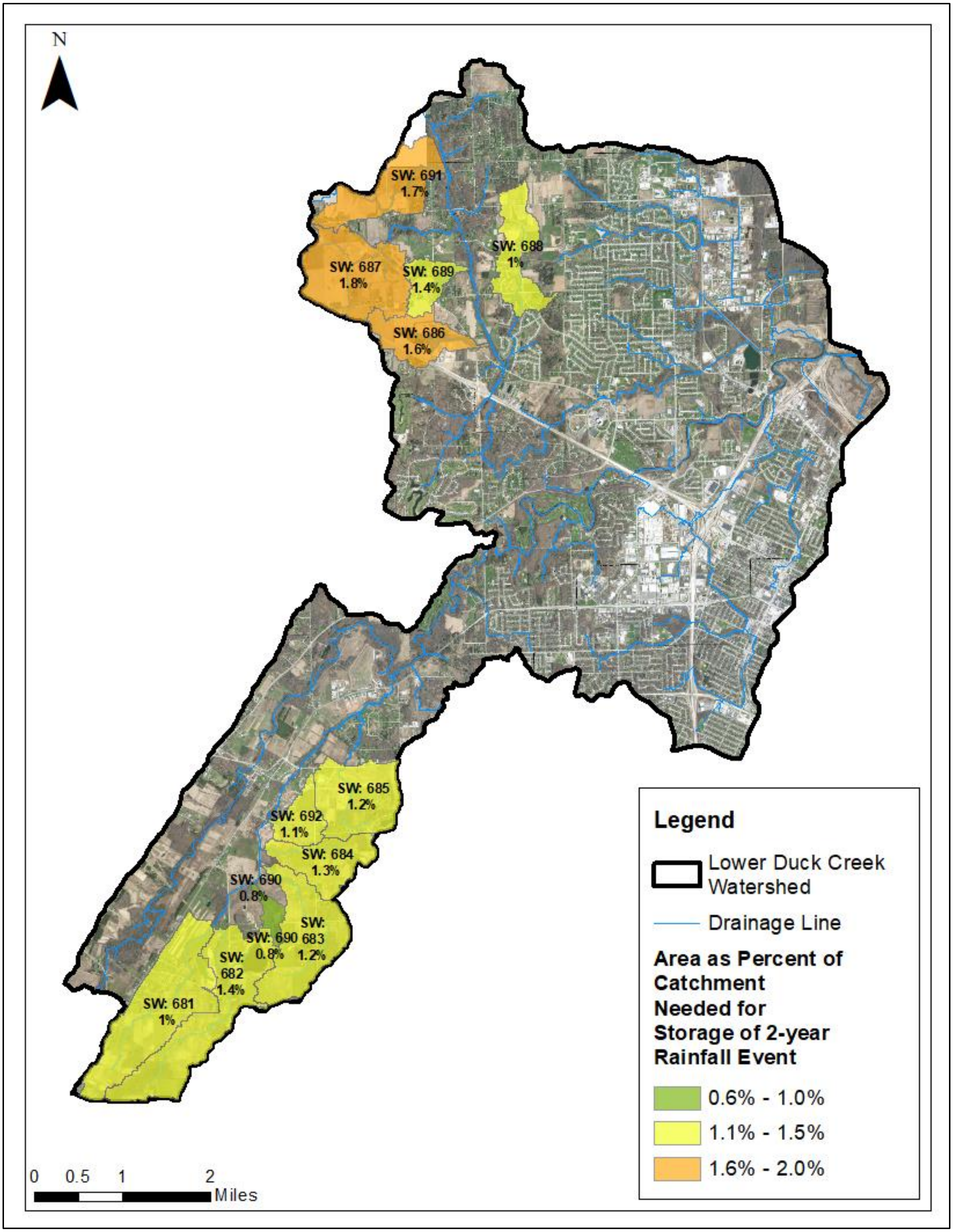

Figure B-20. Lower Duck Creek percent of catchment needed for 2-year rainfall event.

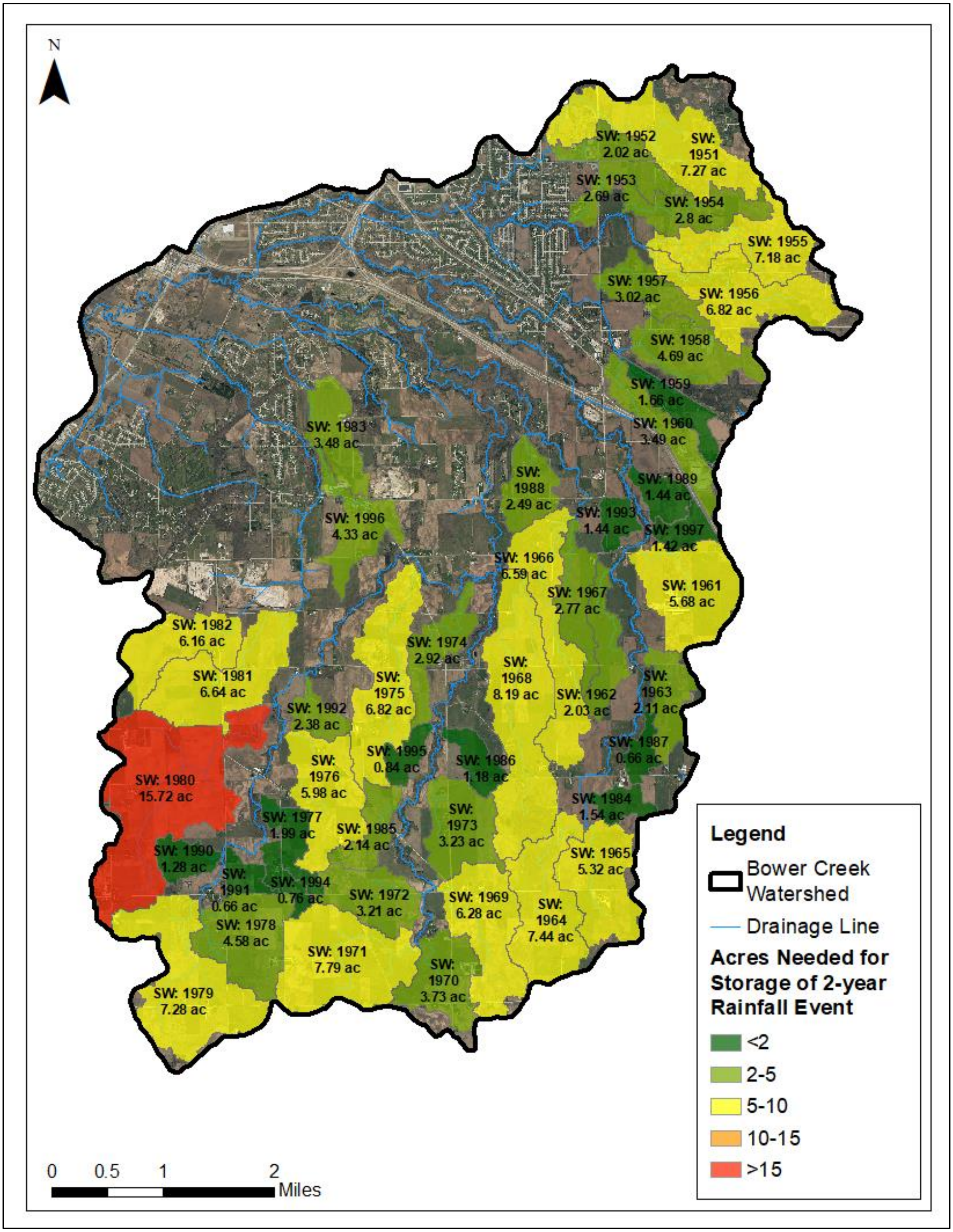

Figure B-21. Upper East River acres of storage needed for 2-year rainfall event.

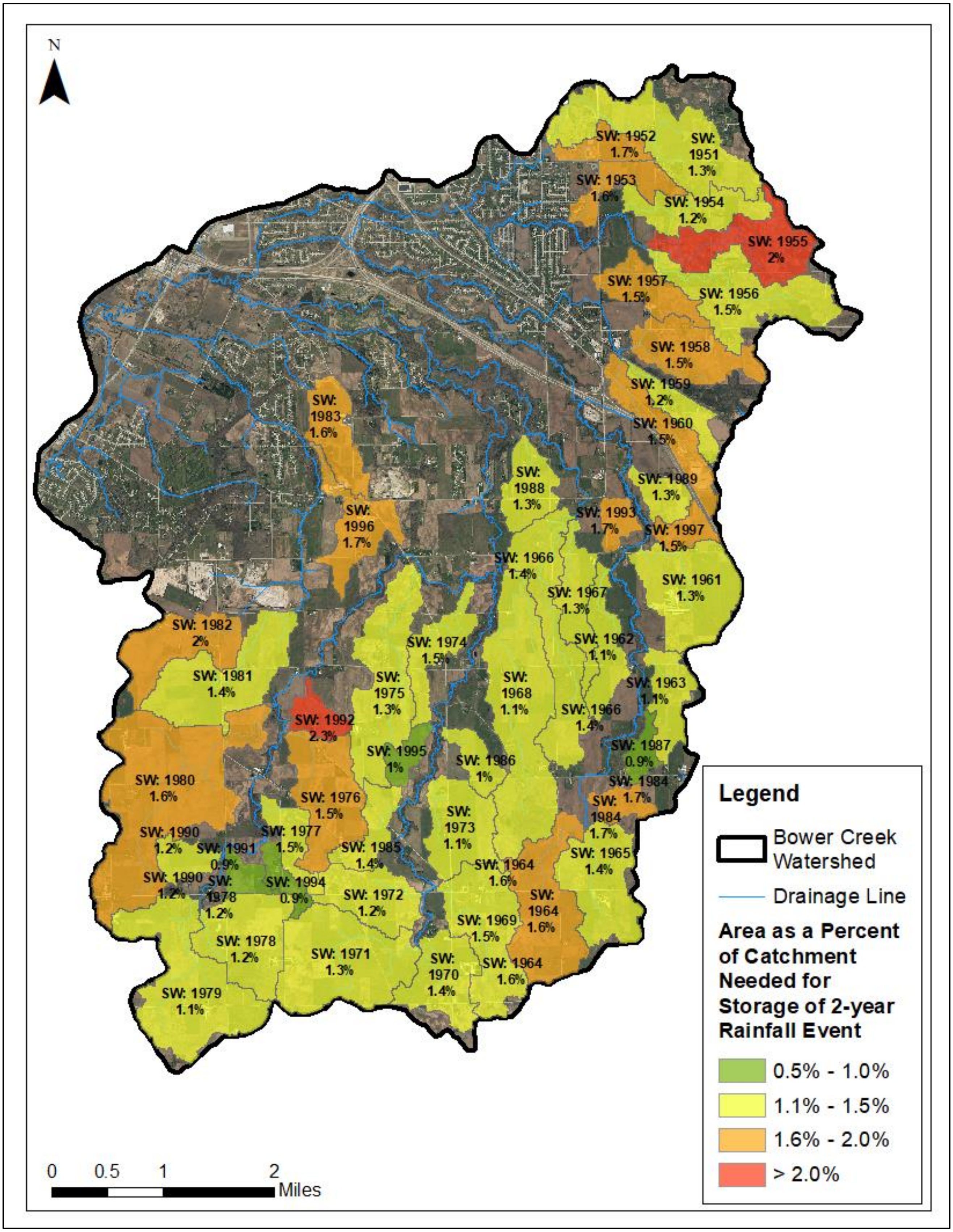

Figure B-22. Upper East River percent of catchment needed for 2-year rainfall event.

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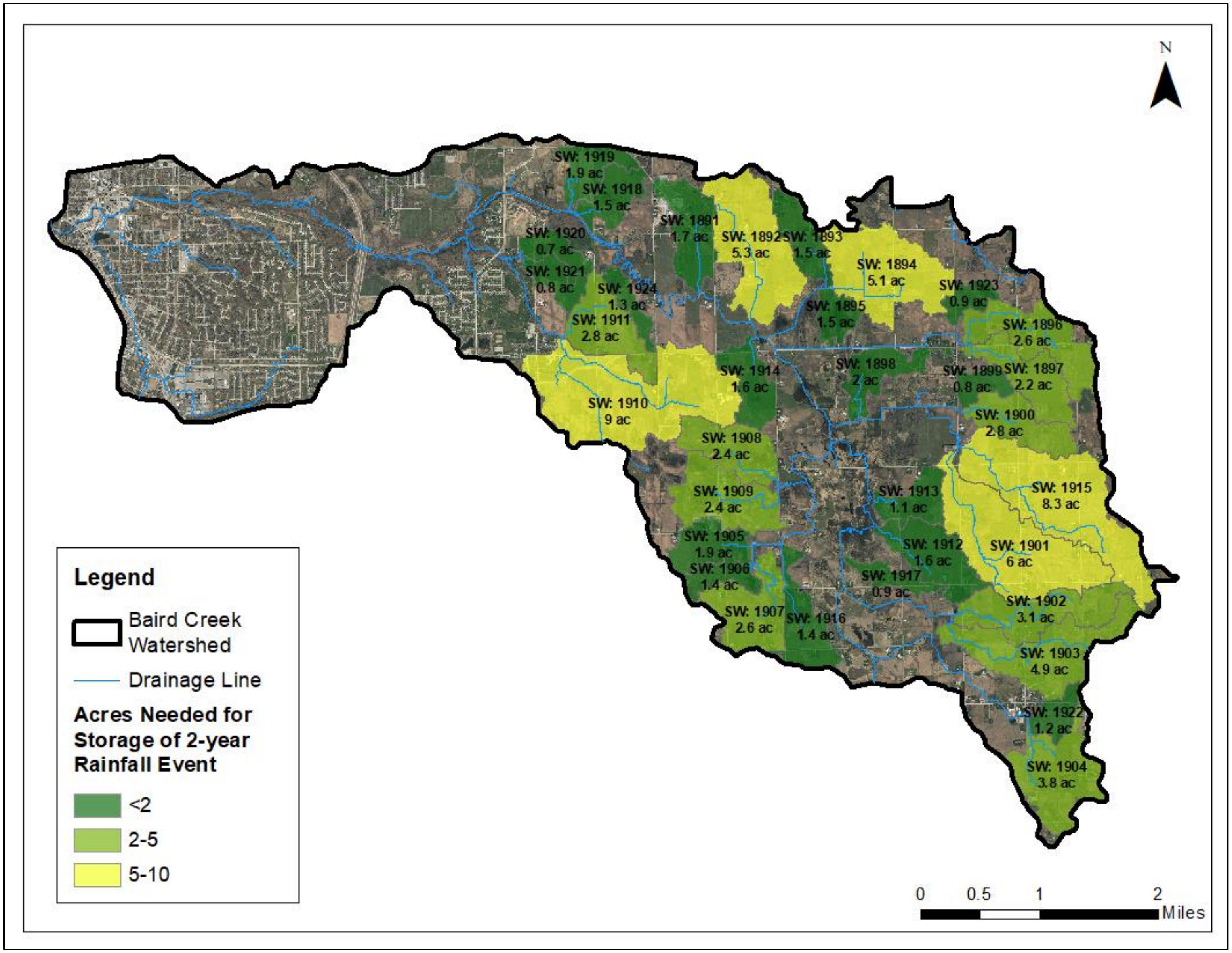

Figure B-23. Baird Creek acres of storage needed for 2-year rainfall event.

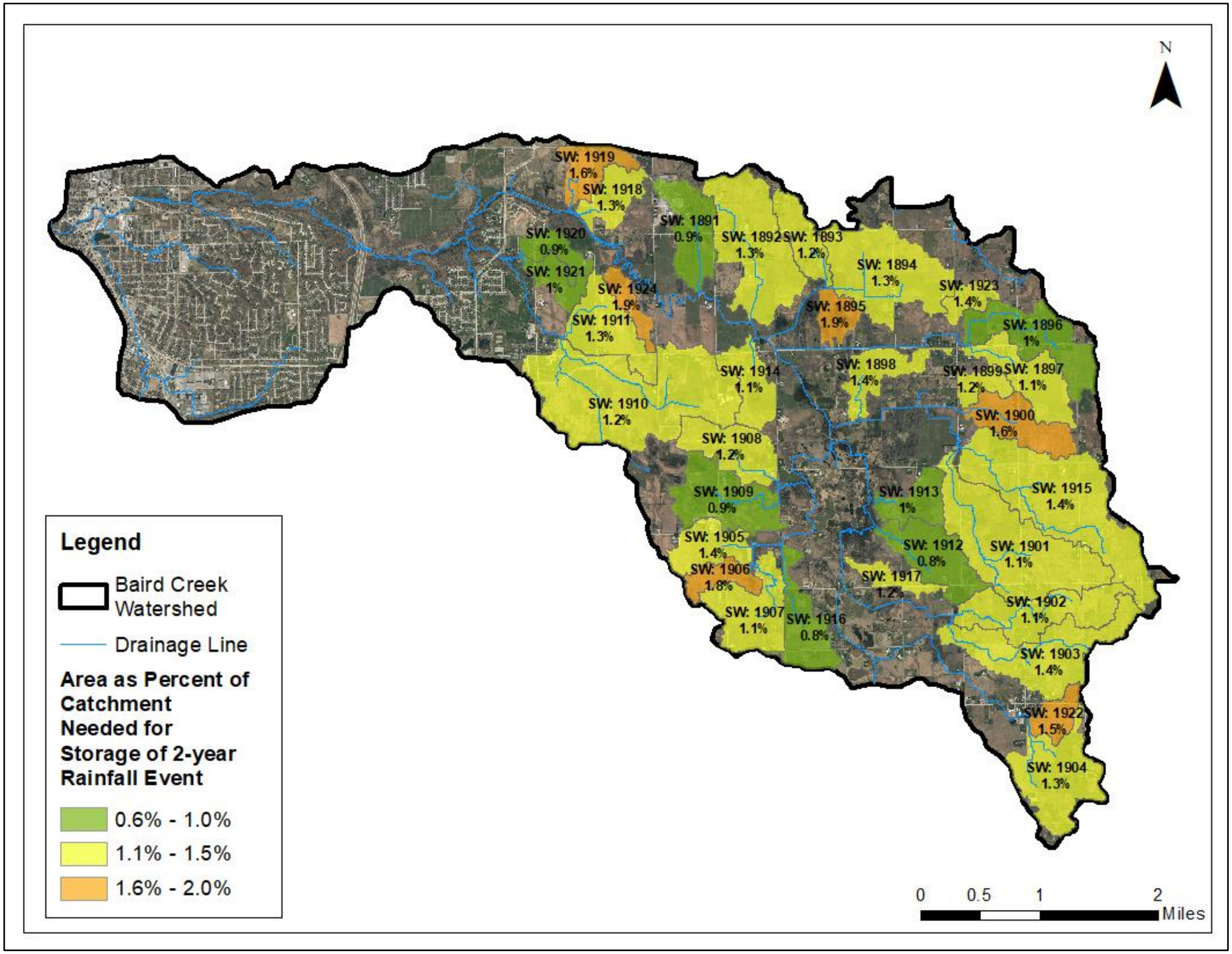

Figure B-24. Baird Creek percent of catchment needed for 2-year rainfall event.

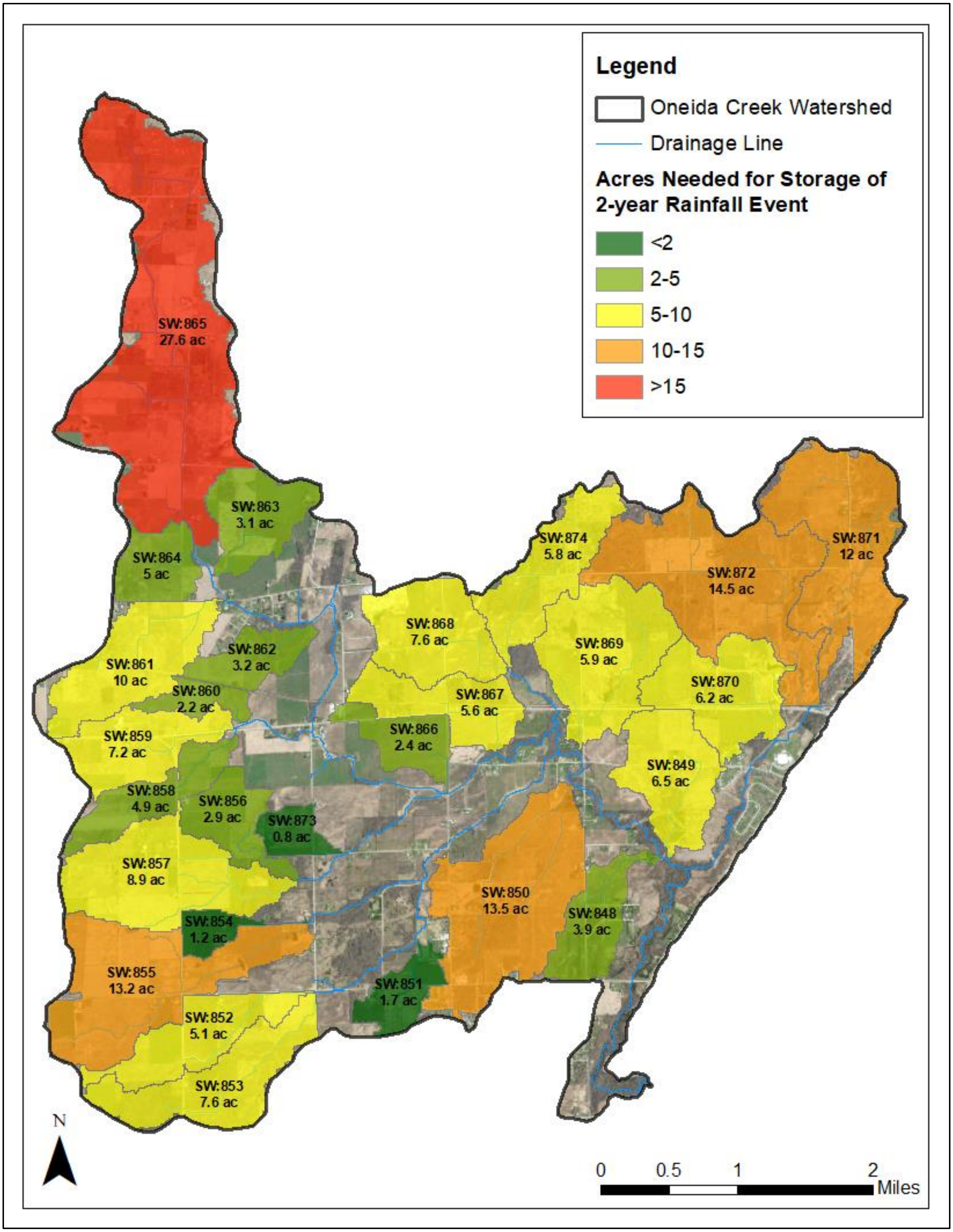

Figure B-25. Oneida Creek acres of storage needed for 2-year rainfall event.

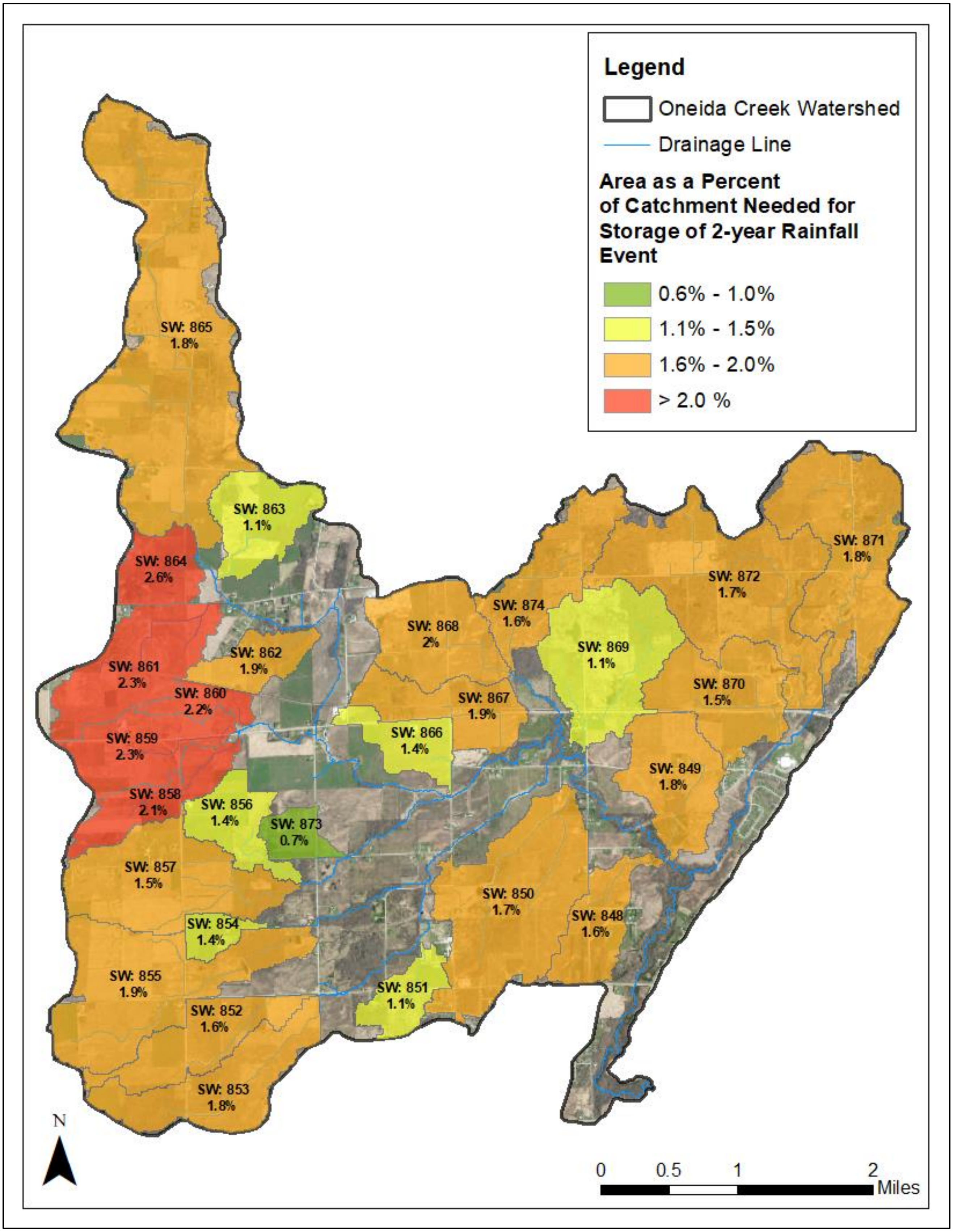

Figure B-26. Oneida Creek percent of catchment needed for 2-year rainfall event.

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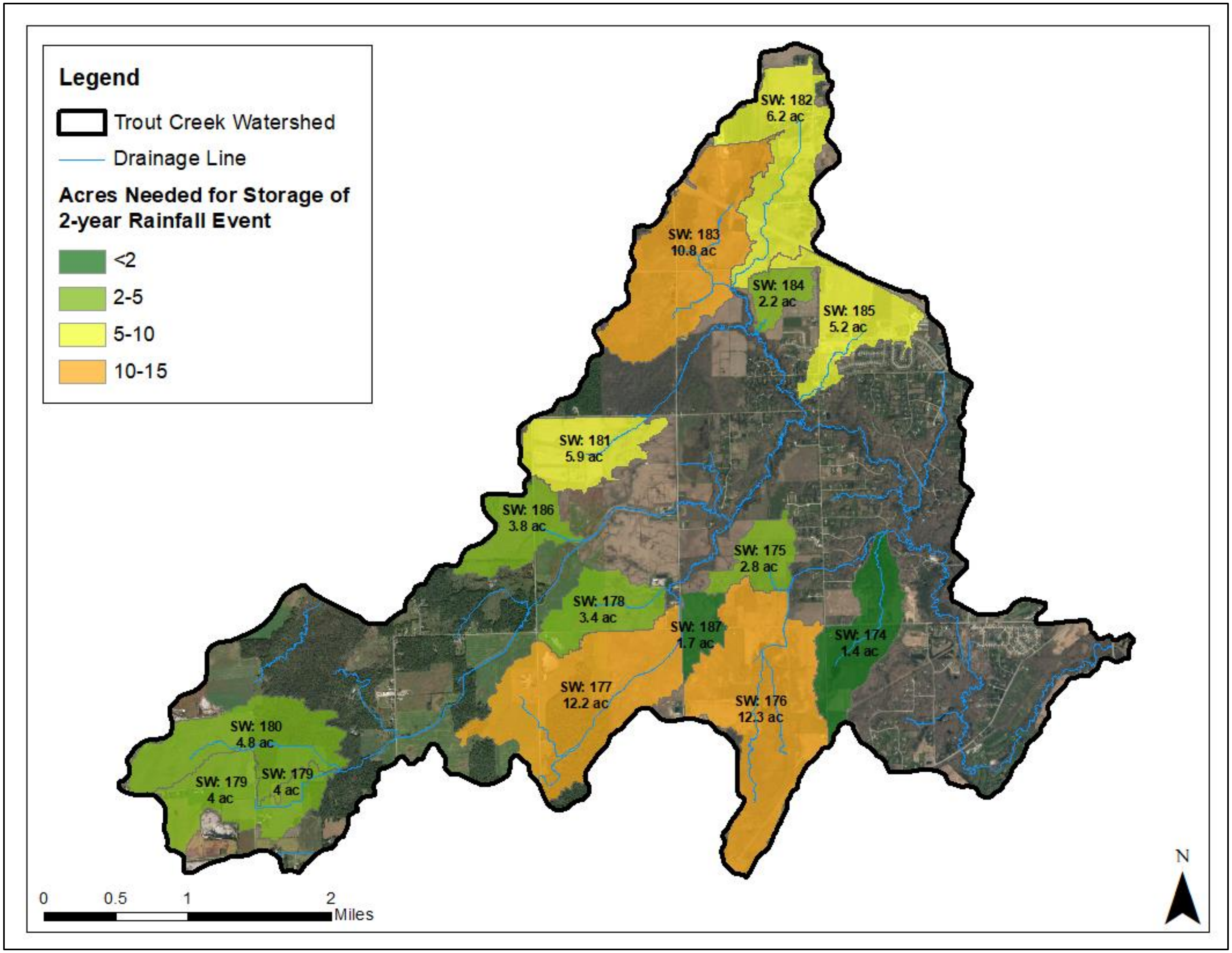

Figure B-27. Trout Creek acres of storage needed for 2-year rainfall event.

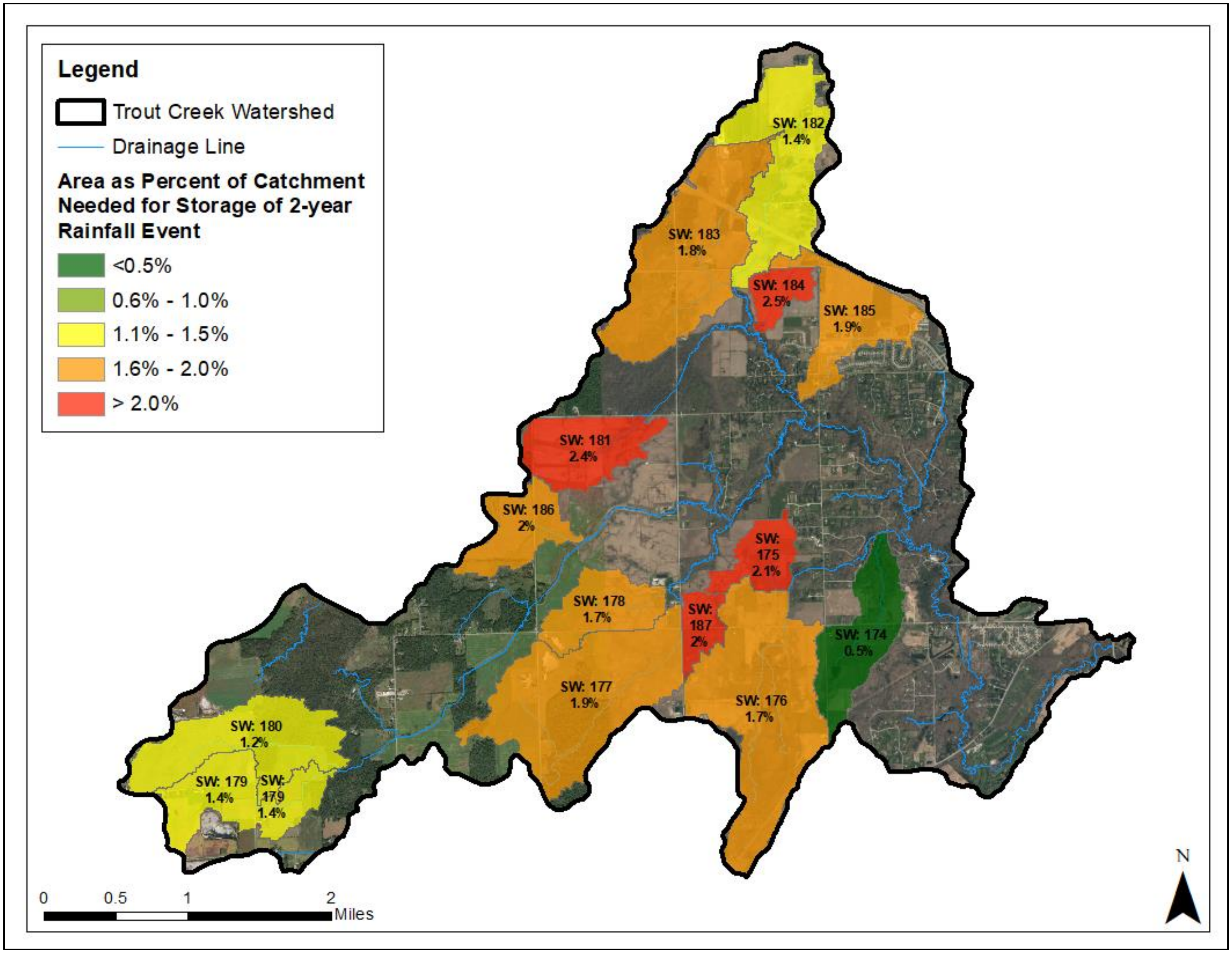

Figure B-28. Trout Creek percent of catchment needed for 2-year rainfall event.

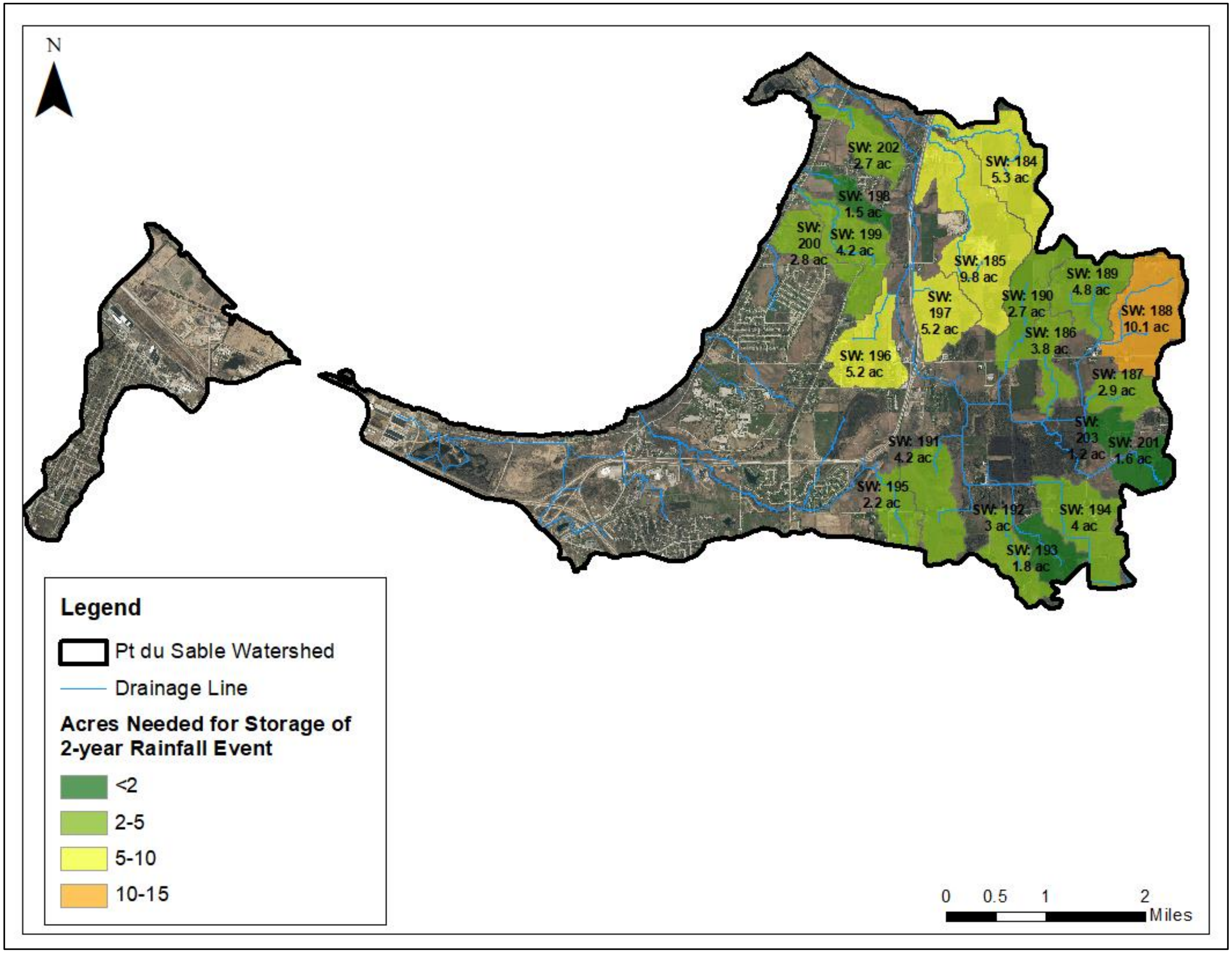

Figure B-29. Point du Sable acres of storage needed for 2-year rainfall event.

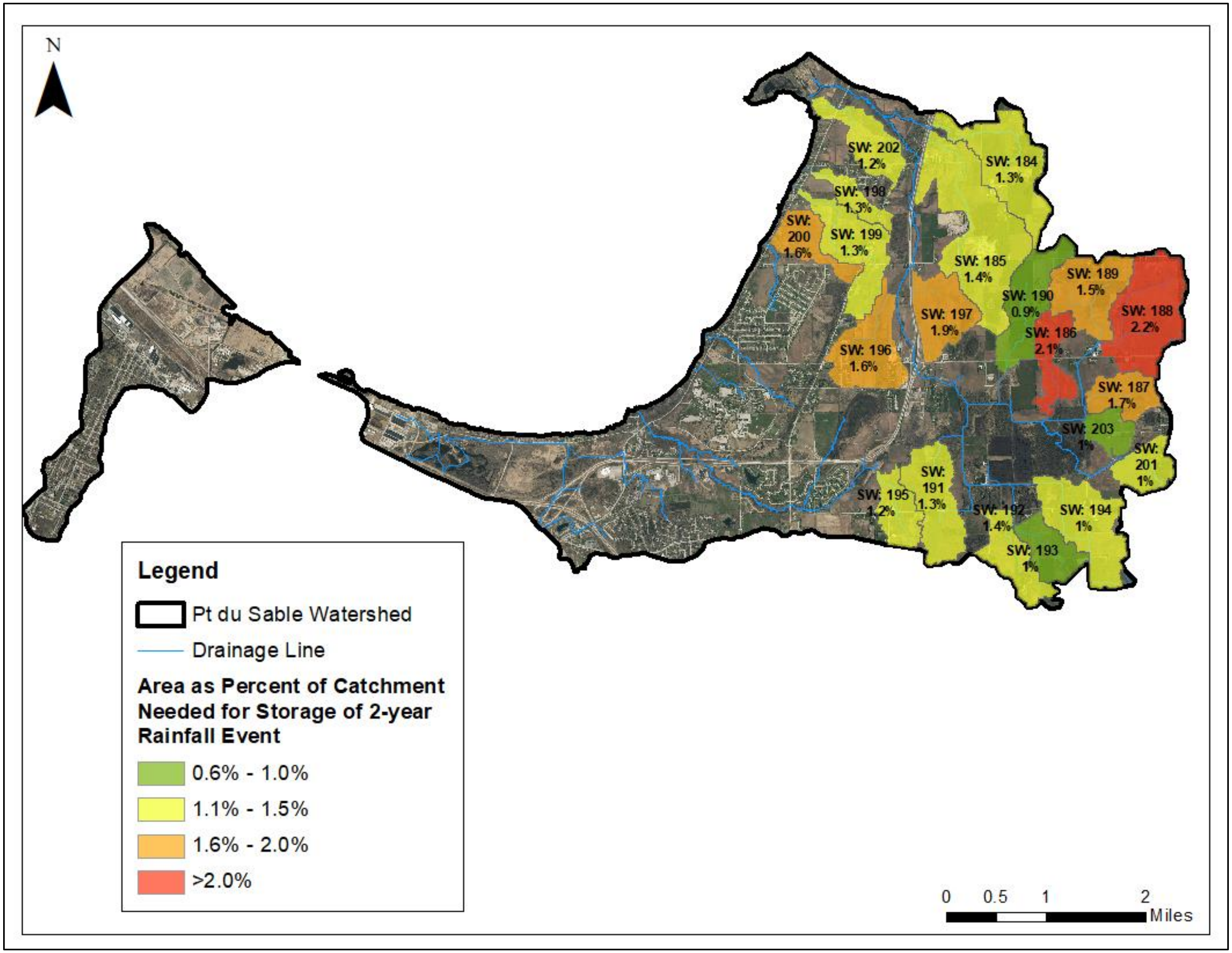

Figure B-30. Pt du Sable percent of catchment needed for 2-year rainfall event.

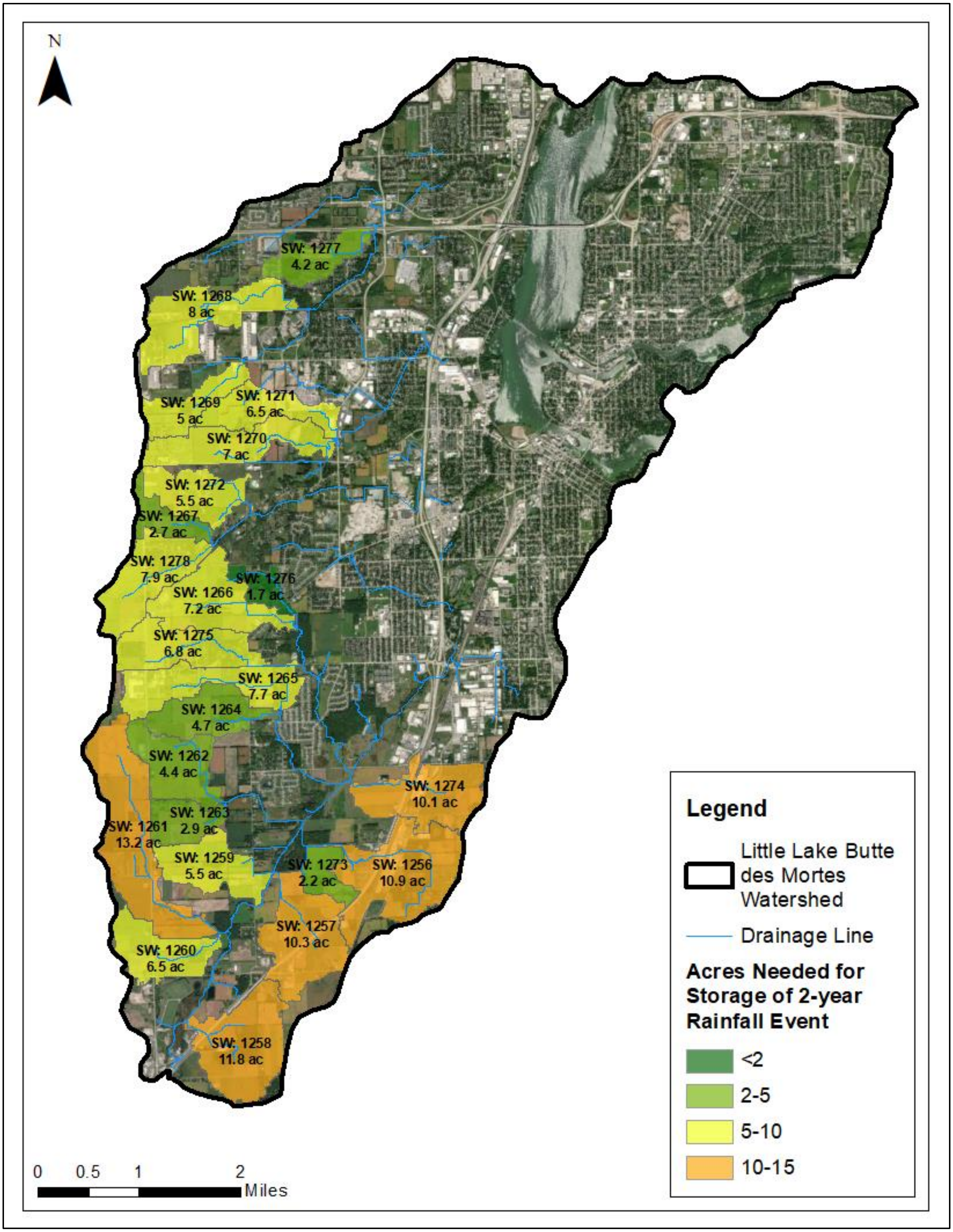

Figure B-31. Little Lake Butte des Mortes acres of storage needed for 2-year rainfall event.

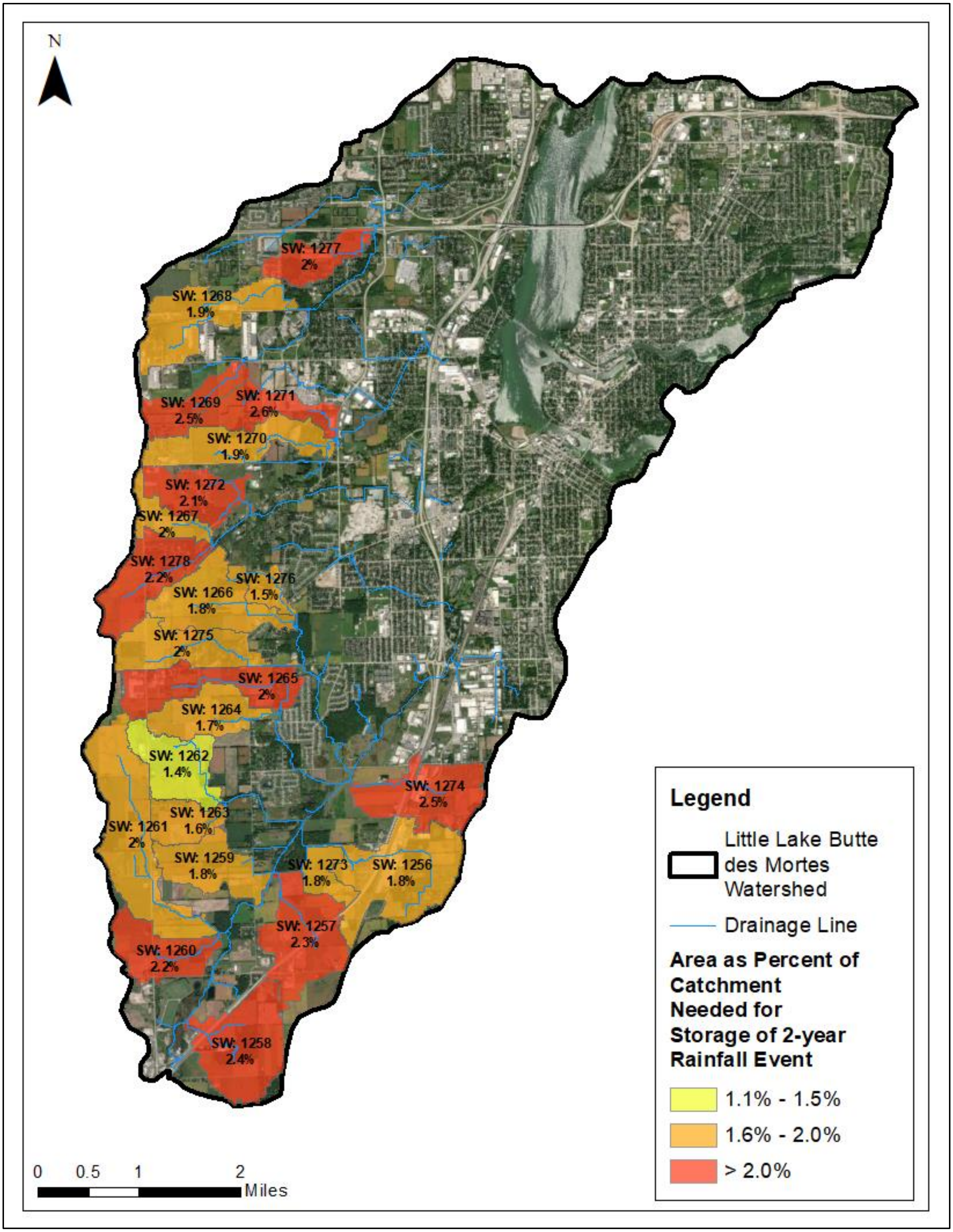

Figure B-32. Little Lake Butte des Mortes percent of catchment needed for 2-year rainfall event.

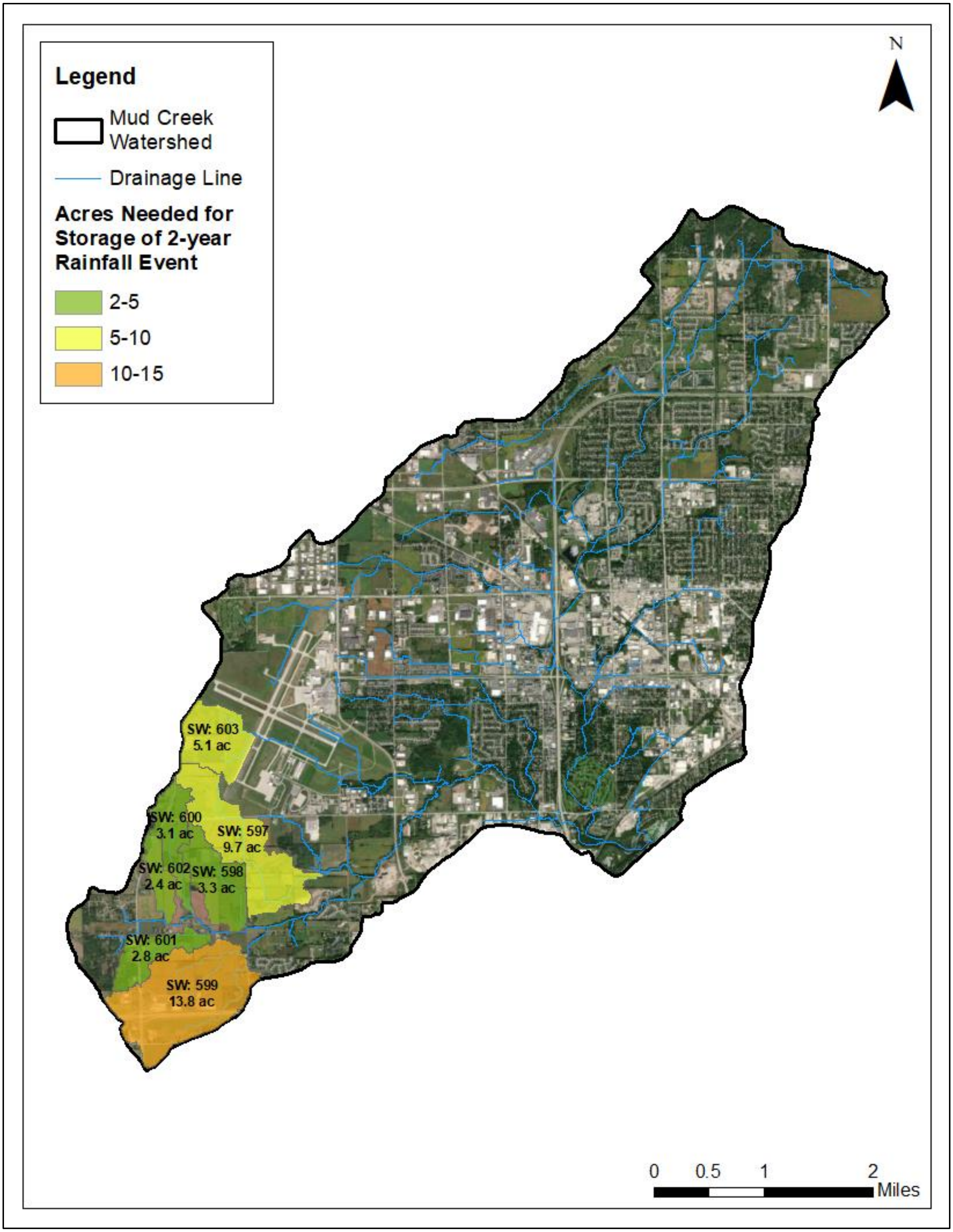

Figure B-33. Mud Creek acres of storage needed for 2-year rainfall event.

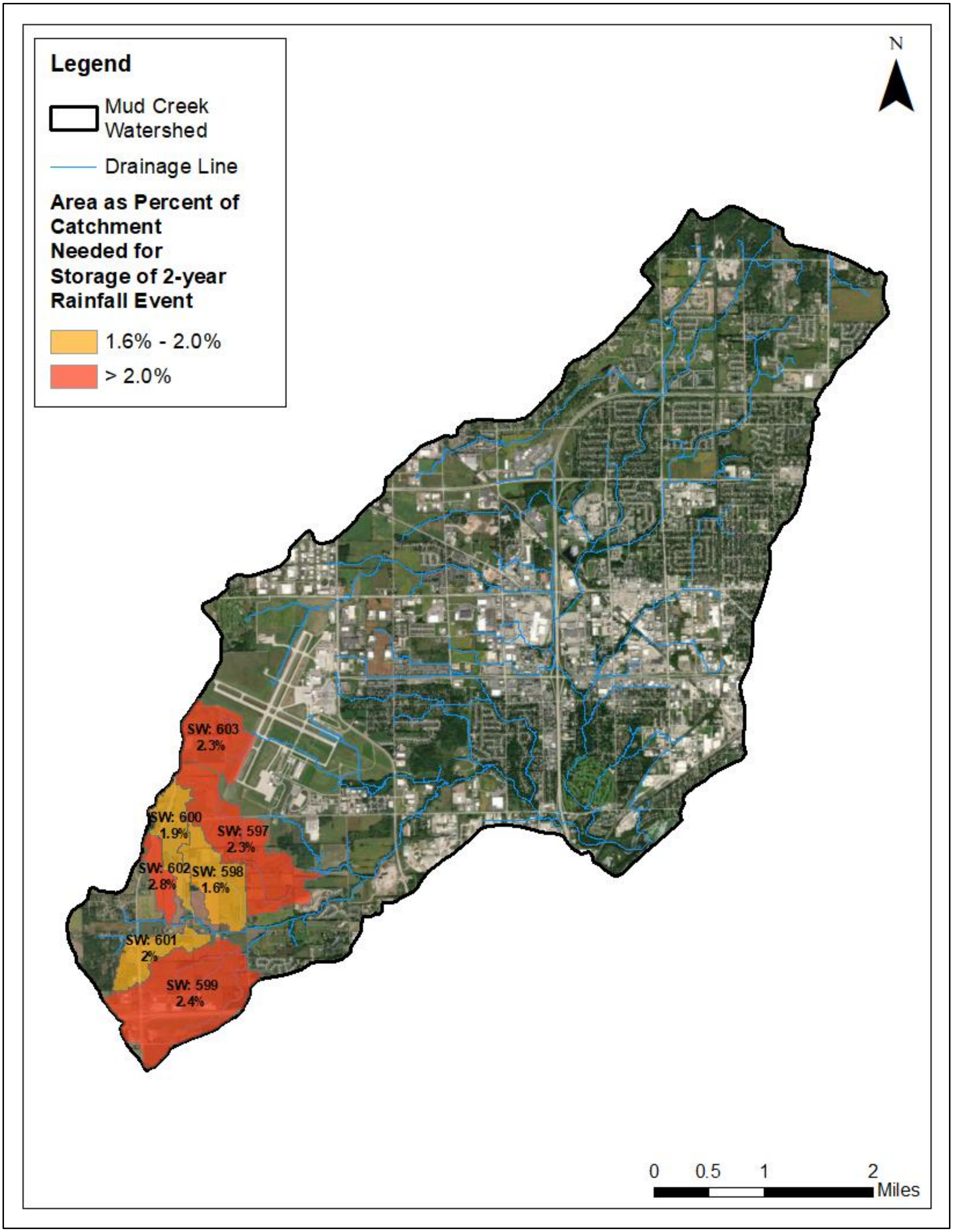

Figure B-34. Mud Creek percent of catchment needed for 2-year rainfall event.

Appendix C. Cost definitions and estimate calculations.

<u>Cost Estimate Definitions:</u>

Subdivision, lease docs- Cost associated with coordinating/drafting legal documents for the purchasing/leasing of land

Design Survey- Cost for topographic survey of the site for design work

Design- Cost to design and generate construction plans for practice

Mobilization- Cost to get equipment/materials to construction site

Excavation- Construction cost associated with earth moving on the project

Restoration/Landscaping- Construction cost to restore landscape after construction (seeding & erosion control)

Erosion Control- Cost of the construction and maintenance of erosion control practices needed during construction.

Land Acquisition- Cost to purchase land

Construction Oversight- Cost for someone to supervise construction (county personnel or consultant) to make sure it is being constructed to design specifications

O&M- Operation and maintenance costs (vegetation management, sediment removal, etc)

Administration- Cost of tracking cost share agreements, lease docs, and implementation, creating project reports

Outreach- Cost of outreach to landowners/public to sell practice on large scale

<u>Cost Estimates Calculations:</u>

Subdivision, lease docs:

If area needed <5 acres, cost is $5,000

If area needed >5 acres, cost is calculated: $5,000 + (acres needed in catchment in catchment/max acres needed in catchment of all catchments in watershed)*$5,000

Design Survey

If area needed <5 acres, cost is $3,000

If area needed >5 acres, cost is calculated: $3,000 + (acres needed in catchment/max acres needed in catchment of all catchments in watershed)*$7,000

Design

If area needed <5 acres, cost is $7,800

If area needed >5 acres, cost is calculated: $7,800 + (acres needed in catchment/max acres needed in catchment of all catchments in watershed)*$72,200

Mobilization

If area needed <5 acres, cost is $3,250

If area needed >5 acres, cost is calculated: $3,250 + (acres needed in catchment/max acres needed in catchment of all catchments in watershed)*$1,750

Excavation

If area needed <5 acres, cost is calculated: acres*2*(43,560/27)*10

If area needed >5 acres, cost is calculated: (10-(acres needed in catchment -5)/(max acres needed in catchment of all catchments in watershed)-5)*5)*acres*2*(43,560/27)

Restoration/Landscaping

If area needed <5 acres, cost is $24,200

If area needed >5 acres, cost is calculated: $24,200 + (acres needed in catchment/max acres needed in catchment of all catchments in watershed)*$287,000

Erosion Control

If area needed <5 acres, cost is $3,250

If area needed >5 acres, cost is calculated: $3,250 + (acres needed in catchment/max acres needed in catchment of all catchments in watershed)*$27,000

Land Acquisition

$15,000/ acre

Construction Oversight

7% of cost sum of Design Survey, Design, Mobilization, Excavation, Restoration/Landscaping and Erosion Control

Operation and Maintenance

3% of cost sum of Design Survey, Design, Mobilization, Excavation, Restoration/Landscaping and Erosion Control

Administration

5% of Total Cost (Subdivision/lease docs, Design Survey, Design, Mobilization, Excavation, Restoration/Landscaping, Erosion Control, Construction Oversight and Operation and Maintenance)

Outreach

Estimated at $1,000,000 for 3 years for all analyzed watersheds in basin.

Appendix D. Glossary of Terms and Acronyms.

Area of Concern (AOC) - Great Lakes Rivers and harbors that have been most severely affected by pollution and habitat loss. They were designated in 1987 as part of an international agreement between the U.S. and Canada known as the Great Lakes Water Quality Agreement

Best Management Practice (BMP) - A method that has been determined to be the most effective, practical means of preventing or reducing pollution from nonpoint sources.

Beneficial Use Impairment (BUI) - An impairment of beneficial uses means a change in the chemical, physical or biological integrity of the Great Lakes system sufficient to cause significant environmental degradation.

Great Lakes Restoration Initiative (GLRI) - The largest funding program investing in the Great Lakes. Currently the Lower Fox River watershed is one of three priority watersheds in the Great Lakes Restoration Initiative Action Plan. Under the initiative nonfederal governmental entities (state agencies, interstate agencies, local governments, non- profits, universities, and federally recognized Indian tribes) can apply for funding for projects related to restoring the Great Lakes.

Hydrologic Unit Code (HUC) - The United States is divided and sub-divided into successively smaller hydrologic units which are classified into four levels: regions, sub-regions, accounting units, and cataloging units. Each hydrologic unit is identified by a unique hydrologic unit code (HUC) consisting of two to eight digits based on the four levels of classification in the hydrologic unit system.

MSE4 - A specific precipitation distribution developed by the United States Department of Agriculture, Natural Resources Conservation Service, using precipitation data from Atlas 14.

Potentially Restorable Wetland (PRW) - Areas that are not currently mapped as wetland, but soil and water pooling data indicate it may be possible to restore them to wetland.

Total Maximum Daily Load (TMDL) - A calculation of the maximum amount of pollutant that a water body can receive and still meet water quality standards.

Total Phosphorus (TP) - Measure of all forms of phosphorus.

Total Suspended Sediment (TSS) - The organic and inorganic material suspended in the water column and greater than 0.45 micron in size.

United States Department of Agriculture (USDA) - The department of the United States government that manages various programs related to food, agriculture, natural resources, rural development, and nutrition.

United States Environmental Protection Agency (USEPA) - Government agency to protect human health and the environment.

Wisconsin Department of Natural Resources (WDNR) – State organization that works with citizens and businesses to preserve and enhance the natural resources of Wisconsin.

Wisconsin Wetland Inventory (WWI) -Graphic representations of the type, size and location of wetlands in Wisconsin developed by WDNR.

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Appendix G

Stream Corridor Sources of Suspended Sediment and Phosphorus from an Agricultural Tributary to the Great Lakes. USGS 2019 Final Report

Stream Corridor Sources of Suspended Sediment and Phosphorus from an Agricultural Tributary to the Great Lakes

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Abstract

Fine-grained sediment and phosphorous are major contaminants in the Great Lakes and their tributaries. Plum Creek, Wisconsin (92 km^2), a tributary to the Lower Fox River, has a Total Maximum Daily Load (TMDL) requiring reductions of suspended sediment and phosphorus loading by 70% and 77%, respectively. In 2016-18, an integrated sediment fingerprinting and stream corridor-based sediment budget study was conducted to help quantify upland and stream corridor sources of suspended sediment and phosphorus at a loads monitoring station on Plum Creek. Sediment fingerprinting results indicated that the proportion of upland and stream corridor sources of suspended sediment in Plum Creek varied by season and the amount of runoff; however, bank and gully erosion accounted for 51% and 24% of the suspended sediment annual load, with one or both sources present in all seasons. The next most common source was roadside ditches (11%), which was also present in all seasons. Cropland and woodland sources accounted for small proportions of the suspended sediment, with cropland mainly in summer and woodland in winter, spring, and summer. Relative source proportions for sediment-bound phosphorus were similar to suspended sediment but made up less of the overall loading because on average 27% of the phosphorus load resides in the dissolved phase. Soft fine-grained streambed sediment had source signatures of mainly bank, gully, and ditches (ordered by decreasing proportion). Results from the field-based rapid geomorphic assessment supported the sediment fingerprinting results and in general showed that the amount of bank erosion increases in a downstream direction. The high proportion of sources from banks and gullies is due, in part, to a 20-km long, deeply entrenched valley and steep eroding bluffs between the majority of cropland and the Plum Creek water monitoring station.

Introduction

Plum Creek (92 km^2) is a tributary to the Lower Fox River, Wisconsin and is located about 16 km upstream of a Lake Michigan Area of Concern (AOC) for the Lower Green Bay and Fox River (Figure 1). The Lower Green Bay and Fox River AOC is a priority area for the Great Lakes Restoration Initiative (EPA 2016). The AOC is working toward removal of beneficial use impairments for eutrophication and undesirable algae through reductions in total suspended solids (TSS) and total phosphorus (TP) loads from the top seven highest loading tributaries, including Plum Creek (WDNR 1988; 2018a). Plum Creek has almost 32 km of stream length on the Wisconsin state impaired waters list for TP and TSS (WDNR 2018b).

Plum Creek is part of the Total Maximum Daily Load (TMDL) and watershed management plan for TSS and TP in the Lower Fox River Basin (EPA 1999; Cadmus 2012). Based on the Soil and Water Assessment Tool (SWAT) modeling results, Plum Creek was estimated to produce 5,500 metric tons/yr of TSS and 14,300 kg/yr of TP, of which 95 and 94%, respectively, were contributed from agricultural land (Cadmus 2012). Agricultural land makes up 76% of the watershed area. The TMDL goals for Plum Creek are to reduce the TSS and TP loading by 70% and 77%, respectively. Sources of TSS and TP from bank erosion were not specified in the SWAT model (Cadmus 2012). However, streambank inventories of Plum Creek in 2014 by the Outagamie Land Conservation Department indicated that 39 of the 69 km of channels inventoried had actively eroding banks, and that these banks could be contributing 45% of the annual TSS load to the stream (Francart 2017).

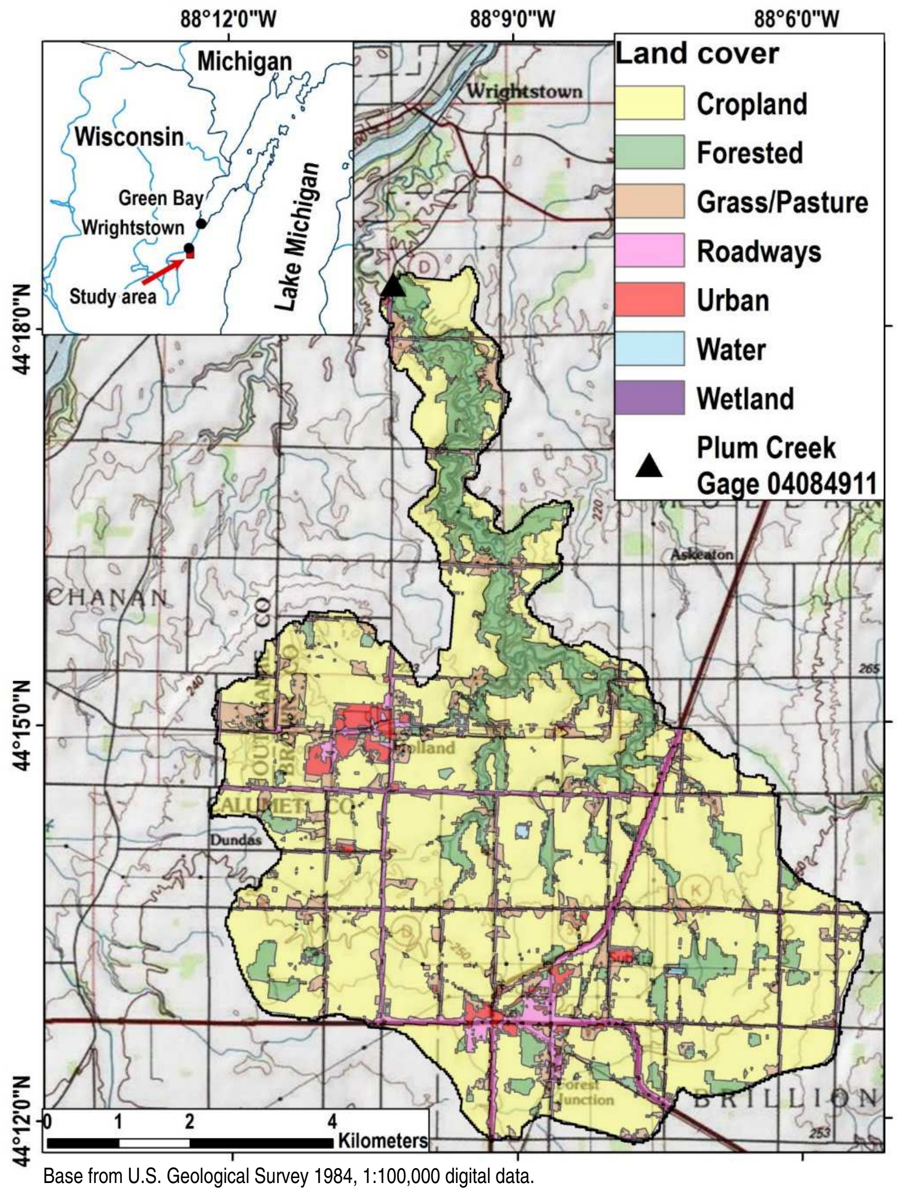


Figure 1. Location of Plum Creek study area with major land-cover categories (Homer et al. 2015)

An integrated sediment fingerprinting and stream corridor-based sediment budget study was conducted by the U.S. Geological Survey (USGS), the Wisconsin Department of Natural Resources (WDNR), and Outagamie County for Plum Creek in 2016-18 to help quantify the proportions of the TSS and TP loadings originating from stream and riparian corridor sources. The study hypothesis was that banks and possibly gullies along the stream corridor are potentially significant sources of TSS and TP. The field-based stream corridor geomorphic assessment included banks and ravines along perennial and ephemeral channels. Integration of sediment budget and source apportionment tools developed by Gellis et al. (2016) for the TMDL process helped to describe spatial and temporal patterns in sources for TSS and TP throughout the watershed compared to loads measured at a water-quality monitoring station run by the USGS and

University of Wisconsin-Green Bay (UW-GB). This report describes the major findings from the study for suspended sediment and soft bed sediment sampled from Plum Creek in 2016-18.

Study Area

Plum Creek is an eastern tributary of the lower Fox River in Outagamie County (fig 1). The watershed is in the Eastern Ridges and Lowland Physiographic Province (Martin 1965). Soils are generally silt loams, silty clay, and clay loams (Soil Survey Staff NRCS 2017). Topography is steep, and the entrenched valley is typical for Great Lakes tributaries where valleys intersect steep zones of post-glacial paleo shorelines (Fitzpatrick et al. 2006). The river enters the lower Fox River upstream of the community of Wrightstown and below Rapide Croche Dam. The drainage area upstream of the USGS streamgage on Plum Creek (04084911) is 54.3 km^2.

Land cover in Plum Creek is mainly cropland (66%), with smaller percentages of woodland (10%), grassland/pasture (10%), roads (7%), wetland (4%) and urban land (2%) (Homer et al. 2015) (Figure 1). Much of the woodland is located adjacent to Plum Creek and its tributaries, along steeply sloping valley sides. Much of the grassland is made up of rights-of-way along roads and grassy areas adjacent to subdivision or rural residential lots. There are few pastures in the watershed.

Baseline monitoring data for streamflow, TSS, TP, and dissolved phosphorus (P) have been collected by the USGS and UW-GB at the Plum Creek streamgage (USGS #04084911) since 2011 (U.S. Geological Survey, 2019). The watershed above the streamgage is 54.3 km^2 or 58.9% of the total watershed. Annual loads of TSS ranged from 3,183 metric tons (MT) in 2012 to 13,491 MT in 2017, with an annual average of 6,040 MT. Annual loads of TP ranged from 6,122 kg in 2012 to 18,691 kg in 2014, with an annual average of 12,622 kg (U.S. Geological Survey, 2019).

Methods

Integrated techniques helped to describe sources, transport, and sinks of TSS and TP throughout the watershed at a range of spatial and temporal scales. Field-based rapid geomorphic assessments (Fitzpatrick et al. 2016) were focused on field measurements of streambank erosion, gully erosion, and soft streambed sediment deposition that were used in the stream corridor sediment budget calculations. Sediment fingerprinting techniques and tools described in Gellis et al. (2016) and Gorman Sanisaca et al. (2017) were used to apportion suspended sediment and soft sediment to specific sources. Results were compared to TSS and TP loads from streamflow monitored at Plum Creek streamgage 04084911 (U.S. Geological Survey 2018).

Field-Based Rapid Geomorphic Assessments

The USGS conducted field-based rapid geomorphic assessments in Spring 2017, which included measurements of streambank and gully erosion and soft streambed sediment deposition. Data collected during the assessments were used in stream corridor sediment budget calculations. Assessments were done at 30 reaches using methods described in Fitzpatrick et al. (2016) and were in part built off the 2014 bank erosion inventory done by Outagamie County (Outagamie County Land Conservation Department 2017). Reaches for rapid geomorphic assessments were selected to represent a range of slope, valley types, stream order, and channel sizes along the stream network longitudinal continuum. The stream network and its physical characteristics were described using an overlay of WDNR streamlines and Lidar-based 3-m digital elevation model data (USGS et al., 2010). The reaches included ephemeral and perennial channels.

Annual volumes of bank erosion were estimated using field measurements of the length and height of eroding banks. Annual lateral recession rates for the eroding banks were determined from categorical rates based on indicators assembled by the Wisconsin Natural Resources Conservation Service (2015). A volume weight conversion of 1,362 kg/m^3 was used for banks and bluffs with heights greater than 1.5 m because they were typically made up of glacial deposits (silt loams, silty clay, clay loams) (Wisconsin NRCS, 2015). For banks less than 1.5 m high and for all gullies a volume-weight conversion of 1,121 kg/m^3 was used because they were typically composed of less dense alluvium.

Estimates of annual volumes of gully erosion were based on the Ephemeral Gully Erosion Estimator for permanent gullies (Natural Resources Conservation Service 2006). Gullies included in the assessments were developed in ravines along the steep slopes of the entrenched valley sides. The ravines had punctuated sections of gully or channel erosion at knickpoints with old channels covered with sediment in between.

Soft bed sediment volumes were estimated from field measurements of length, width, and average thickness of soft sediment deposits. Sediment deposit thickness was measured using a meter stick and recording the depth of penetration. A conservative estimate of a volume-weight conversion of 800 kg/m^3 was used because of the high-water content, based on similar soft sediment samples from the silt-dominated Fever River in southwest Wisconsin (Peppler and Fitzpatrick 2018).

Sediment Source Apportionment

Source and Target Site Selection and Sampling: Sites selected for source and target sediment sampling included uplands (cropland, woodland, and ditch), stream corridors (streambanks and gullies), and streams (suspended and soft fine-grained streambed sediment). Sites designated for upland sediment source sampling were identified through geographic information system (GIS) analyses of available land use (or land cover) (Homer et al. 2015). A stratified random sampling approach was used to select 15 sites per land use type with greater than 10% areal coverage. The three major upland land cover categories included (1) cropland, (2) grassy ditches between roads and fields, and (3) woodlands. Pasture was not included because of the small number of pastures in this watershed. Similarly, urban was not included because of its low percentage in the watershed. The GIS site-selection procedure was run at least twice to select potential alternative sites in case of limited access to some sites on private land, physical or safety impediments, and land-use changes that occurred after mapping, especially if crops were in rotation with pastures. Soil samples were collected from the top 2 cm of the soil surface with a plastic hand shovel at 30 points spaced 10 m in a rectangular grid pattern. The number of transects and transect length were adjusted to stay within the areal shape of the sampled land use. The point samples, consisting of about 2 liters volume, were composited into a zip seal plastic bag. Field replicates were collected for one site in each land use category with a 1-m offset from the original sampling points.

Two stream corridor sources, banks and gullies, were included in the apportionment. Stream reaches sampled for bank and gully erosion sources were from the rapid geomorphic assessments with additional sites from Outagamie County's bank erosion inventory as needed to fill in gaps along the stream corridor. Actively eroding gullies were sampled in a similar fashion to upland soil samples, with the top 2 cm of bare eroding sediment sampled with a plastic hand shovel. The transect or grid size was adjusted to fit the eroding gully dimensions, and sampling points included both the actively eroding bottom and sides of a gully. An optimum of 30 points were sampled and composited into one bag per site. Representative samples of eroding banks were collected from the surficial 2 cm of exposed sediment from the bottom to the top of the bank face. Three to five points along each of three to six transects were sampled, depending on the height and length of the eroding bank, with a total of 15-30-point samples composited into one 4-liter plastic bag. If banks were eroding on both sides of the channel, then samples from an equal number of points were collected on both sides and composited. Field replicates were collected by side-by-side sampling of the same points.

Target samples used to source sediment included soft, fine-grained streambed sediment and suspended sediment. Soft bed sediment was sampled from the rapid geomorphic assessment reaches and was defined as having a high-water content that was not able to support the weight of a person (i.e. one would sink into the sediment when stepping in it). The sediment was collected from 15 points in one or more inundated depositional areas per reach and composited into a 1-L plastic jar. The point samples were collected with an open-ended plastic or Teflon tube and plastic spatula. Field replicates were collected by side-by-side sampling of the same points.

Suspended sediment was collected at the USGS Plum Creek streamgage from October 2016 through February 2018 at roughly one-month intervals (Table 1). An in situ suspended sediment sampler with two stacked sampling tubes was deployed downstream of the bridge crossing at the gage during ice-free months (Phillips et al. 2000; Banks et al. 2010). The sampler was left in over the winter of 2016-2017 but was lost during thick ice movement and breakup. A grab sample was collected on March 8, 2017 to catch a large runoff event associated with ice breakup. A new sampler was reinstalled in April 2017 at the same location as the lost sampler. In August 2017 a second sampler was installed upstream of the bridge crossing. The recovery from the two samplers in September and October 2017 was small and required compositing sediment from both the upstream and downstream samplers. In November 2017 each of the samplers had enough sediment for submitting separate samples for quality assurance checks. Two rain/snowmelt events in January 2018 caused water and sediment to flow over ice. Subsequent rapid drops in temperature caused sediment-laden water to freeze over the top of existing ice. The ice layers, with sediment still in suspension, were collected and thawed at the lab. The sediment melted out of the ice was processed in the same manner as the other in situ suspended sediment samples. The contents of the samplers were emptied into plastic buckets and returned to the USGS Upper Midwest Water Science Center laboratory in Middleton, Wisconsin.

Table 1. In situ suspended sediment samples and associated suspended sediment phosphorus (SS_TP) concentrations collected at the Plum Creek streamgage, October 2016-February 2018

Sample identifier	Start date	End date	Representative period	Type of sample	SS_TP (mg/kg)
--	--	--	10/1 – 10/25/2016	(Prior to project start)	--
--	--	--	10/26 – 11/21/2016	(Prior to project start)	--
03	11/22/2016	12/5/2016	11/22 – 12/25/2016	In situ passive collector	1,768
--	--	--	12/26 – 1/26/2017	River frozen	--
--	--	--	1/27 – 2/27/2017	River frozen	--
04	3/8/2017	3/8/2017	2/28 – 3/26/2017	Grab water sample late winter	1,235
--	--	--	3/27 – 4/25/2017	Sampler destroyed by ice/flood	--
06	4/26/2017	5/25/2017	4/26 – 5/24/2017	In situ passive collector	1,351
07	5/25/2017	6/26/2017	5/25 – 6/26/2017	In situ passive collector	1,084
08	6/26/2017	7/25/2017	6/26 – 7/25/2017	In situ passive collector	1,058
--	7/26/2017	8/23/2017	7/26 – 8/23/2017	Sample too small to analyze	--
09	8/24/2017	9/28/2017	8/24 – 9/23/2017	In situ passive collector[1]	1,662
10	9/28/2017	10/27/2018	9/28 – 10/27/2017	In situ passive collector[1]	1,541
11	10/28/2017	12/7/2017	10/28 – 12/7/2017	In situ passive collector	2,096
11-QA	10/28/2017	12/7/2017	10/28 – 12/7/2017	In situ passive collector[2]	2,061
--	12/8/2017	1/10/2018	12/8 – 1/10/2018	Sample too small to analyze	--
12	2/7/2018	2/7/2018[3]	1/11 – 1/27/2018[3]	Ice layers collected	3,955

[1]Composite of two sets of samplers upstream and downstream of bridge.
[2]Sampler located upstream of bridge only.
[3]Plum Creek streamgage not operating, timing of events based on partial record from nearby East River streamgage (USGS station ID 04085108) (U.S. Geological Survey, 2019)

All sediment samples except those from the in situ suspended sediment sampler were stored frozen until subsampling occurred. The water-sediment mixture from the in situ suspended sediment sampler was allowed to settle in a refrigerator at about 4° C. Clear water from the bucket was decanted until a sediment-rich slurry of generally less than 0.5 L was left. The slurry was transferred to a plastic wide mouth jar and frozen until subsampling occurred. Frozen samples were thawed prior to being subsampled. The sediment was mixed thoroughly with a plastic spatula and spread evenly into a 11- x 17- x 3-inch glass dish. The sediment was divided into 16 equal sections using a plastic knife. A random number generator was used to select subareas for processing. The remaining unsieved portion of a sample was returned to its original container and refrozen. The subsample was wet-sieved through a 63-micron polyester sieve using de-ionized water and all-plastic sieve frame and equipment using methods from Shelton and Capel (1994) and ASTM D3977-97 Method C for wet-sieving filtration (ASTM, 2002). Both the <63 and >63-micron fractions were dried at 60 degrees Celsius for 24-48 hours or until completely dry. After drying, the <63 and >63-micron fractions were weighed to the nearest 0.1 g. If needed, the dried sample was lightly ground with a ceramic mortar and pestle. The <63-micron sieved dry sediment was placed in plastic vial(s) for shipping to analytical laboratories. The >63-micron fraction was retained at the USGS. All sample collection and subsampling equipment was washed with phosphate-free liquid detergent, soaked with 5% HCl, and rinsed with deionized water between samples.

Laboratory Analyses: Sediment samples were analyzed for a suite of 51 major and trace elements, particle size, and organic matter (loss on ignition) (Table 2). The Wisconsin State Laboratory of Hygiene used the ESS INO Method 420.0 Thermo Finnigan ELEMENT2 High Resolution ICP-MS (EPA Method 200.8) method and the milestone microwave digestion system (ESS INO IOP 550.0) for elemental analyses (Wisconsin State Laboratory of Hygiene 2016a; 2016b). (Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government). The analyses included phosphorus in sediment. The elemental data are available on the Wisconsin State Surface Water Integrated Monitoring System (https://dnr.wi.gov/topic/surfacewater/swims/). The elemental analysis includes a near total digestion using three acids.

Particle size and organic matter determinations were completed at the U.S. Geological Survey Cascades Laboratory in Vancouver, Wash. for the less than 63-micron fraction. Organic matter content was analyzed using the I-5753 method for loss-on-ignition. Particle size determinations were completed with a SediGraph 5120 down to 1 micron. Data are available upon request from the U.S. Geological Survey Upper Midwest Science Center, Middleton, WI.

Table 2. Elemental analyses of Plum Creek source and target samples

Ag	Be	Co	Eu	Hg	Lu	Nb	Pd	S	Sn	U	Zn
Al	Bi	Cr	Fe	Ho	Mg	Nd	Pr	Sb	Sr	V	Zr
As	Ca	Cs	Ga	K	Mn	Ni	Pt	Sc	Th	W	
B	Cd	Cu	Gd	La	Mo	P	Rb	Se	Ti	Y	
Ba	Ce	Dy	Hf	Li	Na	Pb	Rh	Sm	Tl	Yb	

Source Apportionment: The Sediment Source Assessment Tool (Sed_SAT) (Gellis et al. 2016; Gorman Sanisaca et al. 2017) was used to apportion the relative contributions of five possible sources of fine-grained suspended and soft bed sediment including croplands, woodlands, roadside ditches, eroding gullies, and banks to the target samples of suspended sediment and soft streambed sediment. Sed_SAT is an automated package of statistical procedures that uses patterns in trace element concentrations to distinguish between the sediment sources. Sed_SAT uses a five-step procedure to apportion sediment sources for each target suspended or bed sample: (1) removal of outlier source samples, (2) application of particle size and organic content corrections to the source data, (3) a bracket test to test conservativeness of the tracer, (4) stepwise discriminant function analysis (DFA) to determine the tracers that best discriminate between the source types, and (5) an "unmixing model" that uses the discriminant tracers and their weighting factors as determined by DFA to determine the percent contribution of each source to the target sediment sample. The default settings for the statistical tests in Sed_SAT were applied to the Plum Creek apportionment.

While the suspended sediment target samples were collected at the watershed outlet near the USGS streamgage, the bed sediment target samples were collected throughout the watershed to determine if sediment sources varied spatially. Source samples from throughout the entire Plum Creek watershed were used in Sed_SAT to determine sediment source contributions for all target samples, meaning that for most of the bed sediment target samples the source samples were not all located within the contributing area of the sample. Source samples are assumed to be representative of the land use areas for the whole watershed, with large enough sample sizes of n=15 for cropland, ditch, and bank source groups and n=16 for woodland and gully source groups to provide robust sampling of source areas in the watershed to account for geochemical variability within each source group.

Three tests are used to assess uncertainty in the sediment fingerprinting results for each target sediment sample: (1) a confusion matrix of the DFA results, (2) a source verification test (SVT) on the unmixing model, and (3) a Monte Carlo leave-one-out cross validation. The confusion matrix demonstrates how well the final set of discriminant tracers determined by DFA distinguishes between the source groups by summarizing the percentage of source samples classified correctly to their source group compared to the total number of source samples in the group. The source verification test (SVT) is a measure of how well the final set of tracers and their weighting factors used in the unmixing model discriminates the sources. In the SVT, each of the source samples are treated as target samples and run through the unmixing model, providing a qualitative determination of how successfully the unmixing model apportions sediment to the correct sources. The Monte Carlo leave-one-out cross validation quantifies the sensitivity of the unmixing model to the removal of samples (Gellis et al. 2016). The Monte Carlo simulation was run 1,000 times, with a random sample removed from each source group for each iteration before the unmixing model was run (Gorman Sanisaca et al. 2017).

The source apportionments for the target suspended sediment samples were applied to the streamgage TSS for water year (WY) 2017 (October 1, 2016 to September 30, 2017) (U.S. Geological Survey, 2018). Monthly suspended sediment phosphorus (SS_TP) loads were calculated by multiplying the SS_TP concentrations of the in situ suspended sediment samples by the monthly TSS load. An average of the WY 2017 SS_TP concentrations was used for calculating the monthly SS_TP loads for months with missing fingerprints. Results for TSS loads from October 2017 forward were not available yet at the time of this writing (April 2019).

Stream Corridor Budgets of Erosion and Deposition

For each segment in the WDNR streamlines that made up the Plum Creek network, stream order (Strahler 1957) and slope category were identified (Table 3). Slope categories were adopted from similar geomorphic assessments done on Lake Superior tributaries that reflect potential channel bedform types (Fitzpatrick et al. 2006; 2016; Montgomery and Buffington 1997). Segments with a stream order of 1 made up most of the network with most having slopes of 0.3-1.0 percent, typical for lowland settings of post-glacial streams in the Great Lakes region. The cumulative length of streams in order 4 was larger than order 3, reflecting the long-neck funnel shape of the watershed (Figure 1).

Table 3. Number of stream segments (gray-shaded) and total stream lengths categorized by stream order and slope for Plum Creek (km, kilometer; <, less than; >, greater than)

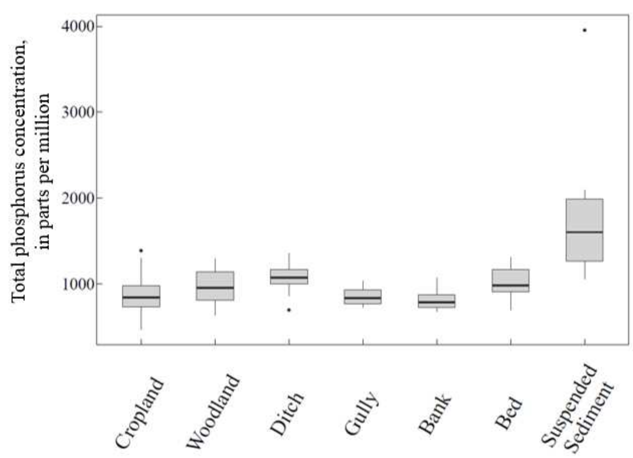
Slope category (percent)	Stream order 1	Stream order 2	Stream order 3	Stream order 4	Total length (km)
<0.3	5	4	5	20	25.3
0.3-1.0	21	18	7	4	51.9
>1.0-2.0	9	0	1	0	9.9
>2.0	3	0	0	0	0.7
Total length (km)	42.5	20.4	10.7	14.2	87.8

Reach-scale assessment data for annual gully and bank erosion, and soft bed sediment volumes were applied to WDNR stream segments with similar slopes, valley entrenchment, stream order, and riparian vegetation in a GIS. Before the application of reach data to the segment lengths, the sediment TP concentration, included in the trace elements sample analysis, was applied to the bank and bed amounts. After the initial automatic application, the assignments were checked and adjusted if needed by hand in the GIS after further investigation with overlays of digital elevation model data for valley setting and aerial photographs for riparian vegetation, and other qualitative data and photos collected during Outagamie County's bank inventory or USGS reconnaissance. If two reaches were in the same segment category and no other differences were observable on aerial photographs, averages of the SS_TP concentrations, reach bank erosion rates, and fine sediment volume were used. The amounts of annual bank erosion and soft bed sediment volume for each segment were summed to get an estimate of the entire stream network contribution of eroded and stored sediment and sediment-bound phosphorus in Plum Creek upstream of the USGS streamgage.

Sources of Sediment and Sediment Related Phosphorus

A multiple-lines of evidence approach was used to determine the relative amounts of potential sources of TSS and TP in Plum Creek. This approach used available and new data with emphasis on quantifying stream corridor sources.

Sediment TP concentrations in source and target samples generally ranged from about 500 to 2,000 mg/kg (Figure 2). These concentrations, which are from near total sample digestions, cannot be directly compared to typical soil P tests done by farmers for nutrient management plans, but give an idea of the relative amount of sediment TP spanning the watershed pathways from uplands and stream corridors to stream channels. Bioavailability and chemical mobilization of the TP likely varies among the sources and is the topic of an ongoing related study in Plum Creek. Highest sediment TP concentrations were from ditches and woodlands and lowest concentrations were from banks and gullies. Some of the ditches sampled were erosional while others were depositional. If depositional, the ditches likely had sediment from nearby adjoining fields as well as roads. Many of the woodland samples were from the valley bottom of Plum Creek, which has a high potential for overbank sedimentation and accumulation of leaf litter. Suspended sediment had the highest concentrations of sediment TP, suggesting that the stream sediment is becoming enriched with phosphorus as it is transported in streams. The highest sediment TP concentration, near 4,000 mg/kg, was from suspended sediment collected from an ice sample (Table 1). The suspended sediment samples were over 80% fines (silt- and clay-sized fractions) except from the ice sample which was closer to 50%. The soft bed sediment had the lowest percent fines (Figure 2).



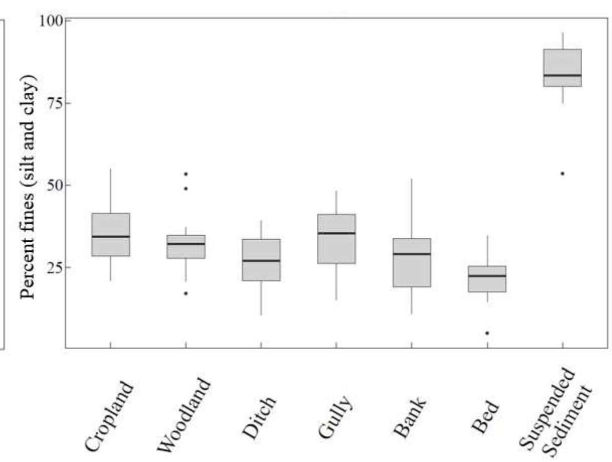


Figure 2. Total phosphorus concentrations and percent fines (silt and clay) in sediment samples from different source locations in the Plum Creek watershed. All samples were sieved to less than 63 microns prior to elemental analysis.

The sediment fingerprinting results showed that source apportionment varied among the target samples, with banks serving as the largest source of sediment on average for both suspended sediment (44%) and for bed sediment (80%) (Table 4). Suspended sediment showed substantial contributions on average from gullies (25%) and ditches (22%), with smaller proportions from woodland (7%) and cropland (2%). The source contribution to soft bed sediment was dominated by banks as well, with small average contributions from gullies (10%), and 5% or less from ditches, cropland, and woodland. Bed sediment sample 81 was the only target sample to not be corrected for organic content because the loss on ignition (LOI) analysis was not available for the sample. However, this difference did not have a negative impact on the relative error and the sediment fingerprinting results are comparable to other nearby bed sediment target samples that were corrected.

Table 4. Apportionment by relative source area and discriminant tracers (ordered by decreasing weighting factor) of suspended sediment and soft bed in Plum Creek, 2017

Sample	Sample type	Cropland	Woodland	Ditch	Gully	Bank	Relative Error	Discriminant tracers
03	Suspended	0	9	15	24	52	0.534	Cr, U, Cd, Ga, Zn, Li, Mo, Sc, Ni, Mg, Ba, Ce, Nb, Mn, Fe, Ti, Na
04	Suspended	0	12	13	54	21	1.169	Cr, U, Ga, Cd, Co, Zn, Dy, Mo, Yb, Y, Ni, Pd, Sb, P, La, Ti
06	Suspended	0	0	0	0	100	0.391	Ga, Cr, U, Zn, Ho, Mo, Li, Pd, Ni, Mn, Fe, Nd, P
07	Suspended	7	9	12	29	43	0.266	Co, U, Cr, Zn, Ga, Pd, Ni, P, Fe, Pt, La, Sr, Ti
08	Suspended	15	8	13	0	63	0.228	Ga, U, Zn, Cr, Mo, Li, Ni, Pd, Y, P, Fe, Mn, Nd, Sr
09	Suspended	0	0	25	0	75	1.633	Cr, Ga, Co, U, Cd, Zn, Li, Pd, Mo, Ni, Ce, Fe, Mg
10	Suspended	0	0	19	0	81	0.413	Cr, Ga, U, Cd, Co, Zn, Li, Pd, Mo, Ni, Ce, Fe, Mg
11	Suspended	0	0	26	74	0	1.459	Cr, Ga, Co, U, Cd, Zn, Mo, Li, Ni, Mg, Fe, Pt, Ce
11Q	Suspended	0	1	45	53	0	1.403	Cr, Ga, Co, U, Cd, Zn, Mo, Li, Mi, Mg, Fe, Pt, Ce
12	Suspended	0	34	54	12	0	0.824	Cr, Ga, Co, U, Cd, Zn, Ni, Pd, Nb, Fe, Ag, La, Mg, Ti
76	Bed	0	0	5	16	78	0.063	Ga, Cr, V, Co, Zn, U, Li, Cd, Sc, Mg, Mo, Ba, Na, Nb, Ti, Fe, Th
76Q	Bed	2	0	4	27	68	0.168	Ga, Cr, Co, U, Zn, Mg, Li, Na, Sc, Mo, Ba, Nb, Ti, Fe, Th
79	Bed	0	0	0	14	86	0.430	Cd, U, Co, V, Yb, Mo, Zn, Ga, Li, P, Ni, Mn, Nb, Th, Ce, Sr
81	Bed	0	0	2	4	94	0.126	Cr, Zn, Co, Cd, Mg, Ni, Pd, U, Fe, Sm
83	Bed	0	0	0	0	100	0.488	Ho, V, U, Co, Zn, Ga, Mo, Cd, Sc, Li Ni, P Th, Pt, Nd, Ag
86	Bed	0	0	0	0	100	0.336	Ho, V, Ga, U, Zn, Mo, Li, Pd, Ni, Fe, Mn, P, Pt, Nd
87	Bed	0	0	0	0	100	0.205	Ga, Cr, Zn, U, Mo, Ni, Pd, Mn, La, Fe
89	Bed	0	0	0	31	69	0.249	Ga, Cr, Co, U, Zn, Y, V, Cd, Pd, Ni, La, Fe
90	Bed	0	0	0	0	100	0.299	Ga, Cr, Zn, V, Cd, U, Mo, Ni, Pd, Fe, Nd
91	Bed	35	8	36	20	0	0.171	U, Co, Cd, V, Zn, Mo, Ga, Sc, Mg, Li, Fe, Ni, P
92	Bed	0	0	11	0	89	0.279	Cr, Ga, U, Zn, Ho, Li, Mo, Mg, Ni, Sc, Ba, Na, Nb, Fe, Mn, Ti

Of the 51 tracers included for sediment fingerprinting analysis, 31 tracers were found to be discriminant for one or more of the target samples (Table 4). Results of the stepwise DFA found that five tracers were discriminant for all suspended sediment target samples (Cr, Ga, Ni, U, Zn) and two tracers were discriminant for all bed sediment target samples (U, Zn). Chromium was the highest weighted discriminant tracer for most suspended sediment target samples, followed by gallium. The highest weighted discriminant tracers for bed sediment target samples were more varied, with gallium the most common. The number of tracers found to be discriminant from the DFA ranged from 10 to 17, providing strong differentiation between sediment source groups.

Results from the three tests for uncertainty in the Sed_SAT procedure give overall high confidence in the sediment fingerprinting results. The confusion matrix summary indicates the percentage of source samples correctly classified by the final set of tracers in the DFA. Woodland and ditches had 100% of the samples classified correctly for the suspended sediment tracers, with nearly all samples classified correctly for cropland (98%), gully (98%), and bank (93%) (Figure 3). Soft bed sediment had similar results (not shown). The high percentage of correctly classified source samples confirmed that the stepwise DFA was successful in selecting tracers that effectively discriminated among the five source groups.

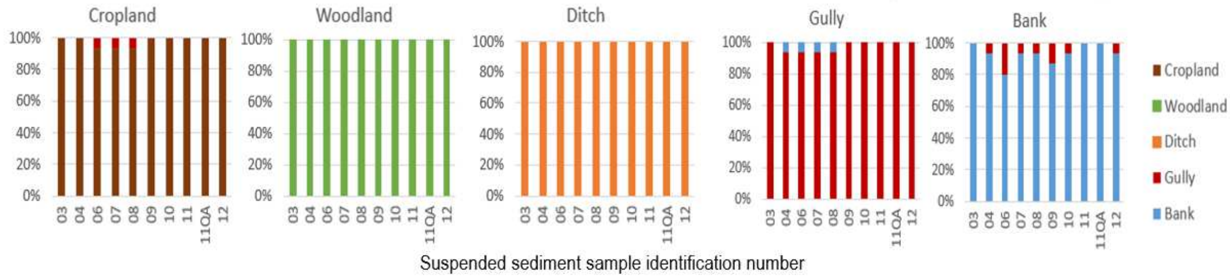


Figure 3. Summary of the confusion matrix results for target suspended sediment samples indicating the percentage of source samples correctly classified by the final set of tracers in the stepwise discriminant function analysis

The source verification test (SVT) also showed that the unmixing models were successful (Figure 4). The SVT test runs each source sample as a target sample and checks for possible misclassification as another source. The median percent contribution attributed to the correct source was greater than 75% for cropland, woodland, ditch, and banks, and was slightly lower at 67% for gullies. Most of the misclassified cropland samples were classified as woodland (9%) and most of the misclassified woodland samples were classified as cropland (10%). Ditches also showed some overlap with cropland and woodland sources, with an average of 15% of misclassified ditch samples classified as cropland and 9% classified as woodland. Gully source samples showed the greatest degree of misclassification by the unmixing model, with an average of 10% of samples classified as cropland, 12% classified as woodland, and 11% classified as bank. Most of the misclassified bank samples were classified as gully (15%). These overlaps are not unexpected among the upland sources because of the possibility that some of the land has changed land-use categories at some point in the past. Gullies physically extend from uplands to wooded slopes to banks, with the possibility of sediment coming from a mix of source categories.

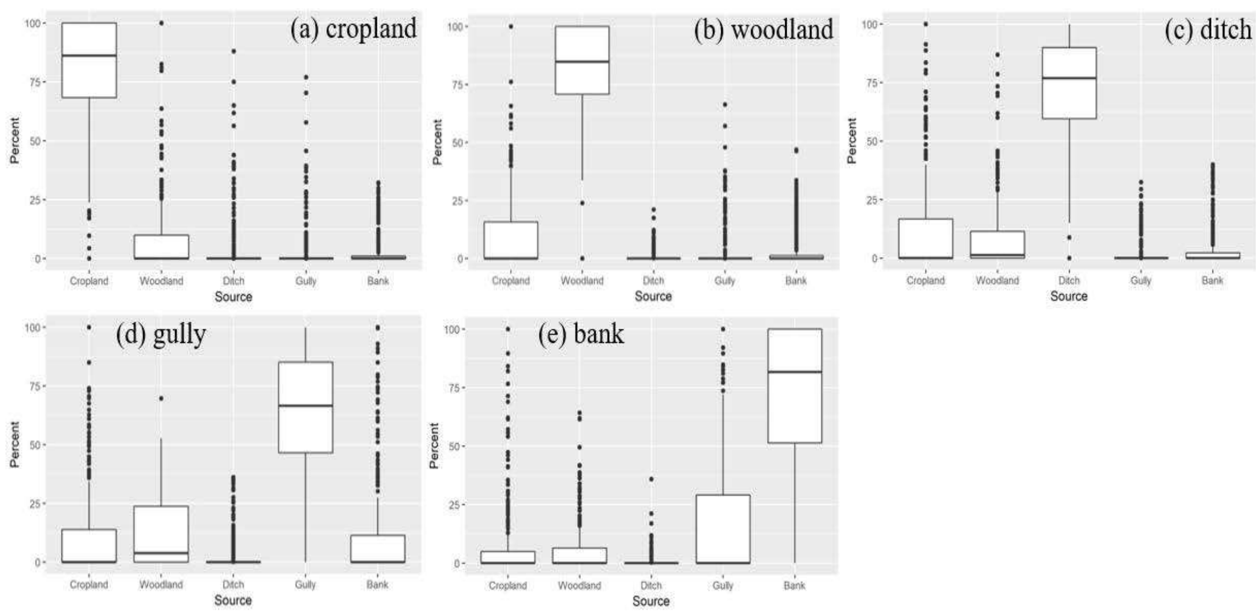


Figure 4. Source verification test results of source samples for all target sample Sed_SAT runs, (a) cropland (n=315), (b) woodland (n=336), (c) ditch (n=315), (d) gully (n=336), and (e) bank (n=315)

The Monte Carlo leave-one-out cross validation demonstrated that the unmixing models were robust and had low sensitivity to removal of individual samples for all 21 target samples except one suspended sediment sample ID 03 from December 2016. Amongst all source groups 20 of the 21 target samples had a standard deviation of the Monte Carlo iterations of less than 5%, with 8 of the target samples with standard deviations of less than 2%. Eleven of 21 target samples showed a difference of less than 10% between the unmixing model results and the maximum or minimum of any Monte Carlo iteration. The gully and bank source apportionment results for suspended sediment sample 03 showed a high degree of variability in the Monte Carlo iterations, with gully contribution ranging from 0-53.5% (median=26.3%, standard deviation = 14.8%) and bank contribution ranging from 22-78% (median=50.0%, standard deviation=14.8%). The reasons for this sample having such high variability compared to other samples are unknown.

The results from the source apportionments for the monthly in situ suspended sediment samples applied to the Plum Creek streamgage TSS and SS_TP loads for WY2017 (October 2016 to September 2017) are shown in Figure 5. Results for samples collected after October 2017 are shown as proportions only because the TSS loads were not yet available. The proportions of the five sources varied seasonally. The month of June had the largest loads for both TSS and SS_TP. Bank sources dominated in the months of May, June, July, September and October. Gully sources were present in March, June, November, and the January 2018 ice sample. Ditch sources were present in all months except May and seemed to increase through the fall and winter months of 2017-18. Woodland sources were present in March, June, July, and the January 2018 ice sample. The January 2018 ice sample had the highest proportions of ditch and woodland sources. The replicate sample from November indicated that the same sources were identified but that source proportions varied by about 20 percent. The proportion of the total TSS and SS_TP loads for WY2017 without fingerprints was 22% and 25%, respectively, with the majority missing from the April sample when the river was still frozen. The March grab sample, and the May and July in-situ samples had similar loads, but different source proportions, further illustrating the need for capturing sediment during all seasons, including cold-season runoff events.

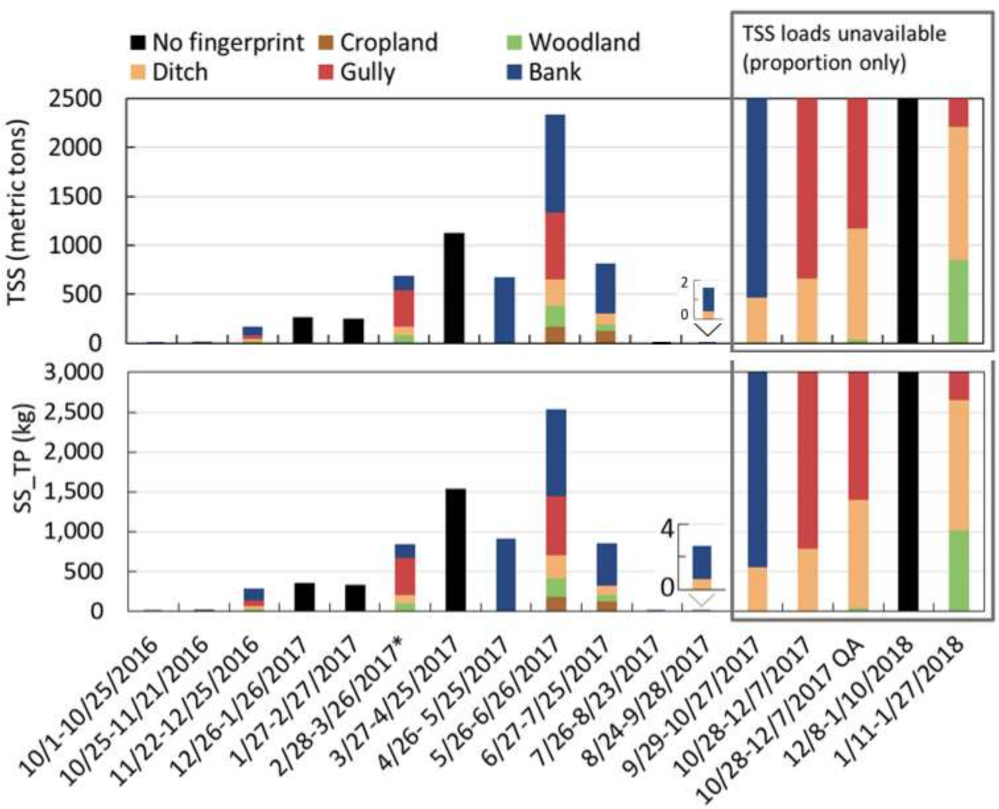


Figure 5. Temporal distribution of source apportionment to suspended sediment at the Plum Creek streamgage, October 2016 to January 2018.

The annual loads for WY2017 for sediment and phosphorus were compared among the streamgage water monitoring, sediment fingerprinting, and stream corridor budget approaches (Figure 6). The water monitoring based TSS and TP loads at the streamgage from WY2017 were similar to the average for 2011-17, which were 1.5 to 2.1 times the baseline TMDLs. The particulate portion of the water TP load was 73% for 2011-17 and 68% for WY2017. In contrast, the calculated SS_TP load from the in-situ sediment samples was 53% of the water TP load in WY2017, even though the suspended sediment TP concentrations are from near total digestions. Applying the fingerprinting apportionments, the sources of TSS were predominantly from banks (51%), gullies (24%), and ditches (11%), with smaller amounts from woodland (8%) and cropland (6%). The relative proportions of sources of SS_TP (assuming SS_TP makes up 53% of the water TP load) are bank (28%), gully (13%), and ditch (6%), with smaller amounts from woodland (4%) and cropland (3%). Completion of WY2018 load calculations and fingerprinting apportionments will give more perspective to the magnitude of potential sources during the fall and winter events with frozen ground conditions.

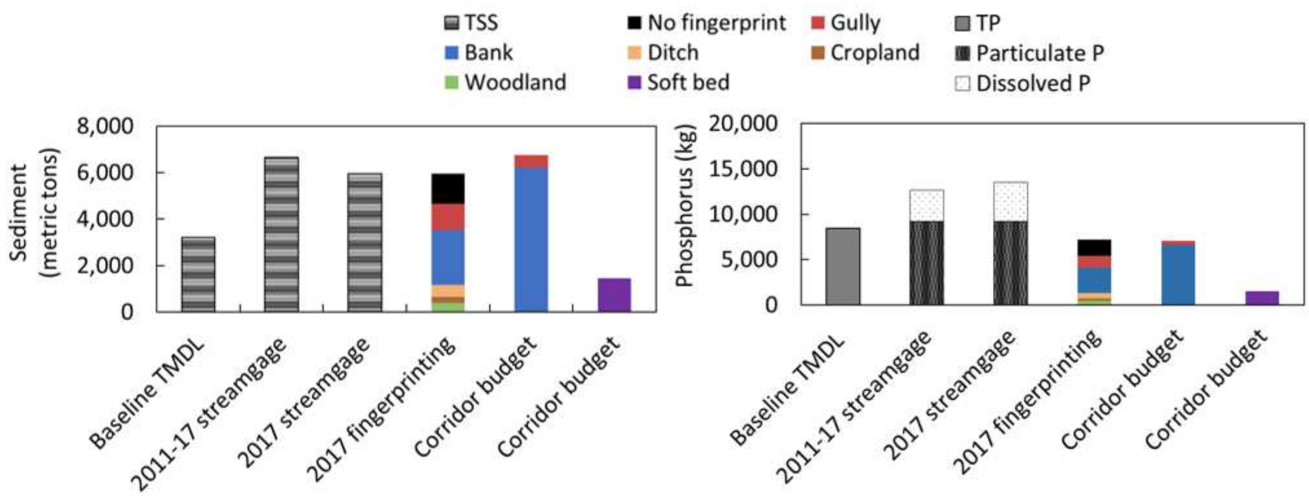


Figure 6. Comparison of annual loadings of sediment and phosphorus from streamgage monitoring, sediment fingerprinting, and stream corridor budgets for Plum Creek.

Sediment and phosphorus loads from the stream corridor budget for bank and gully erosion were within the same order of magnitude as the fingerprinting results (Figure 6). Annual loads of bank erosion from the stream corridor assessment were similar to the WY2017 TSS loads and comprised 49% of the water TP loads. The bank erosion estimates include coarse-grained sediments that would contribute to an unknown, unmeasured bedload at the streamgage. Part of the eroded bank and gully sediment is also deposited in overbank areas, which was not measured as part of this study. The amount of fine-grained soft bed sediment stored in the stream network is 24% of the WY2017 TSS and 11% of the water TP load, indicating that a relatively small amount of sediment and sediment-bound phosphorus is deposited in channels relative to the amount eroded.

The spatially distributed apportionment results from soft bed sediment samples throughout the stream network give further insights into the distribution of sources of TSS and SS_TP along the stream corridor (Figure 7). Banks and secondarily gullies were the main sources of soft bed sediment along the entrenched valley of the main stem. However, the most upstream bed sample, located on a first-order tributary upstream of the entrenched valley, had predominantly cropland, ditch, and gully sources. This observed shift in dominant sediment source is likely more representative of the western and southern parts of the watershed dominated by cropland and drained by first and second order stream channels upstream of the entrenched valley.

Bank erosion and soft bed sediment deposition, calculated by stream length, also supported the sediment fingerprinting results (Figure 8). The amount of bank erosion and soft sediment deposition was highly variable from reach to reach. Annual bank erosion loadings ranged from about 0 to 500 metric tons/km/yr for sediment and 0 to almost 400 kg/km/yr for sediment P. Soft sediment deposition ranged from about 0 to 105 metric tons/km for sediment and about 0 to 40 kg/km for sediment P. In general, sediment and sediment P loads would be expected to increase in a downstream direction because bank heights typically increase and slopes typically decrease with increasing stream size. However, for streams like Plum Creek that intersect multiple post glacial lake shorelines and lake plains, the valley width and slope can vary over short distances. The anomalously high loads from bank erosion were from reaches with active bluff erosion where the channel is impinging on a steep valley side. Chances for bluff erosion remain high along the entire main stem of Plum Creek because the meander belt width is the same as the valley width. The large disparity between amounts of bank erosion and soft bed sediment storage are indications that most of the sediment coming from upland and bank erosion is transported downstream.

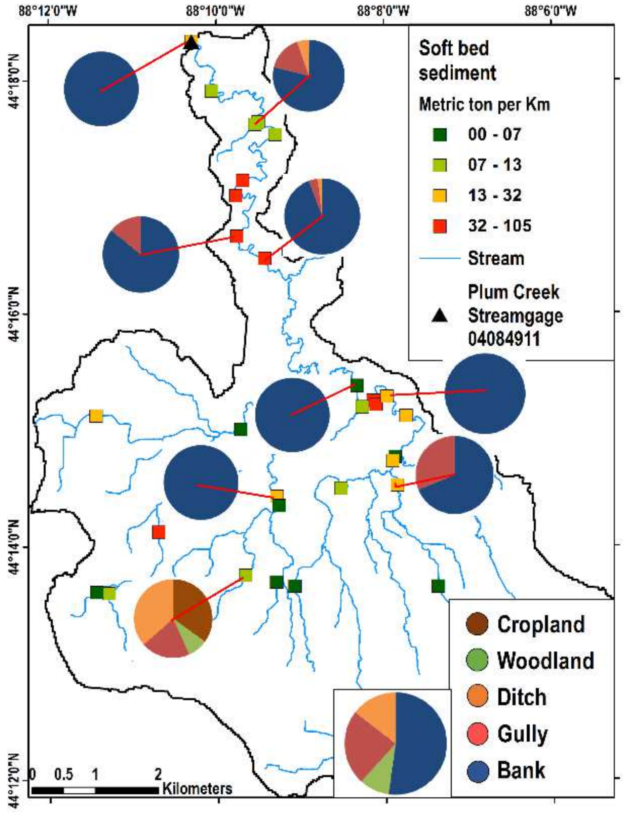


Figure 7. Spatial distribution of source apportionment to soft streambed sediment in Plum Creek.

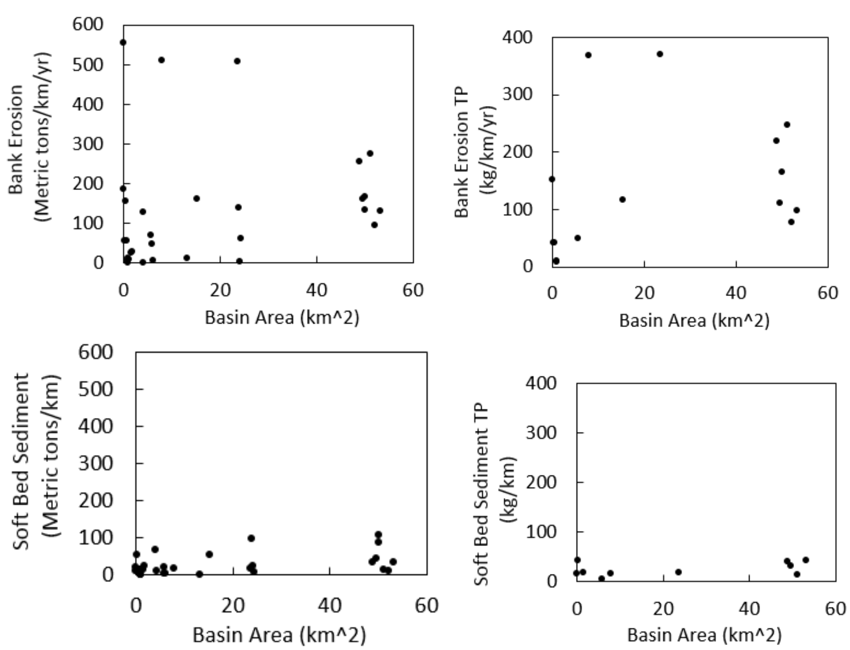


Figure 8. Reach-based bank erosion loading and fine sediment deposition for Plum Creek.

Summary and Conclusions

An integrated sediment fingerprinting and stream-corridor budget approach was helpful for understanding the seasonal and spatial distributions of sources of suspended sediment and sediment-related phosphorus in Plum Creek. The streamgage monitoring of TSS, TP, and dissolved P made it possible to quantify, on a monthly basis, the highly varying distribution of sources of suspended sediment and sediment-bound P. The fingerprinting technique was successful at discriminating between bank, gully, ditch, cropland, and woodland sources. Stream corridor budget estimates of bank and gully erosion supported the sediment fingerprinting results. Annual sediment-budgeted calculated loads of bank and gully erosion were similar to the WY 2017 TSS load and about 52% of the water TP load. The proportion of cropland source of TSS was low (6%), likely because of Plum Creek's geomorphic setting with a long-neck funnel-shaped watershed and the preponderance of bank and gully erosion in the 18-km stretch of main stem in the lower half of the watershed. In addition, cropland-derived sediment entering roadside ditches and mixing with road-derived sediment may form the unique ditch source signature. The fingerprinting-derived contribution of bank and gully erosion was potentially 41% of the water TP load at the streamgage. The proportions of bank and gully sources are likely different for cold season runoff events based on a few, difficult to collect, winter samples. The relatively low amount of soft bed sediment stored in the channels, about 24% of the annual load TSS and 11% of the annual load of TP, are an indication that most of the fine-grained sediment eroded from the watershed is transported past the streamgage. The results from this study indicate that upland and stream corridor conservation techniques are needed for reducing sediment and runoff in accordance with TMDL goals for stream TSS and TP reductions. Conservation techniques to reduce TP likely will differ for dissolved and particulate portions, and cold-season runoff events likely will require targeted sampling. Finally, additional study is required to better understand instream interactions of particulate and dissolved P phases.

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Appendix H

Summary of changes made to document following the public review and comment period

Page 21 and 24, Loss of Fish and Wildlife Habitat and Degradation of Fish and Wildlife Populations BUIs:

Original language:

The proposed target revision is provided above and will be formally adopted by WDNR after this plan's public review period, though revisions to the current proposed target may be made in consideration of comments and feedback received during this plan's public review period. A summary of changes made in lieu of comments and feedback received after the public review period will be included in Appendix H following the completion of the review period.

Revised language:

The proposed target revision is provided above and was formally adopted after the plan's public review period concluded on May 22, 2020. No comments or feedback regarding the revised target language for this BUI were received.

Page 22 and 25, Loss of Fish and Wildlife Habitat and Degradation of Fish and Wildlife Population BUIs:

Additional Actions considered complete with finalization of this RAP Update:

- ✓ *Finalize the "Loss of Fish and Wildlife Habitat" BUI removal target*
- ✓ *Finalize the "Evaluating Progress Toward Removing the Degradation of Fish and Wildlife Populations and Loss of Fish and Wildlife Habitat Beneficial Use Impairments" plan*

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