Supporting project integration and translation: Clinton River Smart Stormwater Management

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Background and Introduction

The Clinton River Watershed in SE Michigan faces stormwater challenges such as flooding and degraded water quality, which are exacerbated by climate change impacts and increasing urbanization in the watershed. The watershed covers 760 square miles in four Michigan counties and is comprised of thousands of bodies of water and hundreds of miles of streams. As the most populated watershed in Michigan, the area is home to 71 communities, 1.5 million people, and a range of diverse plants and wildlife (CRWC Website, 2022). River headwaters begin in rural Northern Oakland County, and the system ultimately drains into Lake St. Clair, which is part of the Great Lakes system (DiCocco and Graves, 2022). In 1987, the Clinton River was listed as an Area of Concern (AOC) by the Environmental Protection Agency. Since then, the Great Lakes Restoration Initiative (GLRI) has provided more than $43 million to fund projects and restoration initiatives with the goal of delisting the Clinton River as an AOC. There are many existing and emerging tools and technologies to assist with stormwater management (e.g., water sensors, modeling, forecasting, remote sensing, etc.), but these tools are often not applied at the watershed scale.

Researchers of the Clinton River Smart Stormwater Management Project aim to develop and integrate stormwater management technologies and apply them to the Clinton River system as a whole. This will demonstrate a systems-based and advanced technology approach to effective stormwater management in the Clinton River system, and will assist water resource managers in making informed and proactive decisions. The project began in 2018 and is funded by the US EPA with GLRI funds. This research, modeling, and outreach effort is led by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) in collaboration with the University of Michigan and Michigan State University. Currently, the project is in phase II with the possibility of obtaining funding for a phase III.

Throughout phase I, the project encountered communication and connectivity problems which are inherent to complex, technical, multi-party research projects. Principal Investigators (PIs) and clients recognized a need for further project support to combat these challenges, so our team of five masters students from the University of Michigan School for Environmental and Sustainability (UM SEAS) was brought on to the project. This was a unique example of both principal investigators and a funding entity (MI EGLE) recognizing the need for boundary-spanning work, and intentionally allocating resources for its completion. Our masters project team was brought on in January of 2021 to help connect project actors across disciplinary and institutional boundaries in four primary project areas: 1) Decision Support System assistance and stakeholder engagement, 2) project administration and evaluation, 3) GIS support and technical assistance, and 5) the design and implementation of a subproject on *E. coli* dynamics in the Clinton River. The following report contains descriptions and outcomes of our work in each of these project areas.

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Project Management Assistance

Authored by: Megan DiCocco

Introduction to Project Management Assistance

Project management and administration is a vital role within a research project team. A project manager is responsible for balancing the structural tasks of a project (i.e., budgeting, grant reporting, and meeting organization) and the human dimensions of a project (i.e., teamwork, cooperation, and communication) to foster a productive and cohesive project culture (Ernø-Kjølhede, 1999). This task can prove difficult when project researchers, clients, and stakeholders come from different professional backgrounds and organizations. When this is the case, project managers must act as boundary-spanners, bridging institutional borders to convene actors and facilitate knowledge-sharing and collaboration (Delozier, 2021).

Actors within the Clinton River Smart Stormwater Management Project have varied disciplinary backgrounds and represent multiple large institutions, which necessitates effective project management. Luckily, the team has a successful project manager, Kate Kusiak Galvin, who balances the needs of Principal Investigators (PIs), clients, and stakeholders; and she ensures the project is progressing efficiently. As project manager, she promotes inter-institution communication and knowledge-sharing, organizes meetings and agendas, tracks project milestones, and manages the team's administrative processes. Her role is vital to the success of the large, complex project.

In order to further expand the extent of project management on the Clinton River Smart Stormwater Management Project, two graduate students from the University of Michigan School for Environment and Sustainability (UM SEAS) capstone project team were brought on to assist the project manager and gain experience in this boundary-spanning role. We assisted the project manager with administrative tasks, organization and communication, project evaluation, and the production of a project factsheet. This assistance maximized efficiency and effectiveness of project management and resulted in even greater overall project capacity and success.

Summary of Project Management Assistance Work

Our primary responsibility as project management support was to assist with the administrative tasks of the project. We took notes and meeting minutes at full-team meetings and stakeholder working group meetings, and we archived these notes as a record of meeting progress. We provided edits on the first draft of the project's Quality Assurance Project Plan (QAPP), which outlines technical procedures of the project and is required by the Michigan Department of Great Lakes and Energy (EGLE) and the funding source, the United States Environmental Protection Agency (US EPA). We helped prepare quarterly grant reports for the client at MI EGLE, making sure reports were thorough and included all necessary information. A large administrative responsibility we managed was the organization and facilitation of monthly client update meetings, which brought together student project team members, the project manager, and clients from MI EGLE and the Clinton River Watershed Council (CRWC). At these meetings, the student team presented updates on project progress and provided a time for client input and discussion. At the request of the client, we also organized and facilitated a webinar describing the Clinton River Smart Stormwater Management Project. All PIs and the student team presented at this webinar and advertised project work to professionals in the MI EGLE Water Resources Division. At the conclusion of this webinar, we developed and administered a survey to attendees, which collected feedback and metrics on audience interest in the project work. These are some examples of how we supported project administration; and we also assisted with many other administrative tasks which the project manager or PIs were unable to complete due to time constraints or conflicting commitments.

We developed an updated and comprehensive project factsheet. When the UM SEAS student team joined the project in January 2021, the original project factsheet (Appendix A) was outdated and lacked a narrative component. We updated the factsheet twice (Appendices B and C) with Phase II information, developed a more compelling narrative voice, and included more information on the Clinton River Watershed to induce more of a "sense of place" (Williams & Stewart, 1998) These updates were specifically requested and approved by the client at MI EGLE. The updated factsheet provides the overall project story and can be used as a public outreach and engagement tool. It will be disseminated to stakeholders and colleagues at the clients' discretion.

To assist with project assessment and future-phase improvements we designed a project evaluation guide to be implemented once final deliverables are complete. Project evaluation is an important tool to assess and increase project effectiveness, improve project operations, and integrate feedback from clients and stakeholders (Hobson, Mayne, & Hamilton, 2014). The client at MI EGLE expressed a need for project evaluation of the Clinton River Smart Stormwater Management Project, but an evaluation protocol was not available. This is a common occurrence because researchers are focused on the technical aspect of a project, and the project manager is focused on the day-to-day administrative tasks that keep the project running smoothly. We had the bandwidth and necessary knowledge about the project to design a project evaluation guide (Appendix D). This guide includes four tools for project evaluation: 1) a protocol for a stakeholder survey to collect feedback from end-users on the value and useability of project deliverables; 2) an interview guide for stakeholder interviews to gain in-depth insight from a subset of stakeholders in a conversational setting; 3) an interview guide for discussions with organizations outside of the Clinton River system to discern if a similar project would be applicable to watersheds across Michigan; 4) and finally, a guide for internal interviews with project team members and PIs. These resources have been handed-off to the project team and client to implement in a future phase of the project once deliverables are complete.

Finally, In order to evaluate the internal workings of the team during Phase II, we conducted the internal interview portion of the aforementioned evaluation guide. We interviewed all three PIs and four other key team members about project communication, connectivity, and productivity. These discussions also included reflections on project goals, achievements, and the value of deliverables.

Discussion

Our assistance with project management tasks was beneficial to the project overall because it freed up time for the project manager and PIs to focus on larger project tasks and goals. When we took notes at large team meetings, the project manager and all attendees were able to be fully present and engaged with meeting conversation but still have a record of meetings to look back on for milestone tracking and setting agendas for future meetings. We also kept a record of meeting progress and frequency, which was used as a metric of project progress in reporting to the client at MI EGLE. Our assistance editing the QAPP allowed the document to be submitted in a timely manner and with higher quality. When asked about the value of student assistance with the QAPP one PI was quoted as saying "[the QAPP] would have gotten done, but I don't know if it would have been the same level of quality and timeliness." Student assistance preparing the quarterly grant reports was also valuable because there were sometimes details about certain areas of the project that the project manager did not have intimate knowledge of. The student team was embedded within each project team, so we knew when details were missing and could adjust the grant reports accordingly.

Another beneficial outcome of our assistance with administrative tasks was increased connection with clients. When we organized and facilitated monthly client update meetings, we brought the project team and clients together for additional facetime. This created a space to receive feedback from the client, clarify expectations between parties, exchange ideas and information, and importantly, to build relationships and trust with the clients. By the end of our time on the project, our clients trusted us as consultants and we were empowered to make confident decisions and recommendations. For example, the client trusted us to organize and facilitate the professional webinar for MI EGLE staff. This event served as an outreach effort and connected our project team with other water professionals across the state. We had notable professionals in our audience, and our client at MI EGLE was pleased with the networking outcomes from the event. The student team also collected insightful survey results from the webinar audience, which provided metrics for the need for, and interest in, similar projects across Michigan. Our client at MI EGLE can use these survey results to explore potential extensions of the Clinton River Smart Stormwater Management Project.

Once we were intimately familiar with project goals and client needs, we were able to curate a story of the project and develop the project factsheet. Prior to our involvement, the story of the project had not been developed in a comprehensive, narrative manner, which made public communication about the project difficult. While updating the factsheet, we considered the client voice and told the story of the project in a way the client wanted it advertised to colleagues and stakeholders. We made the technical science more relatable, understandable, and engaging to the public and stakeholders, thus we created a more effective tool for outreach and engagement.

As the connective tissue entity of the Clinton River Smart Stormwater Management Project, the UM SEAS capstone team was in a unique position to design a robust project evaluation guide. We took responsibility for the nitty gritty tasks of designing a comprehensive evaluation protocol, which allowed the project manager to focus on the big-picture goals of project evaluation. It was also important for us to be the ones to look forward and design this evaluation, because we were the objective boundary-spanners working only for the neutral good of the project. Therefore, we developed the evaluation guide with all aspects of the project in mind, including stakeholder needs and client goals. The evaluation design can be applied iteratively throughout future phases of the project to assess project success and indicate where adjustments may be needed.

Our experience working closely with the project manager and PIs prepared us to enter the professional world with well-rounded and applicable knowledge and skills. While assisting the PIs with their administrative work and interviewing them for internal evaluation, we learned about the interdisciplinary technical aspects of the research project. While assisting the project manager, we learned a great deal about professional project management and the complexities that arise with large, interdisciplinary research projects. In our communications with clients and stakeholders, we developed the ability to listen to end-user needs and communicate those to researchers. This experience provided hands-on, real-world exposure to the environmental research project field and encouraged growth in our personal and professional confidence. We had access to multiple professional mentors and role models, and we appreciate the knowledge and wisdom they imparted on us. We will carry these skills and experiences with us as we graduate and begin our careers.

Findings From Internal Evaluation Interviews

The internal evaluation interviews provided insight and perspective on the inner workings of the project team. We interviewed seven team members to assess team communication and cohesion during Phase II. Results from these interviews can be used to improve project dynamics. The results also serve as a record of Phase II mechanics and can be used for comparison of progress in future phases. As of January 2022, all seven team members indicated high-levels of satisfaction with team communication and connectivity, even between institutions. Team members communicate often and effectively with other sub-teams of the project, clients, and stakeholders.Team interviewees who participated in Phase I of the project, all noticed a distinct improvement in project communication, cohesion, organization and productivity after the addition of the project manager in Phase II. This demonstrates the value of project management in this complex project. All seven interviewees also recognized the success of the UM SEAS capstone team in our connective tissue role. Multiple team members mentioned feeling more connected and engaged with other sub-teams because of the boundary-spanning provided by the student team. One interviewee stated that the students helped their team to more quickly understand and receive results from other sub-teams. Another interviewee said that the student team was “often more engaged than some of the PIs even were,” which “vastly improved coordination.” Most interviewees also indicated high satisfaction with the student team’s project support and their ability to increase project capacity “so the researchers can focus on research.” These responses indicate the value of the UM SEAS capstone team in connecting project actors, and we recommend the project continues to include a dedicated connective tissue entity in future phases.

Interviewees had specific suggestions to improve project cohesion. One interviewee suggested that the project team make a greater effort to get to know each other personally. This was difficult throughout the COVID-19 pandemic as all meetings were held virtually, but looking forward, the team should continue to build relationships between sub-teams and institutions during team meetings. The interviewee noted “it would improve information flow if we knew each other better.” One team member from Michigan State University did express mild dissatisfaction with communication about the UM SEAS capstone team’s role. The interviewee stated that expectations could have been communicated more clearly, and this response indicates that there is still a need for greater integration, cohesion, and connection between organizations. This is something that the project team should never cease to work on throughout future phases. Interviewees were also asked specifically about communication and connection with stakeholders, and multiple team members mentioned a need for better organization of stakeholder working group meetings. Almost all interviewees valued feedback from stakeholders during Phase II and understood the importance of regular interactions with the stakeholder working group. However, multiple interviewees expressed concern that stakeholders are not being given an effective opportunity to give vital feedback. We suggest the project manager hosts monthly stakeholder planning meetings with a subset of team members. This time should be dedicated to designing more engaging and effective stakeholder meetings, developing stakeholder meeting agendas, and clarifying goals and expectations of these meetings. We also recommend brainstorming ways to receive greater amounts of feedback more efficiently (i.e., breakout rooms in Zoom, surveys, or specific questions to address). The project team should repeat these internal interviews throughout future phases of the project to continue to assess and improve internal dynamics.

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Assistance with the Decision Support System, including Stakeholder Engagement

Authored by: Analise Sala

Compelling Rationale

The Decision Support System (DSS) is an online tool being developed by the Clinton River Smart Stormwater Management Project that will provide local water managers with a visualization of the Clinton River hydrologic system, and its current and future management challenges. Of particular interest to stakeholders are flooding and degraded water quality, both of which are exacerbated by climate change impacts and increasing levels of urbanization in the system. The project aims to provide technological solutions to the flooding and water quality management issues in the Clinton River Watershed. These technological solutions coalesce around the three major project parts - an online decision support system, integrated hydrologic modeling, and a real-time field-based sensor network. Both the hydrologic modeling and sensor network data will be incorporated into the DSS, allowing managers to conduct assessments of management actions and what-if scenarios. Ultimately, the DSS aims to empower local water managers in near- and long-term decision making related to stormwater management and related resource allocation.

However, throughout phase I of this multiparty complex project, disciplinary, institutional, and geographic boundaries contributed greatly to difficulties in convening and communicating between institutions. This hindered project progress as the individuals working on hydrologic modeling and the real-time sensor network were not consistently speaking with the creators of the DSS - a final landing place of their work. Moreover, the DSS team occasionally faced difficulty in addressing stakeholder concerns. Thus, in the beginning of phase II, the project team decided to budget for and allocate time to the incorporation of boundary spanners, in this case a masters project team, to assist with connection, communication and translation. Two members of the team were assigned to provide assistance for the DSS group and support stakeholder engagement.

DSS Team Support and Incorporation of Stakeholder Requests

Our role in DSS connection and support involved working closely with Dr. Glenn O’Neil of Michigan State University, the primary developer of the web tool. Before our involvement, Dr. Glenn O’Neil and the researchers working on the hydrologic model had minimal communication so we were tasked with facilitating their connection. Fortunately, they re-organized on their own and held weekly meetings together for the remainder of our time on the project. This reprioritized our role from primarily connection to include both support and inclusion of stakeholder input. Our role can be summarized by the following three objectives: DSS development support, ensuring stakeholder concerns were addressed, and connecting the DSS team to the other project teams. Responsibilities, described below in more detail, varied widely and depended largely on the immediate needs of the DSS team.

In order to support the DSS developers and ensure inclusion of user needs, it was crucial we attend project meetings within every sub-group. Thus, we partook in weekly meetings with researchers developing the hydrologic models, bi-weekly meetings with the entire project team, and monthly stakeholder engagement meetings led by the MSU team. Prior to our integration into the various meetings, we became familiar with the initial user questions developed by the MSU team. These preliminary user questions were based on the results of a Phase 1 user-needs analysis of stakeholder issues and represent typical challenges water resource managers are faced with. The questions identified five priority water management issues: infiltration areas, water quality improvements, green infrastructure, *E. coli* source tracking, and stormwater management. Familiarity with these questions allowed us to provide feedback and suggestions to the DSS developers with stakeholder concerns in mind. In light of the framework provided by these user questions, we tracked stakeholder feedback in the monthly stakeholder meetings and followed up with principal investigators to ensure feedback was addressed (Table 1).

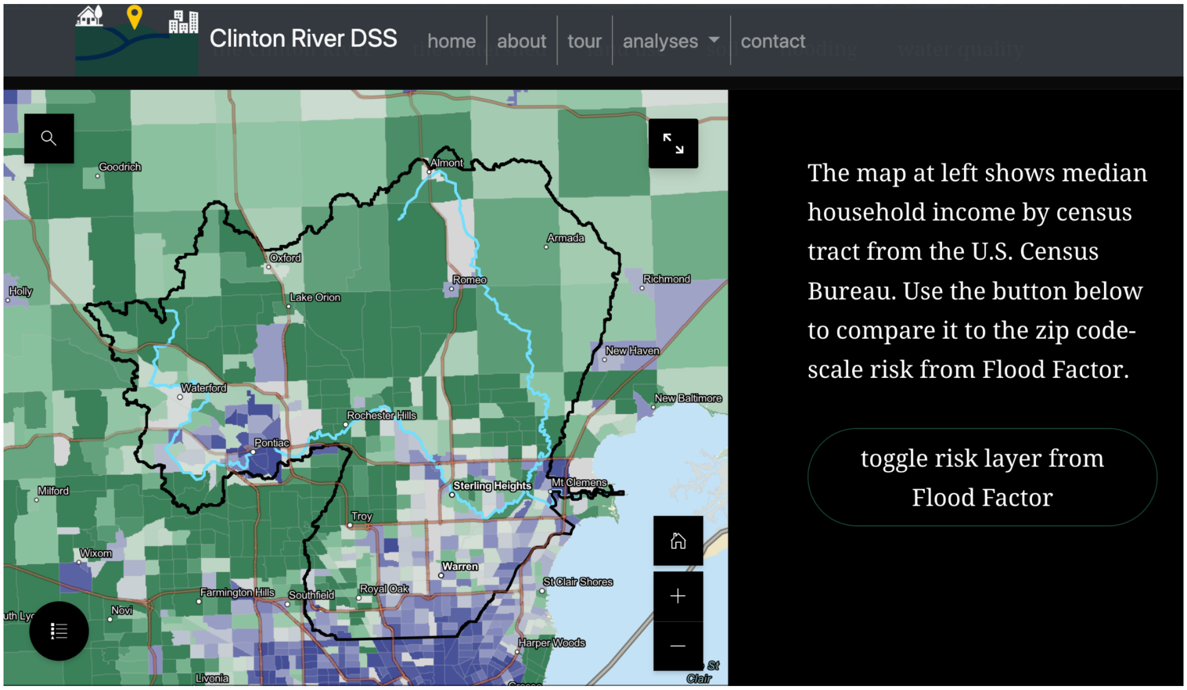
Table 1. Example row from Stakeholder Feedback Tracking document. Feedback was given by Joel Kohn, an Environmental Planner for Oakland County, at a May 2021 stakeholder engagement meeting.

Date	**Feedback**	**From who?**	**Will/can this be integrated?**	**Plan to integrate, or reason cannot be integrated.**
5/13/21	Tool should point out examples of successful green stormwater infrastructure (GSI) implementation in the tour as well	Joel Kohn (Oakland)	Yes	MSU and SEAS student team will compile examples of successful GI from clients and stakeholders to be included in the tour feature of the DSS or the tools tab. Interactive map of locations.

During these stakeholder engagement meetings, end-users provided suggestions and feedback that the student team was able to assist in implementing. As one example (Table 1), an Oakland County Environmental Planner suggested the DSS include examples of successful green stormwater infrastructure (GIS) already in use in the Clinton River system. We compiled examples of these practices and found both images and news articles for incorporation into the DSS. We had assistance in this research from MSU team member Mike Thomas and Eric Diesing from the Clinton River Watershed Council (CRWC). Examples included rain gardens and bioswales implemented by the Clinton River Watershed Council's WaterTowns program, a "green infrastructure retrofit" of the Sterling Relief Drain in Sterling Heights, a bioretention area in Normandy Park of Clinton Township, and others. Bioswales and rain gardens were the most common examples found throughout the watershed.

In addition to our involvement in already-organized meetings, we often planned and implemented tactical meetings in response to project concerns. This facilitated communication between project actors and data-sharing between entities, e.g. the Clinton River Watershed Council and the University of Michigan modeling team, that would not otherwise have communicated. Sometimes, this involved the use of GIS to transform data into a more usable form for the intended recipient.

Another specific request from stakeholders was to incorporate an Environmental Justice component into the DSS. Therefore, we reviewed and compiled existing Environmental Justice mapping resources and provided a recommendation to the DSS developers. We recommended the use of Michigan EJ Scores from the Michigan Environmental Justice Coalition (MEJC), as this was the only Michigan-specific tool, and facilitated conversations with the developers for use of their data. Unfortunately, MEJC was slow to respond and our contact there recommended we seek out other sources of EJ data for the DSS. In place of the Michigan EJ Score layers, the DSS now includes a mean household income layer from the US Census Bureau (Figure 1) and an Equity Emphasis Areas tool developed by the Southeast Michigan Council of Governments (SEMCOG). Michigan EGLE has released a draft of their upcoming tool MiEJScreen[1] that has been shared with the developers of the DSS for potential future incorporation.



The map at left shows median household income by census tract from the U.S. Census Bureau. Use the button below to compare it to the zip code-scale risk from Flood Factor.

Figure 1. A screen capture of the DSS watershed tour feature where median income data from the U.S. census bureau can be overlaid with flood factor risk in the Clinton River Watershed.

MSU researchers requested our assistance with additional supportive tasks during and after project meetings, which allowed us to provide a substantial amount of support for the

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[1] https://gis-egle.hub.arcgis.com/datasets/egle::miejscreen-draft-data/about

development of the DSS. We completed a literature review on the effectiveness of low impact development (LID) practices. Our charge was to seek out qualitative data describing percent change in a given water quality parameter (e.g., nitrogen or total dissolved solids) after the implementation of primary or secondary LID practices. Primary LID practices included green roofs, rain barrels or cisterns, rain gardens or bioretention, and porous or pervious pavement. Secondary LID practices included buffer or filter strips, grassed waterways and swales, wetlands (both constructed and natural), and tree planting. Our literature review informed the hydrologic model, specifically in its estimating how future implementation of these practices in the Clinton River watershed might impact water quality.

We developed a narrative for the incorporation of data from our team's *Escherichia coli* subproject into the DSS. We crafted a story to introduce our data and the compelling rationale behind its inclusion. This included background, details regarding our methodology, and general inferences that could be drawn from the data. We ensured successful data sharing and correct interpretation of the results between the student team and the MSU DSS team.

Our work on DSS assistance, ensuring stakeholder concerns were addressed, and connecting the DSS team to the other project teams, culminated in *Alpha* testing of the tool, where we provided critical feedback on the usability and content of the DSS.

Importance and Outcomes of Boundary-Spanning Role

Boundary-spanners are traditionally defined as individuals who work across the divide between information producers and users (Tushman, 1981). In our case, boundaries existed both between project researchers and between researchers and stakeholders. Through our involvement in numerous project meetings, we obtained a broad and full understanding of the Clinton River Smart Stormwater Management Project. Familiarity with the priority user questions gave us knowledge of stakeholder concerns and this understanding anchored our facilitation of connections among project actors, clients, and stakeholders. We were often looked to in meetings to answer simple questions related to the work of other teams and could point individuals to the correct person outside of their subteam if a problem or question arose. As is often the case with dedicated boundary spanners, we functioned primarily to acquire and deliver information (Aldrich & Herker, 1977). Ultimately, the knowledge obtained through meeting involvement bolstered our role as "connective tissue," allowing us to organize tactical meetings when necessary, facilitate data sharing and more.

However, the success of organizations or individuals in the role of boundary spanning, depends largely on the consent of all parties (Guston, 2001). Fortunately the Clinton River Smart Stormwater Management Project explicitly allocated both time and resources to the inclusion of our project team as "connective tissue." Actors had previously discussed and recognized a need for individuals to occupy such a role and thus, our incorporation was both welcomed and seen as critical for project success. This act deserves recognition, as the buy-in of researchers, who are likely already stretched thin by competing commitments, was a massive contributor to our success.

Our role in mediating, facilitating, and translating across boundaries was incredibly important for project progress. The Clinton River Smart Stormwater Management Project is an example of Integrated Water Resource Management (IWRM), a process that encourages collaboration from stakeholders at multiple levels (Delozier & Burbach, 2021). Research has demonstrated the importance of boundary-spanners in IWRM projects, specifically in facilitating the flow of information between organizations and stakeholders (Delozier & Burbach, 2021). We were perceived as neutral individuals acting in the best interest of the overall project, granting us the ability to communicate effectively with all parties and stakeholders

Moreover, familiarity with user questions, involvement in stakeholder meetings, and consistent communication with the funding agency, Michigan Department of Environment, Great Lakes, and Energy helped ensure DSS effectiveness. The success of our role cannot be quantitatively measured but feedback from principal investigators given in internal interviews and informally assured us our involvement was valuable and necessary. Complex, technical projects such as this may benefit greatly from the consistent inclusion of and allocation for individuals who occupy similar roles.

A limitation to achieving our utmost effectiveness was time, as longevity can improve boundary-spanning effectiveness (Safford et al., 2017). The length of our involvement could not exceed 16 months and unfortunately, writing responsibilities shortened this to 12 months of effective involvement. Future IWRM projects may benefit from institutionalized boundary-spanners, or those in a position to occupy the role throughout the entirety of its lifespan.

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Characterization of *E. coli* baseflow concentrations and responses to storm events in the Clinton River of Southeast Michigan

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Abstract

Urbanization and climate change create stormwater management challenges in the Clinton River of Southeast Michigan, where high *Escherichia coli* concentrations often exceed Water Quality Standards. With no warning system in place and gaps in understanding of *E. coli* dynamics, stakeholders of the Clinton River Smart Stormwater project indicated concern over the often high *E. coli* concentrations. The first flush effect is known to increase *E. coli* concentrations in streams, but a lack of comprehensive coverage of *E. coli* data during storms makes informed and effective decisions for local water managers difficult. Moreover, data from one location cannot represent the entire Clinton River due to landscape heterogeneity in the different sub-watersheds. Therefore, this study aimed to: characterize the relationship between *E. coli*, stream discharge, and precipitation at both baseflow and during storm events at downstream locations on four branches of the Clinton River; as well as develop discharge- and precipitation-based exceedance thresholds for *E. coli* risk at each branch for watershed management decision-making. During the summer of 2021, we conducted 12 weeks of comprehensive baseline sampling and storm sampling of five events at the four branches. We developed time series analyses of *E. coli* overlain on hyetographs, and linear regression and logistic regression models of the relationship between *E. coli* and precipitation and streamflow; and generated four thresholds of *E. coli* risk for each branch from the logistic regression models. We found *E. coli* concentrations in the four branches were lower at baseflow than during high flow or storms, but still often exceeded Water Quality Standards for body contact. *E. coli* concentrations rose dramatically and rapidly during storm events and consistently peaked prior to the ascending limb of the storm hydrograph at all four sites, albeit with different patterns. Logistic regression models illustrated that increased precipitation and streamflow led to increased probabilities of exceeding Water Quality Standards at all four branches. The threshold analysis indicated the most sensitive branch to *E. coli* was the Red Run, while the most resilient branch was the North Branch. Findings from this study will be incorporated into a decision support system to assist with watershed management and public awareness of *E. coli* dynamics. Our findings suggest the creation of a real-time risk warning system based on exceedance thresholds may be beneficial for public use. Moreover, our results stress the importance of comprehensive watershed sampling, and suggest the use of riparian buffers and retention wetlands may increase the resilience of urbanized rivers to increasing pathogen loans. Further research on seasonal variability, the antecedent dry period before storms, and additional source tracking may be needed to confirm our results and evaluate the impacts of our study limitations.

Introduction

Many river systems in the Great Lakes Region face stormwater management challenges related to urbanization and climate change. Urbanization produces increased impervious surfaces and drainage infrastructure, both of which contribute to excessive and rapid stormwater runoff. This can increase flooding and degrade water quality throughout a river system. Effects of climate change, such as increased frequency and severity of rain events, further exacerbate these stormwater issues. The Clinton River in Southeast Michigan faces such stormwater concerns, and these contributed to the river being listed as an Area of Concern (AOC) by the Environmental Protection Agency (EPA) in 1987 (MI EGLE, 2022).

In urban river systems with stormwater challenges such as the Clinton River, there are often high loads of bacteria such as *Escherichia coli* (*E. coli*). This *E. coli* can originate from both point and nonpoint sources and is typically associated with fecal contamination from either human or animal sources. Fecal contamination from both pose a significant human health concern (Ishii & Sadowsky, 2008). Water resource managers also use *E. coli* as an indicator for the presence of other pathogens and pollutants of concern.

In order to address the impacts of fecal contamination on surface waters, U.S. lawmakers enacted Section 303(d) of the Clean Water Act, allowing the EPA to assist states in listing impaired waters and developing Total Maximum Daily Loads (TMDLs) for those listed. Under the CWA, states must first set Water Quality Standards (WQS) to manage pollution levels, then develop TMDLs for every pollutant/waterbody pair identified in the WQS. A TMDL establishes the maximum amount of a pollutant a waterbody can sustain and still meet the WQS. *Escherichia coli* is used as an indicator for fecal contamination so state WQS were developed for *E. coli* in Michigan.

The Clinton River in Southeast Michigan failed to meet the WQS for *E. coli*, prompting the Michigan Department of Environment, Great Lakes, and Energy, or MI EGLE, to create TMDLs for *E. coli* in 3 branches of the river system (MDNR, 2010). The Lower Clinton *E. coli* TMDL established a total body contact limit (TBC) and a partial body contact limit (PBC) based on the beneficial uses for recreational waters. The TBC limit was set at 300 *E. coli* per 100 ml and the PBC limit at 1000 *E. coli* per 100 ml (MDNR, 2010). Additional TMDLs were set for the Red Run Drain and Bear Creek tributaries of the Clinton River, specifically a TBC limit of 300 *E. coli* per 100 ml and a sanitary wastewater discharge limit of 400 *E. coli* per 100 ml. To ensure compliance with TMDLs, point sources are addressed through discharge permits from the EPA National Pollutant Discharge Elimination System (NPDES). However, nonpoint sources are left for local and regional water managers to address.

To this day, the Clinton River AOC often does not meet WQS for *E. coli*, which continues to be a concern for water resource managers and stakeholders working and recreating within the Clinton River system. *Escherichia coli* concerns in the Clinton River were highlighted to the public in recent years after unsafe levels of *E. coli* caused multiple beach closures at Lake St. Clair Metropark, located near the outlet of the Clinton River. County water managers test for *E. coli* in recreational swimming waters, post health warnings, and issue these beach closures when *E. coli* concentrations are found to be elevated; however, no such warning system is in place for the Clinton River and its tributaries.

Moreover, since 2018, a team of researchers has collaborated on the Clinton River Smart Stormwater Project. This is a research, modeling, and outreach effort led by MI EGLE in collaboration with the University of Michigan (UM) and Michigan State University (MSU), and funded by the Great Lakes Restoration Initiative (GLRI), through a capacity grant to MI EGLE's Water Resources Division. It is also a Clinton AOC project through the same capacity grant. The project leverages existing and emerging technologies to inform stormwater management decision-making for the Clinton River. The project team is developing an online Decision Support System (DSS) to visualize stormwater management scenarios and assist managers in making near- and long-term management decisions. High levels of *E. coli* in the river are a specific concern of stakeholders of this project, therefore the DSS will include information on *E. coli* dynamics for local managers to consider when making decisions about water safety.

There are gaps in understanding *E. coli* dynamics throughout the Clinton River system, and additional data could assist managers to make informed and effective decisions. For example, it is well documented that concentrations of *E. coli* are higher in a river system during the "first flush" of a rain event (McCarthy, 2009). The degree of this increase is uncertain in the Clinton River because historical *E. coli* data lack comprehensive coverage during precipitation events. Additionally, existing technologies for river monitoring can indicate or predict increases in river flows, but they often lack information on associated risk from elevated *E. coli* concentrations. Specifically, where and under what precipitation and flow conditions do *E. coli* concentrations exceed the public health standards set by the EPA and MI EGLE; i.e. precipitation and flow thresholds. These challenges are difficult for managers to address because they exist at a river system scale. Furthermore, the Clinton River system has several main branches draining distinct sub-watersheds within portions of four different Michigan counties. These sub-watersheds differ in area, land use type, population density, and management techniques, so it is not possible to use a single *E. coli* precipitation or flow threshold for the entire Clinton River system.

We therefore collected additional *E. coli* data at sites near the downstream end of the four main branches that form the lower Clinton River system during storm events and used that data to characterize *E. coli* dynamics in the system. We sought to determine thresholds of precipitation and streamflow where *E. coli* concentrations are likely to exceed TBC and PBC limits and thus pose a human health risk. These thresholds will be included in the online DSS to help water managers understand *E. coli* dynamics and risks in their jurisdictions. At our four study sites, our study objectives were to: 1) Evaluate *E. coli* levels during baseflow periods when rain has been scarce, and during several individual storm events; 2) Determine under what precipitation and discharge conditions *E. coli* concentrations exceed both partial and total body contact limits set by the EPA and Michigan EGLE and finally; 3) Develop specific statistical thresholds, describing when *E. coli* exceeds the aforementioned standards, to be incorporated into the DSS software.

Methods

Site Description

Sampling Locations

We collected baseline and storm *E. coli* samples at four sites within the Clinton River from May 11th to July 27th, 2021; one on a downstream reach of each major branch: Main Branch, Middle Branch, North Branch, and Red Run. The four sites allowed for comprehensive coverage across various hydrologic conditions within the watershed and captured the *E. coli* response in four different major sub-basins of the Clinton River. The Middle Branch and Red Run sites were chosen due to their use in previous studies (Brown, 2020) while the Middle Branch and Clinton Main sites are proximate to United States Geological Survey (USGS) gages. The sample location for the Clinton Main Branch of the Clinton River was near the Sterling Heights Nature Center in Sterling Heights. This location was a public park with access to the river via a pedestrian bridge. The stream has steep banks that transition to a gently sloped floodplain with forest, swamp, and marsh habitats. The sampling location for the North Branch was near 25 Mile Road and Foss Road in Macomb Township. The bridge for sampling was located on the closed road between Foss and Card roads. The river at this location was located in between multiple farms. The sampling location for the Middle Branch was near 25 Mile Road and Romeo Plank Road in Macomb. Sampling at this location took place at a small pedestrian bridge located within the grounds of a local plant nursery (Figure 1). The sampling location for the Red Run section of the Clinton River was at the Maple Lane Golf Club in Sterling Heights, 5.78 miles downstream of the George W. Kuhn retention and treatment basin.

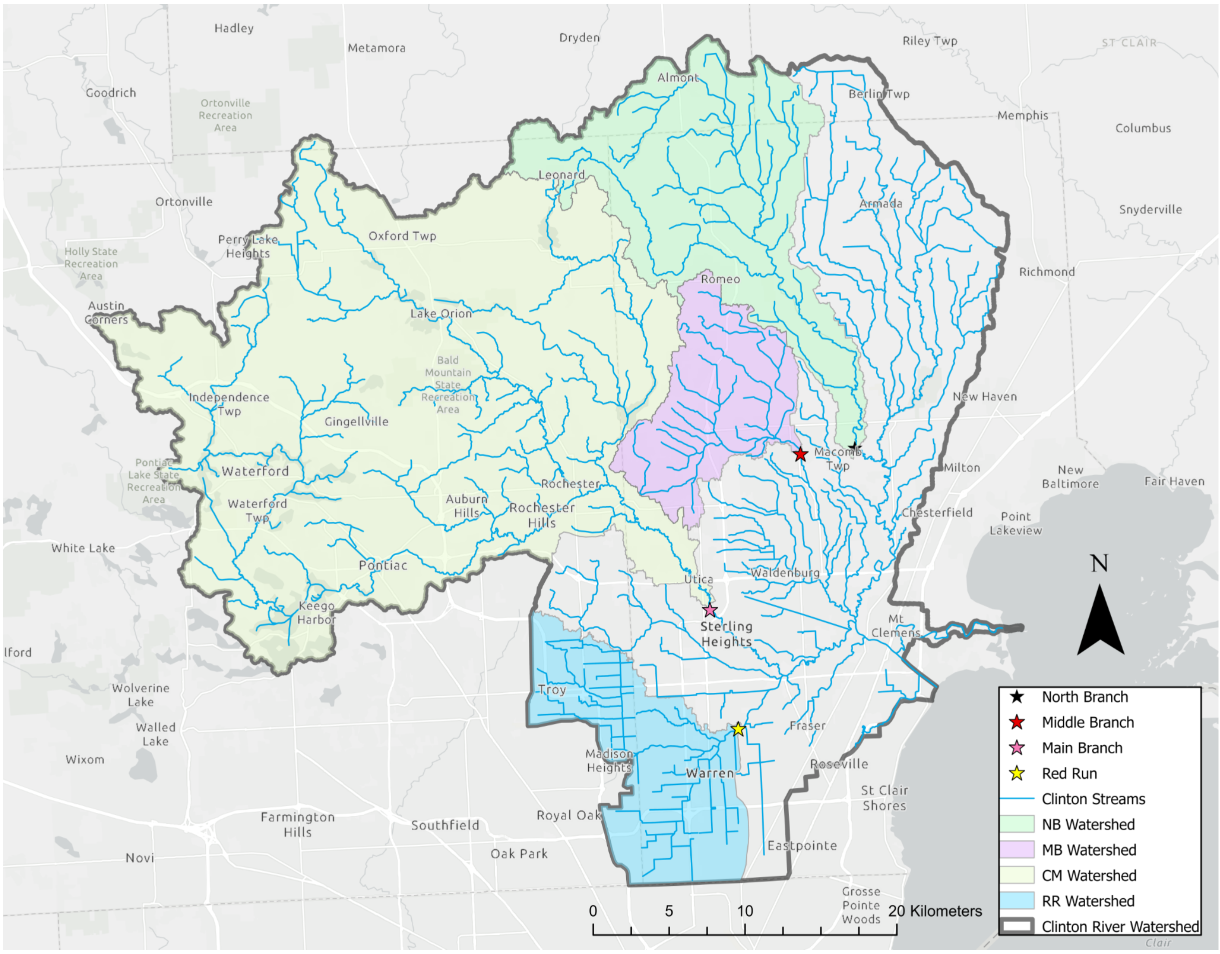


Figure 1. Clinton River subwatersheds and the location of our four testing sites for *E. coli* water quality sampling.

Landscape Character

Surficial geology

Surface geology of the Clinton River System provides essential insight into the differences between the four chosen sampling sites and how they respond to storm events. The Clinton Main Branch drains a moraine with a mix of coarse and medium-textured tills as well as outwash plains with sand and gravel. The surface geology of the Middle Branch subwatershed upstream of our site is mostly lacustrine sand and gravel. This gives them a reasonable potential for infiltration and groundwater storage as well as higher base flows. The North Branch drains mostly lacustrine silt-clay, and the soils of the Red Run subwatershed are a combination of lacustrine clay and silt, and lacustrine sand and gravel (Figure 2). Silt-clay lake plains have extremely low levels of natural infiltration and groundwater storage, creating naturally low base flows and high flashiness in these branches during storm events.

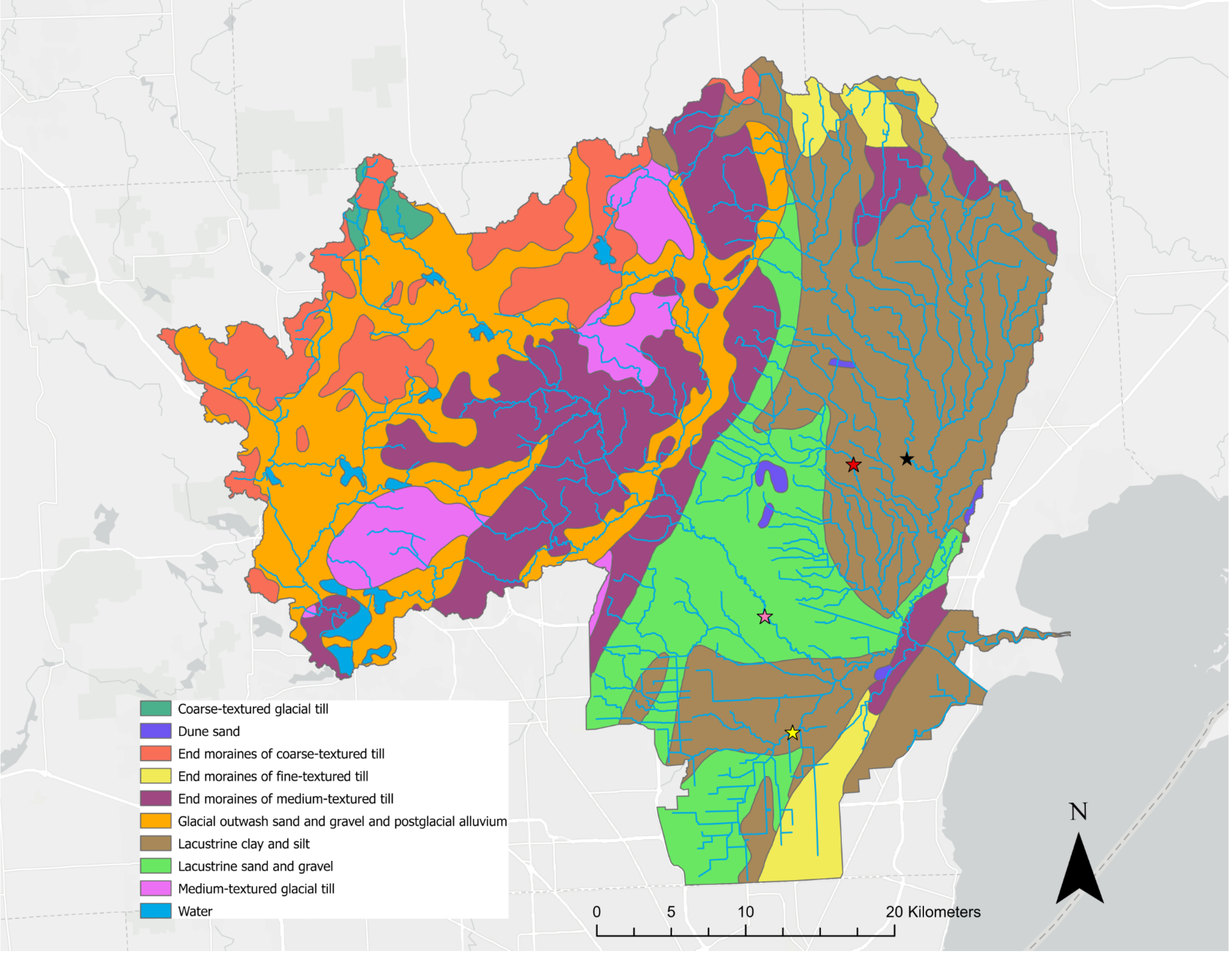


*Figure 2***.** Surface geology of the Clinton River watershed. Maps are modified images from the Michigan DNR Fisheries Division, Special Report 39, Clinton River Assessment (Francis & Haas, 2006).

Land use

Land use and degree of development are important factors in stormwater management as the amount of impervious surfaces greatly influences runoff regimes. The land use of the Clinton Main Branch subwatershed is mostly built areas with small amounts of forested land around select northeastern, upper tributaries. The Middle Branch subwatershed land use is urbanized in the southwest and agricultural in the northeast. The North Branch of the Clinton River is surrounded primarily by cultivated land for agriculture, with growing development. Land-use surrounding the Red Run branch is overwhelmingly urban with residential development, industrial use, and commercial use (Figure 3).

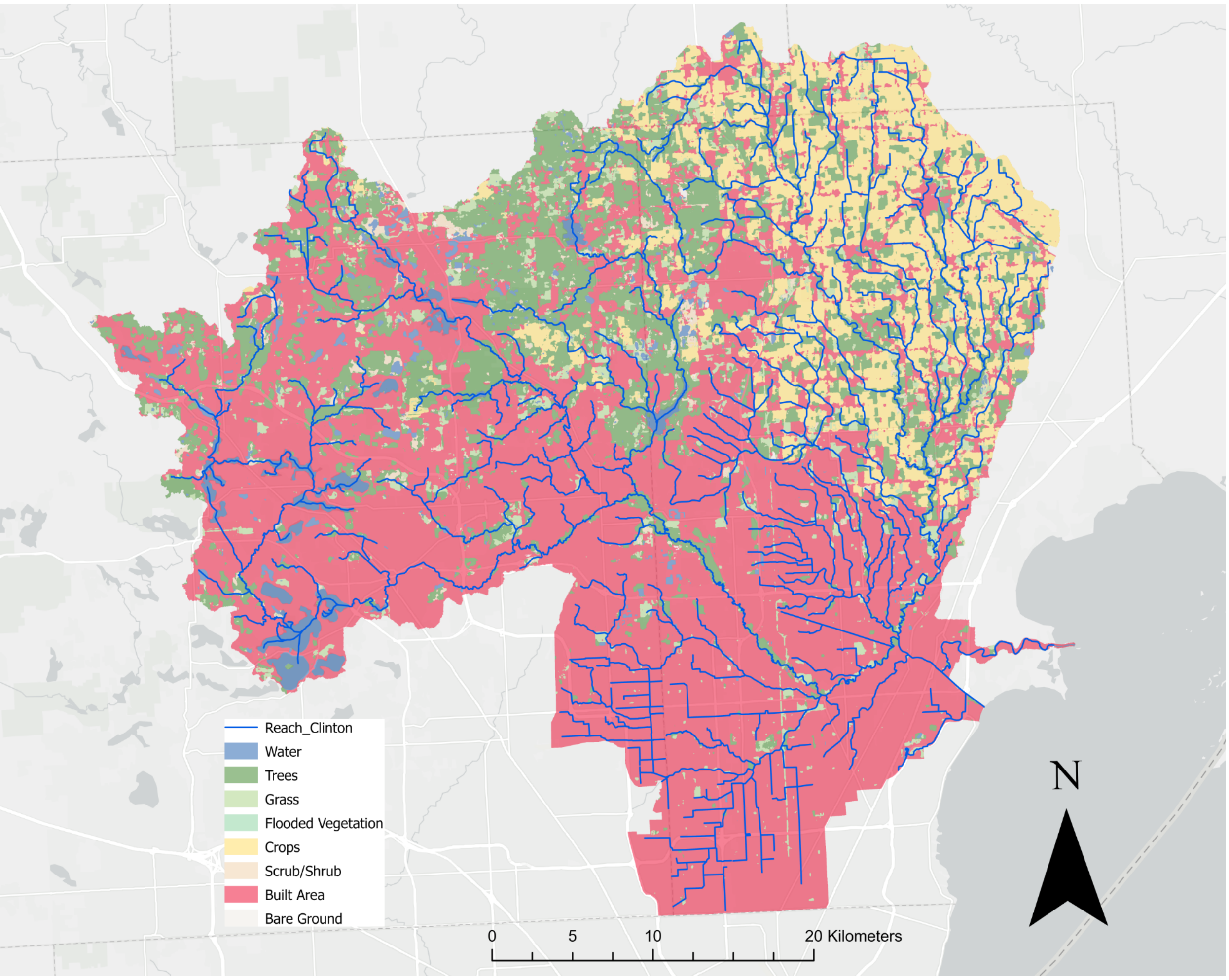


*Figure 3***.** Land use land cover map. Data used was ESRI 2020 land cover clipped to the watershed boundaries.

Data Collection

Baseflow Sampling (Objective 1)

We collected baseline samples at the four sites every Tuesday for 12 weeks during summer 2021 to provide a reference of average (and typically at summer baseflow levels) *E. coli* concentrations in each branch of the Clinton River. We started at the Middle Branch at 9:00 AM and progressed sequentially to North Branch, Main Branch, and Red Run. Before arriving at the Middle Branch site, we prepared all supplies, including a cooler with ice to keep samples below 4℃ and sterile 120-ml polystyrene bottles. Once the team arrived at the first sampling site, we created a field blank using distilled water to control sample quality during transportation and processing. The control sample bottle was washed three times with distilled water, filled with 100 ml of distilled water; sealed with a cap; labeled with site location, time, date, sampler initials; and placed in the cooler. For collecting baseline samples, we placed the sampling bottle into a corn holder bird feeder (Figure 4) with a rope attached and slowly lowered it down into the river. We washed the bottle with river water three times before it was filled with approximately 100 mL of the river water, sealed with a cap, labeled, and placed in the cooler. This process was repeated three times per site. The corn holder bird feeder was disinfected after every site. Once all data were recorded and collected, we packed up all supplies and moved on to the next site. Once all four sites were sampled, the samples were delivered to the Great Lakes Water Authority (GLWA) laboratory in Detroit, and analyzed using the Colilert-18 method with both 1x and 10x dilutions; results were reported as Most Probable Number per 100 ml (MPN/100 ml). After receiving the results, we calculated the geometric means of the triplicate samples for use in our analyses.

Figure 4. Corn-holder bird feeder utilized as bottle-holder for water sampling at the North Branch location in Macomb County Michigan.

While at each site collecting baseline samples, we also collected additional water quality data for use by local water managers at the Clinton River Watershed Council (CRWC). We used a Multi-Parameter Water Quality Sonde (YSI Inc.) to collect dissolved oxygen, total dissolved solids, specific conductance, temperature, and pH levels. We also used a turbidity tube with a Secchi disk to record turbidity at each site. These data were turned over to the CRWC, and not used in our analysis of *E. coli* dynamics.

Storm Sampling (Objective 1)

Storm sampling was less routine than baseline sampling due to the irregularity of precipitation events. We decided to sample a storm after considering the expected rainfall amount, duration, and storm size. We closely monitored the radar forecast for rainfall events using online weather services such as Weather Underground. However, due to the unpredictability of rain events, there were times when a storm would dissipate before it reached the watershed, despite having been predicted as a substantial event. We sampled five rainfall events on May 23rd, May 28th, June 25th, July 7th, and July 11th.

Once we identified a suitable storm, two teams of two researchers sampled each branch, every two hours through a 12-hour period, to cover the entire rising limb of the storm hydrograph, including a baseflow sample before the storm. The first team of two began sampling at the Middle Branch. Once at the site, we created a field blank sample using the same method as baseline sampling. We then collected an initial sample at each site before the storm started using the same method as weekly baseline sampling to provide a pre-storm control. Once these initial samples were completed, the Middle Branch and Red Run sites were sampled every two hours for 12 hours. We took samples to either the Biological Research Solutions, Inc. laboratory or the Oakland University laboratory every six hours to ensure a maximum holding time of eight hours was not exceeded. Due to a time lag between the onset of precipitation and a rise in discharge in the North and Main branches, the second team of two began sampling these sites after the first team completed their 12-hour shift on the first two sites; the North and Main branches were then sampled every two hours for 12 hours, with samples taken to the lab after six and 12 hours of sampling. Samples were analyzed using the Colilert-18 method; results were reported as Most Probable Number per 100 ml (MPN/100 ml). Samples for the first storm were diluted by 10x and 100x by the laboratory. As *E. coli* concentrations for some 10x dilutions still reached the maximum detectable limits, samples were diluted solely by 100x for the remaining storms. Geometric means of the triplicate samples were calculated for use in our analyses.

Precipitation Data (Objective 2)

We aggregated precipitation data from hourly forcing data acquired from the North American Land Data Assimilation System (NLDAS) relative to each of our sampling sites. The catchment boundaries draining to each of our *E. coli* sampling locations were created in a GIS and these were overlaid on the map of all NLDAS sampling locations. Any NLDAS sampling location that was inside, or just outside of an *E. coli* sampling point catchment was identified. We obtained NLDAS hourly precipitation data associated with our *E. coli* sampling location catchments and calculated total average hourly precipitation using the arithmetic mean for each catchment. We also aggregated hourly precipitation data into total precipitation by events by identifying rain events based on precipitation amount and duration of hours. We aligned the identified total precipitation by events with our summer sampled *E. coli* data in summer 2021 for analysis.

Streamflow Data (Objective 3)

We acquired streamflow data from nearby United States Geological Survey (USGS) discharge gaging stations at the Middle Branch (04164800) and the Clinton Main (04161820) sites; data were at 15-minute intervals in units of cubic feet per second (cfs). However, there are no USGS gages near our North Branch and Red Run sampling sites. Thus, we acquired streamflow data estimates for North Branch and Red Run from a hydrologic model run by a University of Michigan engineering team led by Valeriy Ivanov. This team used the tRIBS Distributed Hydrologic Model and precipitation data, to simulate estimates of hourly streamflow for North Branch and Red Run of the Clinton River.

Historical E. coli Data (Objective 4)

We obtained historical *E. coli* monitoring data from MI EGLE and the Macomb County Health Department as additional support for *E. coli* patterns analyses. We identified monitoring stations that were either downstream, upstream, or approximately located at our summer *E. coli* sampling sites along the four branches of the Clinton River, and *E. coli* grab data from 1997 to 2021 were acquired from these monitoring stations. While the historical data were compiled, they were not fully analyzed due to time constraints; we used these data as supporting material.

Our 2021 sampled *E. coli* data from the summer, additional historical *E. coli* data, and streamflow and precipitation data were compiled and organized using Microsoft Excel and stored as CSV files.

2.3 Data Analyses

We analyzed the sampled *E. coli* data from summer 2021 in concert with associated streamflow and precipitation data, to characterize the dynamics of *E. coli* responses of each branch under both baseline and storm conditions by visualizing data on time-series plots of *E. coli* concentrations overlaying streamflow and precipitation hyetographs. The open-source statistical software R version 4.1.1 was used to produce the plots.

We produced a time series, water quality parameters, and graphic panel for each sampling site, to illustrate the temporal relationships among water quality parameters during the monitoring period.

Logistic Regression Models

Using the *E. coli* data we collected during the summer, for each sampling site we used a logistic regression model to explore and describe relationships between *E. coli* concentrations, precipitation and streamflow; given the two analytical constraints of partial- and total-body-contact-limit Water Quality Standards. These graphs showed the amount of rainfall (mm) and streamflow (cfs) that would cause an exceedance of each respective *E. coli* standard: partial body contact limit (1000 MPN per 100 ml) and total body contact limit (300 MPN per 100 ml). For each logistic regression analysis, *E. coli* concentrations that did not exceed the contact limit were assigned to zero, while *E. coli* concentrations that exceeded the contact limit were assigned to one. Using these assigned data, we applied a logistic regression model and plotted the logistic regression curve to view the patterns. We used R packages "ggplot2" and "ggpubr" for this analysis. Major outliers that heavily skewed the logistic regression curves were discarded. In this case, we discarded high *E. coli* concentrations above 1000 MPN/100 ml when there was no rainfall; these likely were not related to stormflow sources. The *E. coli* concentrations referred to the geometric means of the triplicate samples.

Thresholds Identification

We identified precipitation and streamflow thresholds for each sampling site based on the exceedance of both partial and total body contact limits. The thresholds were developed using a margin of safety (MOS) of 10%, which is a relatively common MOS used in TMDLs (Nunoo et al., 2020). Besides the common MOS of 10%, we identified thresholds at 25%, 50%, and 75% exceedances to provide a spectrum of risks for our clients to incorporate into the DSS. We examined the logistic regression curves and found the discharge or precipitation amount that would lead to an exceedance of *E. coli* standards with 10%, 25%, 50%, and 75% probability. Due to a large amount of model uncertainty, we based the thresholds on the mean of the logistic regression (the line). For example, for graphs with means that started above 10%, we were confident *E. coli* levels would always exceed the 10% MOS. We calculated the flow yields in cms/km^2 of all discharge thresholds to compare the unit streamflows per area of the four branches.

Results

Characterization of *E. coli* responses

E. coli concentrations at baseflow

By creating time-series plots of *E. coli* concentrations overlaying streamflow and precipitation hyetographs, we were able to characterize *E. coli* concentrations at baseflow and during storms for each branch during summer 2021, from May 11th to June 27th. We took 384 individual samples in the form of triplicates including both weekly samples and storm samples, resulting in 128 geometric means of *E. coli* concentrations. There were 31 mean concentrations for Clinton Main, 33 mean concentrations for Middle Branch, 30 mean concentrations for North Branch, and 34 mean concentrations for Red Run. We found both similarities and differences in *E. coli* responses among branches.

The majority of weekly baseline *E. coli* concentrations in May were below Michigan WQS for surface waters, i.e., total body contact limit of 300 *E. coli* per 100 mL. However, almost every geometric mean of *E. coli* in June and July exceeded this limit (Figure 5). From the hyetographs, we observed a much higher baseflow in July than June and May for all branches. The average June Tuesday (when we collected baseline samples) baseflow was higher than that for May. We also observed more rainfall and heavier rain events during June and July than in May (Figure 5). We collected 13 baseline geometric means for Clinton Main, 12 baseline geometric means for Middle Branch, 11 baseline geometric means for North Branch, and 11 geometric means for Red Run. Every weekly baseline geometric mean of *E. coli* concentrations was below the TBC limit in May for the Middle Branch and North Branch. Three out of four weekly baseline *E. coli* concentrations were below the TBC limit for the Clinton Main branch in May, and two out of four weekly baseline *E. coli* concentrations were below the limit for the Red Run in May. Every baseline geometric mean of *E. coli* concentrations exceeded the TBC limit in June and July for each branch.

E. coli concentration responses to storms

During storm events at all sites, *E. coli* levels rose dramatically and very rapidly, decreased slightly after they peaked, and then stayed high for multiple hours. *E. coli* levels at Middle Branch and Red Run responded to rainfall more quickly than those at Clinton Main and North Branch. For example, during the large storm event from June 25th to June 26th, 2021, it took about five hours for *E. coli* levels at Middle Branch and Red Run to peak, and it took approximately 15 hours for *E. coli* levels at Clinton Main and North Branch to peak (Figure 6). During this large storm, *E. coli* levels exceeded both WQS limits (total- and partial-body contact) and resulted in concentrations of over 10,000 MPN/100 ml (Figure 6). *E. coli* levels exceeded the 1000 MPN/100 ml PBC limit during the first two hours of precipitation at Middle Branch and Red Run, and *E. coli* levels far exceeded the PBC limit when we sampled these two branches 12 hours after the initial baseline sample (Figure 6). During smaller storms, the Middle Branch and Red Run *E. coli* concentrations exceeded the 300 MPN/100 ml total body contact limit and peaked above the 1000 MPN/100 ml partial body contact limit. In contrast, *E. coli* concentrations exceeded the 300 MPN/100 ml TBC limit and peaked below the 1000 MPN/100 ml PBC limit for Clinton Main and North Branch. There were two *E. coli* concentrations for Clinton Main and three *E. coli* concentrations for North Branch on July 11th below the 300 MPN/100 ml total body limit under a light rain situation. The hours to peak and *E. coli* responses depended on rainfall intensity and duration.

E. coli concentrations consistently peaked prior to the ascending storm hydrograph at all four sites, with a time lag between these peaks, and time lags varied between branches. There were relatively short time lags between *E. coli* and streamflow peaks for the Middle Branch, Red Run, and Clinton Main, but there was an approximately 3x longer time lag between *E. coli* peaks and streamflow peaks for North Branch. For example, during the storm event from June 25th to June 26th, 2021, the time lag between *E. coli* level peaks and streamflow peaks was five to 10 hours at Middle Branch, Clinton Main, and Red Run. It took 30 hours for streamflow at North Branch to peak after *E. coli* levels peaked (Figure 6).

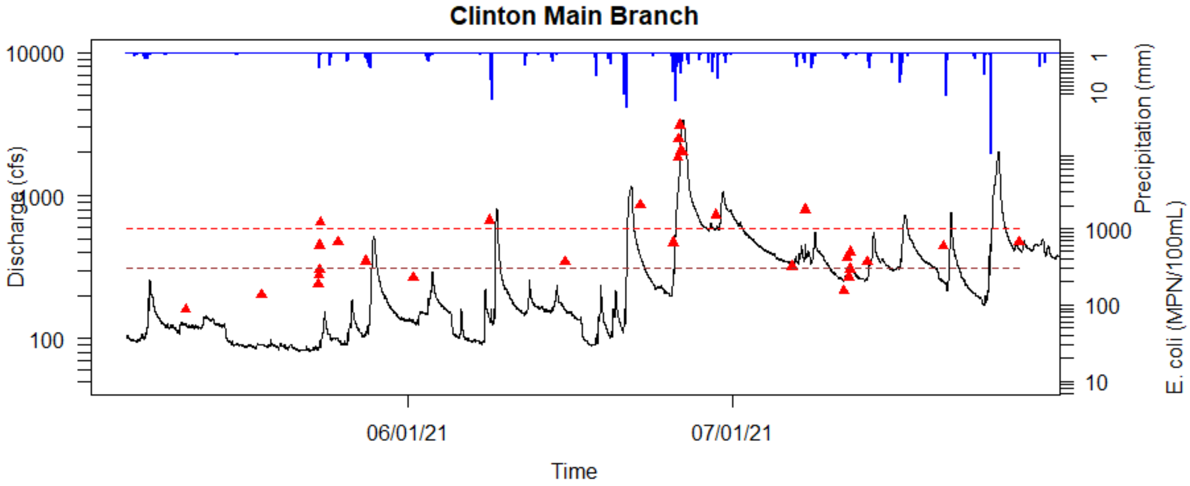


Figure 5-a. A time-series plot showing *E. coli* concentrations overlaying the streamflow and precipitation hyetograph for the Clinton Main site during the summer 2021 sampling period, from 5/11 to 7/27/2021.

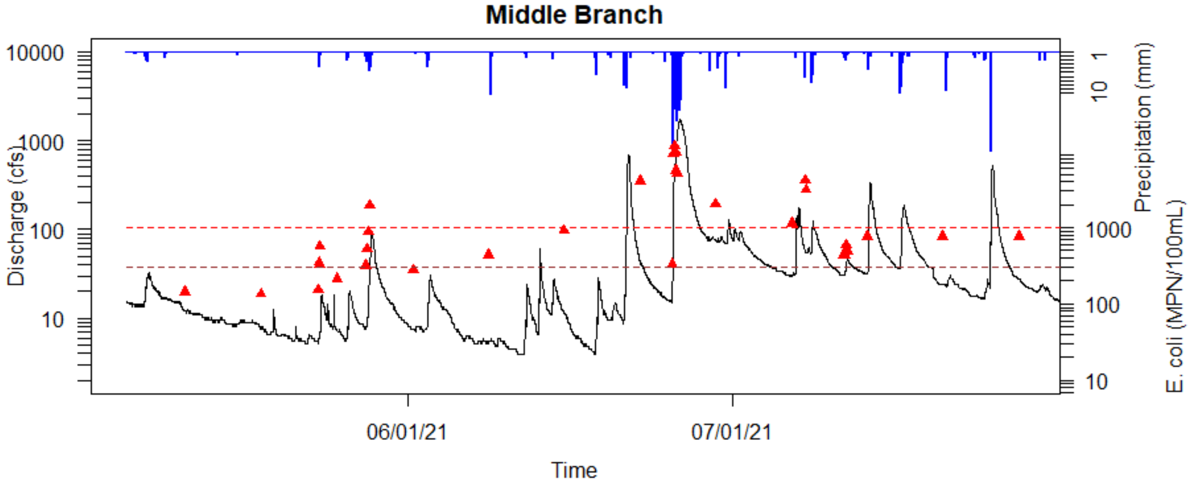


Figure 5-b. A time-series plot showing *E. coli* concentrations overlaying the streamflow and precipitation hyetograph for the Middle Branch site during the summer 2021 sampling period, from 5/11 to 7/27/2021.

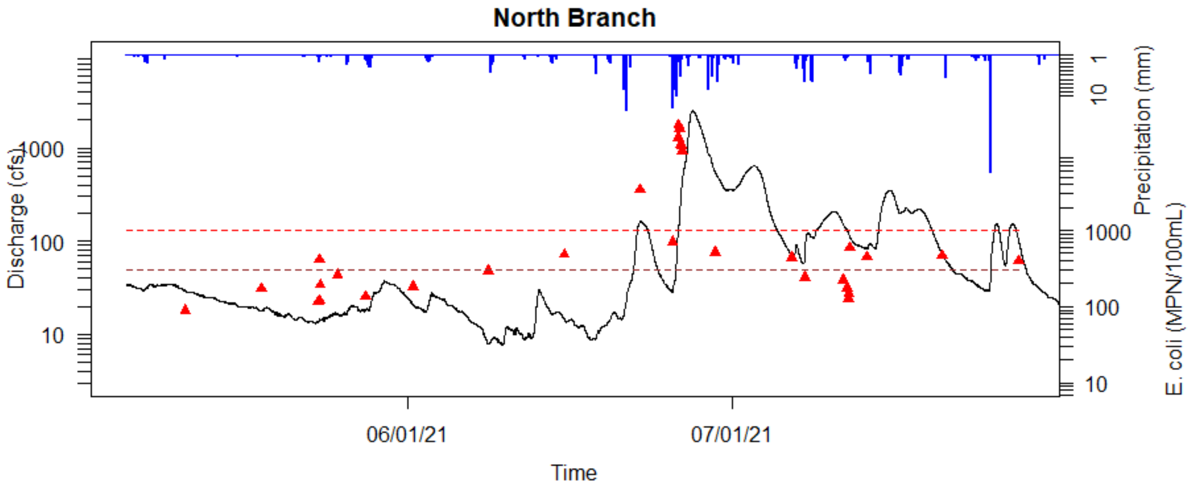


Figure 5-c. A time-series plot showing *E. coli* concentrations overlaying the streamflow and precipitation hyetograph for the North Branch site during the summer 2021 sampling period, from 5/11 to 7/27/2021.

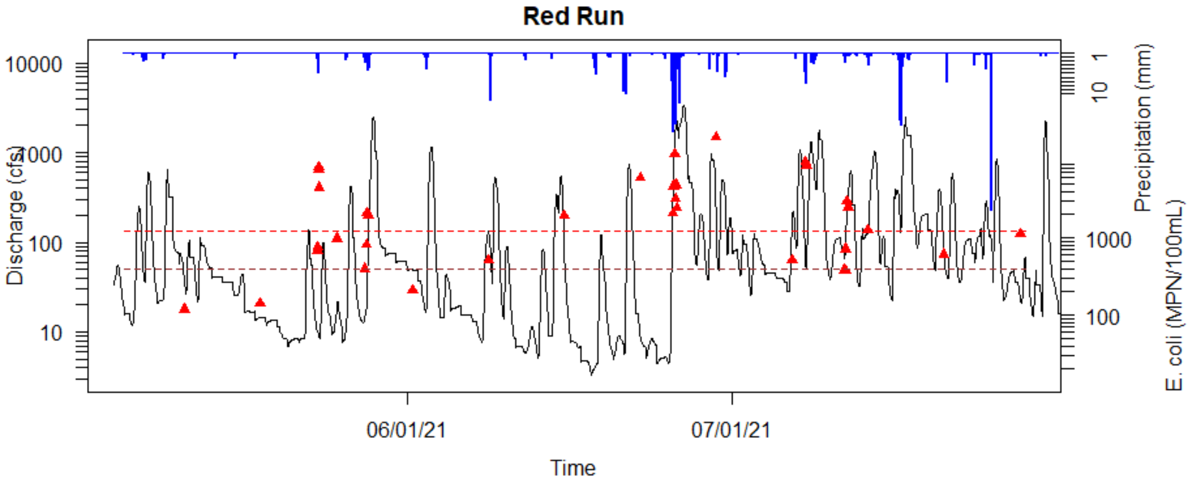


Figure 5-d. A time-series plot showing *E. coli* concentrations overlaying the streamflow and precipitation hyetograph for the Red Run site during the summer 2021 sampling period, from 5/11 to 7/27/2021.

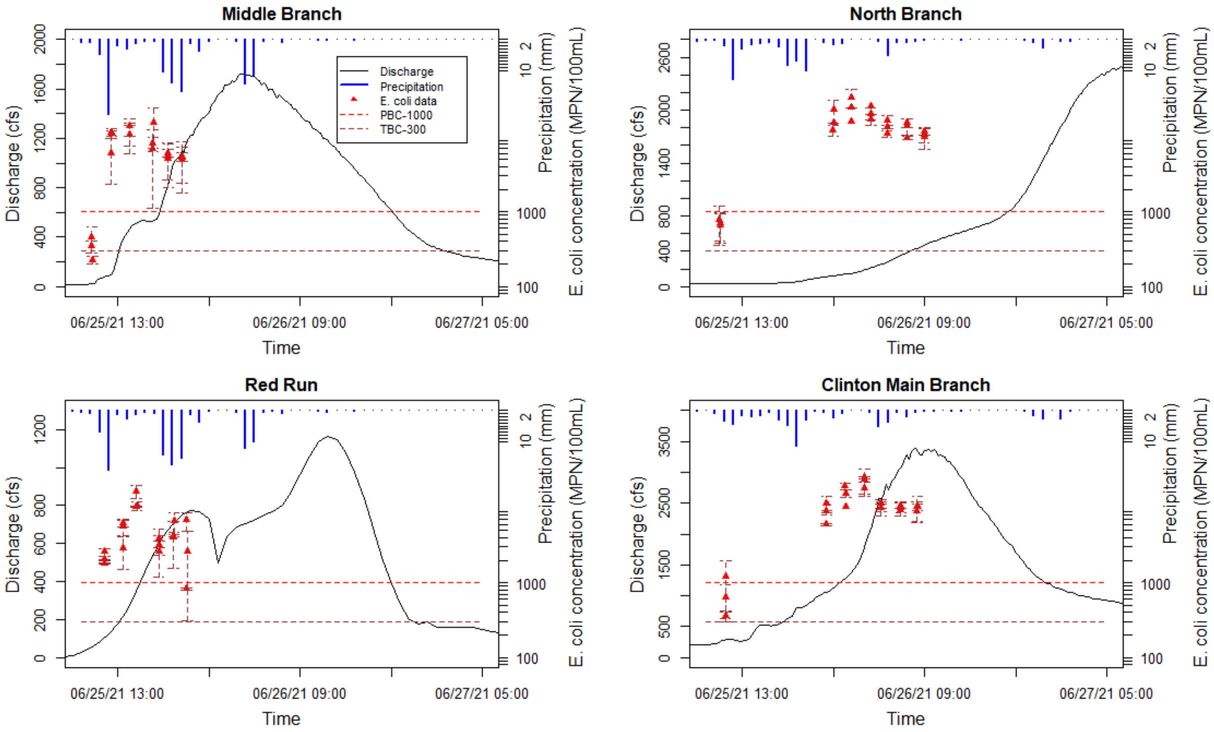


Figure 6. A time-series panel describing *E. coli* concentrations overlaying on the streamflow and precipitation hyetograph of a large storm event for our four sampling sites. Plots are organized by site. The storm sampling event occurred between 6/25 and 6/26/2021. The vertical dash line on each triangle is the error bar based on the triplicants. *E. coli* concentration y-axes are based on logarithmic scales.

Relationships between *E. coli* and Precipitation and Streamflow

Relationships at baseflow

Through regression models of *E. coli* vs streamflow and precipitation, at all four study sites *E. coli* concentrations were much lower at baseflow than during high flow but often still exceeded the Water Quality Standards (Partial Body Contact and Total Body Contact limits). At baseflow or relatively low flow conditions, the majority of *E. coli* concentrations in Clinton Main were below the 1000 MPN/100 ml PBC limit, with several exceeding, and more than half of the *E. coli* concentrations exceeding the 300 MPN/100 ml TBC limit (Figure 7 A and 9-3). Under dry conditions, we had 13 geometric means from Clinton Main with *E. coli* concentrations ranging from 86.6 MPN/100 ml to 658.6 MPN/100 ml with two outliers over 1000 MPN/100 ml (Figure 8 A). For the Middle Branch and North Branch, no *E. coli* concentrations exceeded the PBC limit at low flow (Figures 7 B and C). More than half exceeded the TBC limit at Middle Branch (Figure 9-1), and less than half exceeded at North Branch (Figure 9-2). When there was no precipitation, there were 12 geometric means from the Middle branch of *E. coli* concentrations ranging from 135 MPN/100 ml to 901 MPN/100 ml with three outliers (Figure 8 B). There were 11 dry-weather geometric means from the North Branch with *E. coli* concentrations ranging from 89 MPN/100 ml to 475 MPN/100 ml with one outlier (Figure 8 C). At low flow, half of the *E. coli* concentrations of Red Run exceeded the PBC limit, and only a few did not exceed the TBC limit (Figure 7 D and 9-4). There were 11 dry-weather geometric means from the Red Run with *E. coli* concentrations ranging from 118.5 MPN/100 ml to 979 MPN/100 ml with four outliers (Figure 8 D).

Relationships during Storms

The logistic regression models illustrated that at all four sites, both increased precipitation and streamflow led to increased probabilities of exceeding the TBC and PBC limits. As total precipitation increased, the likelihood of exceeding the PBC and TBC limits increased to a precipitation threshold point at which *E. coli* concentrations exceeded the limits at each of the four sites. For Red Run and Middle Branch, *E. coli* levels exceeded the 300 MPN/100 ml TBC limits when there was any precipitation, regardless of rain event severity. For Clinton Main, a small number of *E. coli* concentrations were below the TBC limit when there were light rains under 8 mm. Some *E. coli* concentrations at the Clinton Main Branch, the Middle Branch, and the Red Run were below the 1000 MPN/100 ml PBC limit only with light rain events under 10 mm, and all *E. coli* concentrations at the three branches exceeded the PBC limit as precipitation increases above 10 mm. For the North Branch, half of the *E. coli* concentrations were below the TBC limit, and all the E. coli concentrations were below the PBC limit when there was light precipitation under 11 mm (Figure 9). The *E. coli* concentrations at the North Branch exceeded the PBC limit with larger rain events of 30 mm to 50 mm, indicating the North Branch *E. coli* ecosystem is less responsive to precipitation than other branches. In most cases, *E. coli* levels exceeded the TBC and PBC limits at higher flow rates for the four sites, except for one North Branch *E. coli* concentration of 514 MPN/100 ml.

We found positive correlations between *E. coli* levels and precipitation and instantaneous streamflow, at varying extents among sites. For the generalized linear relationship between *E. coli* levels and instantaneous streamflow, we observed moderate correlations with coefficients of variation (R^2) of 0.69 and 0.71 for the Clinton Main and the Middle Branch, respectively. We observed a weak correlation with R^2 of 0.37 for the North Branch and a poor correlation with R^2 of 0.12 for the Red Run (Figure 7). For relationships between *E. coli* levels and total precipitation, we found a moderate correlation with R^2 of 0.66 for the Clinton Main Branch, a moderate correlation with R^2 of 0.57 for the Middle Branch, and weak correlations with R^2 of 0.33 and 0.32 for the North Branch and the Red Run, respectively (Figure 8). The results indicated higher streamflow and larger storm events could lead to higher *E. coli* concentrations for the Clinton Main and Middle Branch, while the Red Run and North Branch lacked a clear linear relationship.

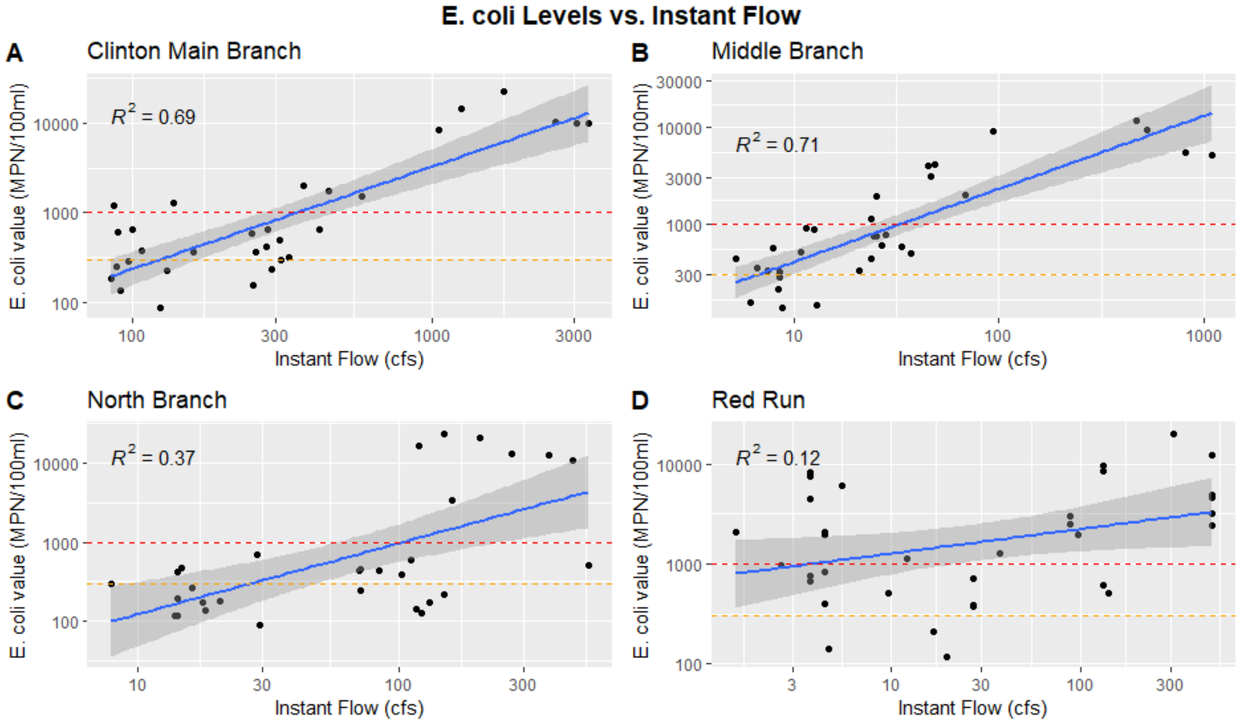


Figure 7. Generalized linear regression models showing relationships between *E. coli* concentrations and instantaneous streamflow for the four sampling sites. The y-axis and the x-axis are logarithmic scales. The coefficient of variation (R^2) is displayed in the upper left corner of each graph. The gray areas represent confidence intervals of the regression lines, indicating the predicted errors.

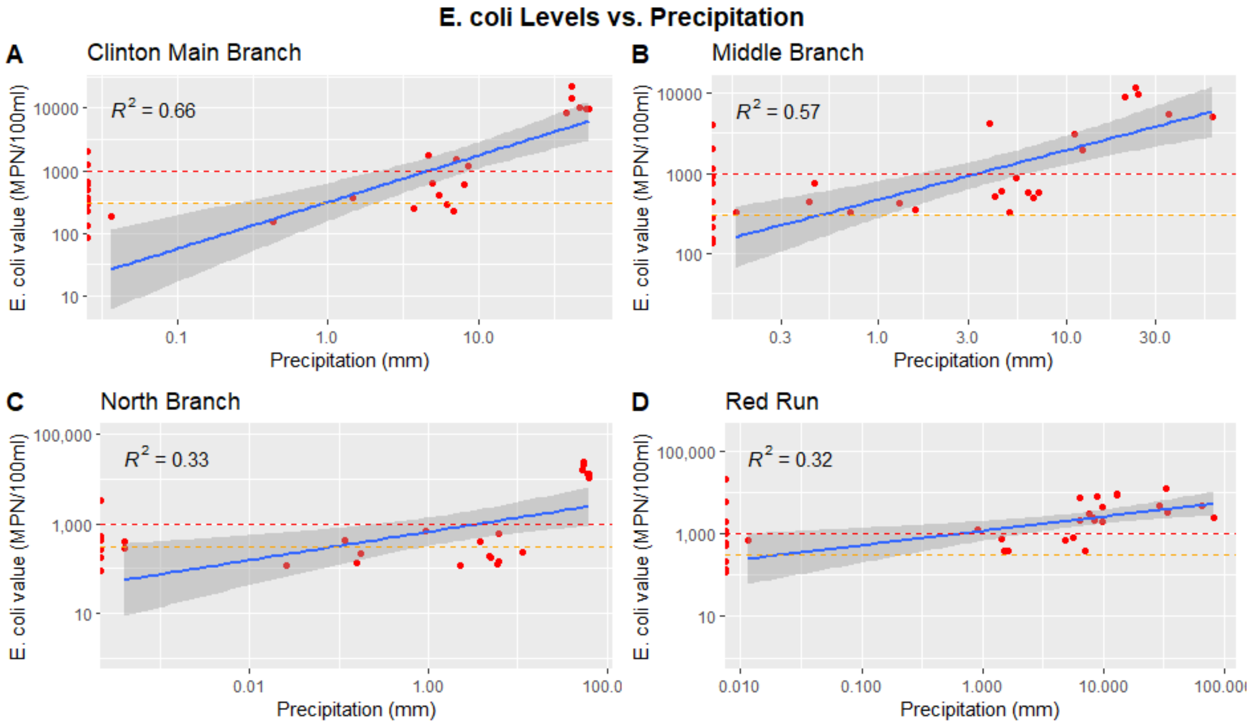


Figure 8. Generalized linear regression models showing relationships between *E. coli* concentrations and total precipitation for the four sampling sites. The y-axis and the x-axis are logarithmic scales. The coefficient of variation (R^2) is displayed on the upper left corners of each graph. The gray areas represent the confidence intervals of the generalized regression lines.

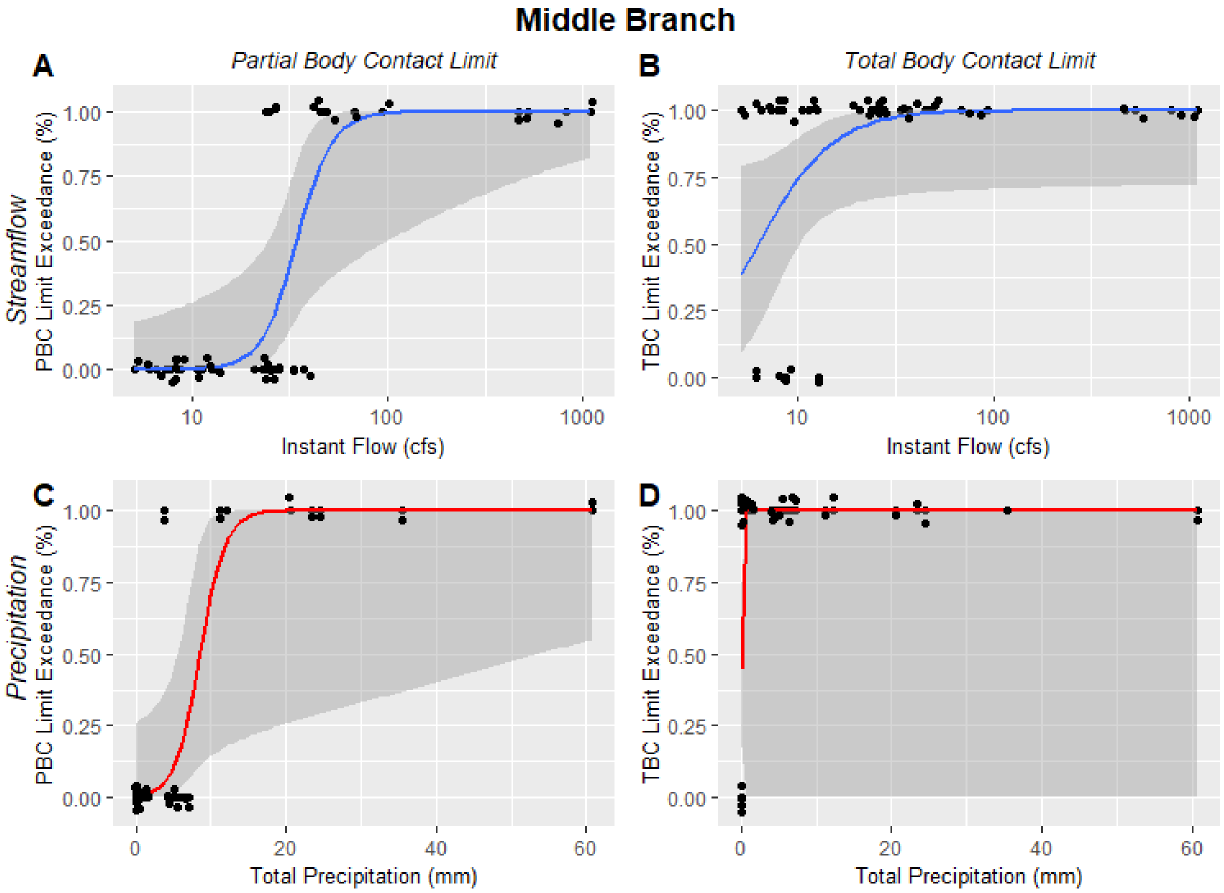


Figure 9-1. Logistic regression model for Middle Branch showing the probability of exceeding *E. coli* TBC and PBC limits under different precipitation and flow conditions. A) the relationship between streamflow and the exceedance of the PBC limit. B) the relationship between streamflow and the exceedance of the TBC limit. C) The relationship between total precipitation and exceedance of PBC limit. D) the relationship between total precipitation and exceedance of TBC limit. Jitter was added to the plots to improve clarity. X-axes representing streamflow are logarithmic scales. The gray areas represent confidence intervals of the logistic regression lines.

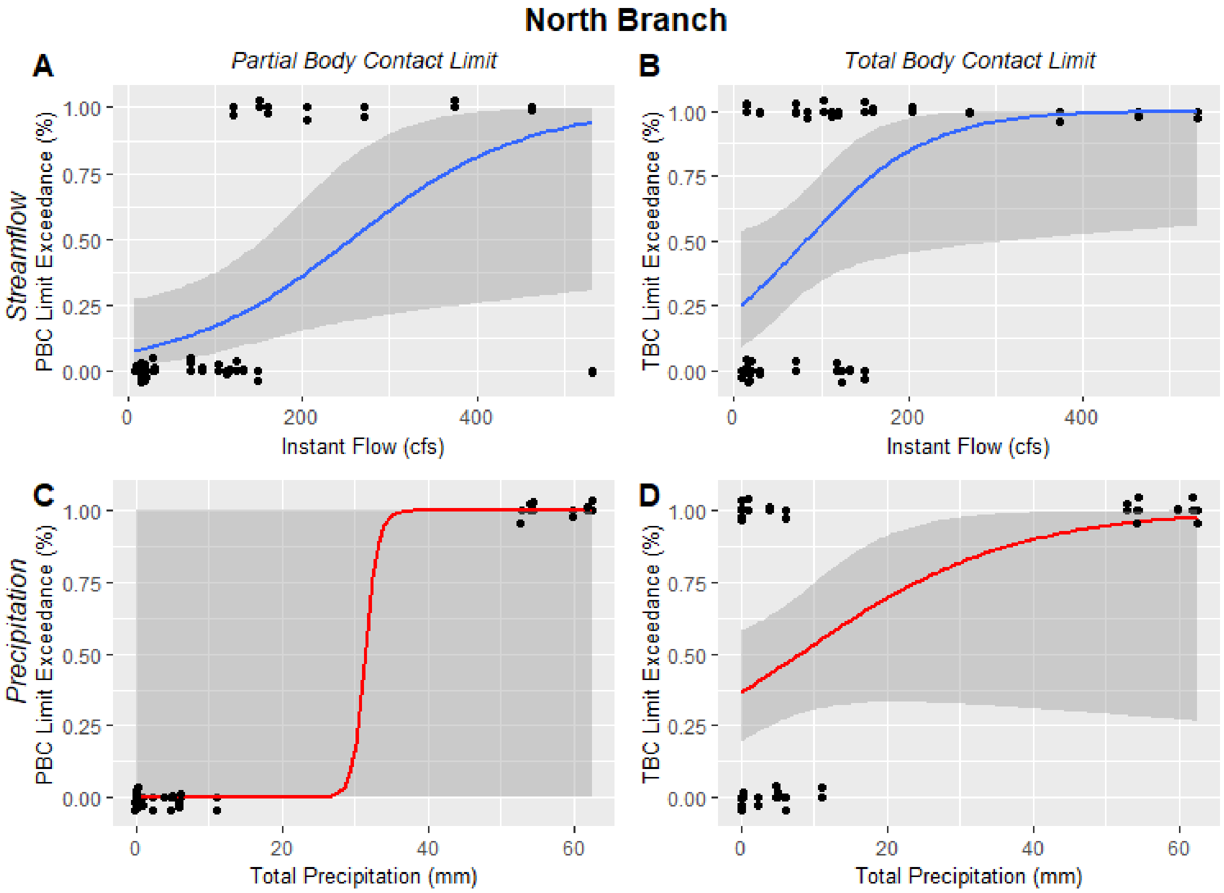


Figure 9-2. Logistic regression model for North Branch showing the probability of exceeding *E. coli* TBC and PBC limits under different precipitation and flow conditions. Jitter was added to the plots to improve clarity. The gray areas represent confidence intervals of the logistic regression lines.

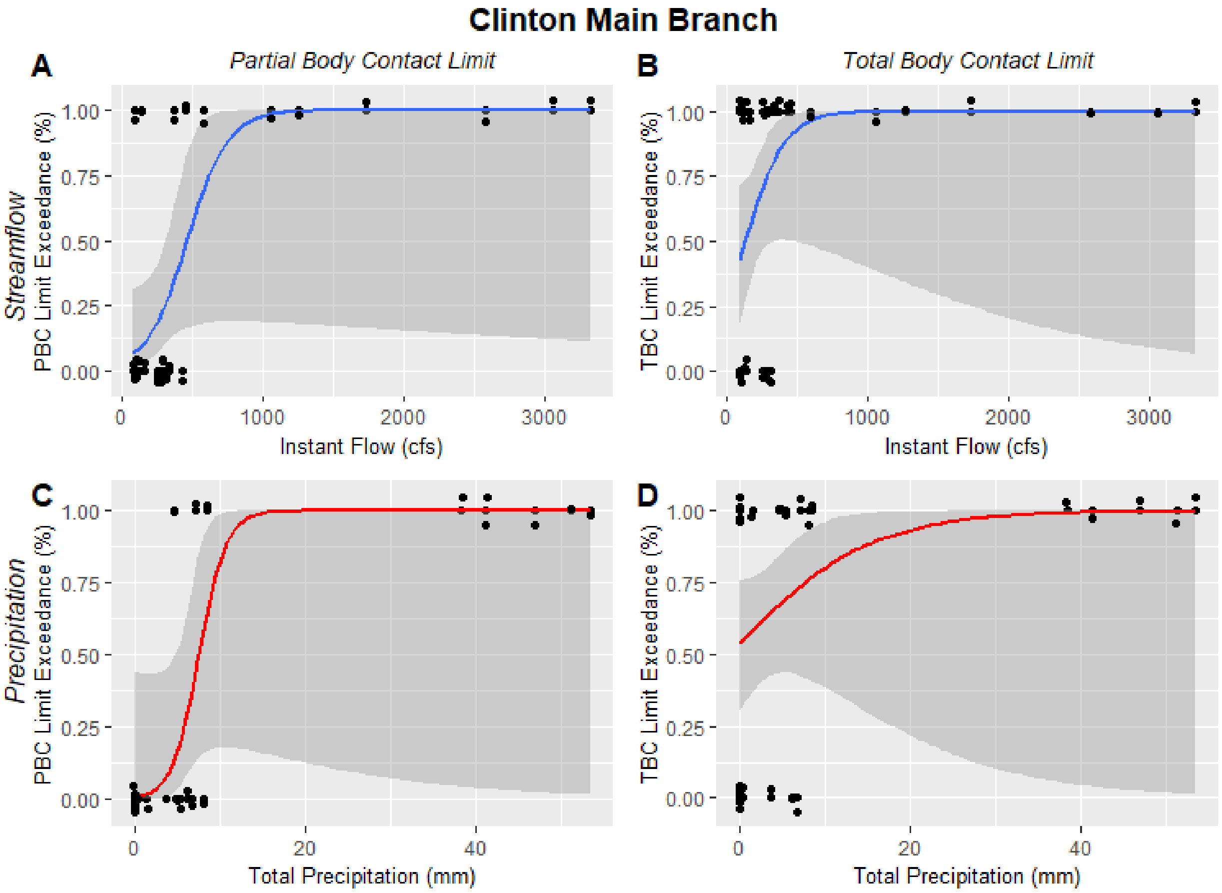


Figure 9-3. Logistic regression model for Clinton Main Branch showing the probability of exceeding *E. coli* TBC and PBC limits under different precipitation and flow conditions. Jitter was added to the plots to improve clarity. The gray areas represent confidence intervals of the logistic regression lines.

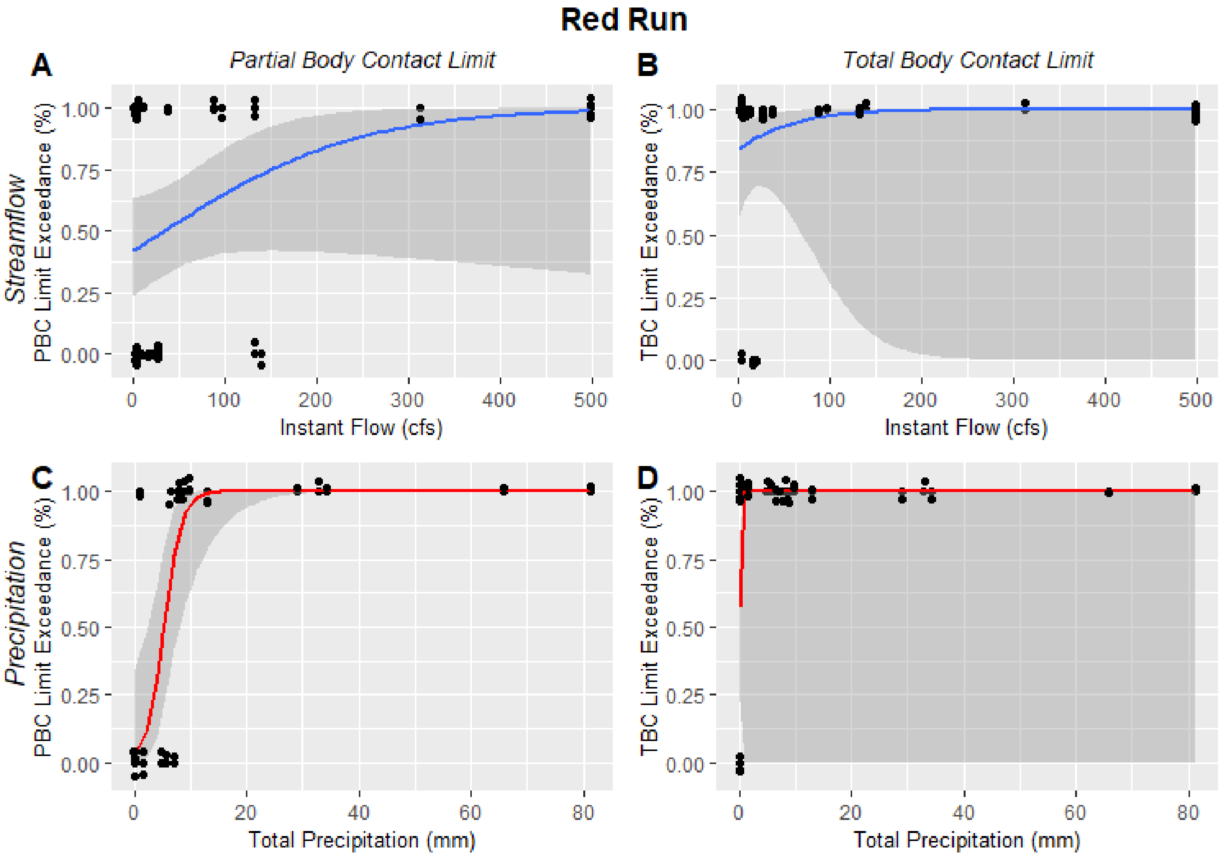


Figure 9-4. Logistic regression model for Red Run showing the probability of exceeding *E. coli* TBC and PBC limits under different precipitation and flow conditions. Jitter was added to the plots to improve clarity. The gray areas represent confidence intervals of the logistic regression lines.

E. coli Exceedance Thresholds

For each branch of the Clinton River, we identified *E. coli* exceedance thresholds for both flow and precipitation based on logistic regression graphs. We generated a spectrum of threshold percentages to give our clients a range of risks that could be incorporated into the DSS. We identified thresholds at 10%, 25%, 50%, and 75% exceedances. High threshold variability indicated that the branch had a low sensitivity, which means it would take a larger amount of discharge or precipitation to cause *E. coli* to exceed the threshold. Low threshold variability indicated the branch had a high sensitivity, meaning it would not take much discharge or precipitation to lift *E. coli* concentrations above the threshold.

Clinton Main Branch (Table 1.)

The partial body contact (PBC) and total body contact (TBC) thresholds for discharge and precipitation increase dramatically as the exceedance thresholds increase. The Clinton Main

Branch had the highest variability in discharge from the 10% to 75% thresholds for the PBC limit at 490 cfs. This branch also had the highest discharge threshold of the branches, reflecting the large size of the branch.

Middle Branch (Table 2.)

In regards to discharge, the Middle Branch consistently had low thresholds (high sensitivity) and not much variability between them. The Middle Branch had the lowest increase in discharge from the 10% to 75% thresholds for the PBC limit at 55 cfs. The Middle Branch and the Red Run Branch were tied with the lowest precipitation thresholds with 75% TBC thresholds of 0.5 mm. It did have the highest increase in precipitation threshold from 10% to 75% with a change of 6.5 mm, just beating out the Red Run Branch which had a change of 6 mm.

North Branch (Table 3.)

The North Branch had the second-highest increase in discharge from the 10% to 75% PBC thresholds at 300 cfs. Out of all four branches, the North Branch had the highest precipitation thresholds. The lowest PBC threshold was 10% at 29 mm and the highest was 75% at 33 mm. The lowest North Branch PBC precipitation threshold was 22.5 mm higher than the next highest PBC precipitation threshold, which was the Middle Branch at 10.5 mm. The North Branch also had the highest TBC precipitation threshold, which was 75% at 23 mm. This branch was the only one that had a 50% TBC precipitation threshold that did not always exceed the limit, at 7 mm.

Red Run Branch (Table 4.)

Of all four branches, the Red Run Branch was the only one to have PBC thresholds that always exceeded the margin of safety. Both the 10% and 25% discharge PBC thresholds were always exceeded. The TBC limit for the Red Run Branch was always exceeded for every exceedance threshold except for 75% precipitation, which was 0.5 mm. The Red Run Branch only had two total discharge thresholds that were able to be determined, 50% and 75% for PBC.

Comparing Discharge and Precipitation Thresholds (Table 5.)

To compare thresholds between the branches, we looked at the percent change in precipitation and discharge yields in reference to the lowest yield that would result in a branch exceeding the threshold, which for PBC was the Red Run Branch, and for TBC was the Middle Branch. We calculated the yield of the discharge for all four branches in cms/km^2. Yields for branches that were always exceeding the thresholds were designated N/A. We focused on the 50% exceedance threshold for discharge because it had PBC limit yields for all branches and TBC yields for all branches except Red Run. For discharge, the Red Run, with a yield of 0.0063 cms/km^2, was the most similar to the Middle Branch, with a yield of 0.0132 cms/km^2. This was an increase of roughly 109%. The Red Run was most different from the North Branch, with a yield of 0.0307 cms/km^2. This was an increase of roughly 387%. This is consistent with the raw data we acquired, which showed that the most sensitive branch, or the branch with the lowest thresholds, was the Red Run, and the most resilient branch or the branch with the highest thresholds was the North Branch. This observation is similar to the TBC discharge yields. However, the Red Run was always exceeding the 50% threshold, so the next lowest yield was the Middle Branch, with a yield of 0.0013 cms/km^2. The North Branch, with a yield of 0.0071 cms/km^2 was the most different, with an increase of 438%.

We found similar results when we directly compared the precipitation between all of the branches. We focused on the 75% exceedance threshold since every branch had a precipitation threshold for both PBC and TBC limits. We also used the Red Run Branch as a comparison for precipitation. For the PBC limit, the branch that was most different from Red Run was once again, the North Branch, with a precipitation increase of 312.5%. The Clinton Main Branch was most similar to the Red Run for PBC with an increase in precipitation of 12.5%. For TBC, the most different branch was again, the North Branch with a dramatic precipitation increase of 4500%. The branch most similar to the Red Run was the Middle Branch, which had the same TBC thresholds.

Table 1. The *E. coli* exceedance thresholds for both discharge and precipitation for the Main Branch of the Clinton River based on margins of safety (MOS) of 10%, 25%, 50%, and 75%. These thresholds include both partial and total body contact limits.

Discharge

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	160 cfs (4.53 cms)	Confident the branch will always exceed 10% MOS
25%	300 cfs (8.5 cms)	Confident the branch will always exceed 25% MOS
50%	480 cfs (13.59 cms)	130 cfs (3.68 cms)
75%	650 cfs (18.4 cms)	270 cfs (7.65 cms)

Precipitation

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	4 mm	Confident the branch will always exceed 10% MOS
25%	6 mm	Confident the branch will always exceed 25% MOS
50%	8 mm	Confident the branch will always exceed 50% MOS
75%	9 mm	8 mm

Table 2. The *E. coli* exceedance thresholds for both discharge and precipitation for the Middle Branch of the Clinton River based on margins of safety (MOS) of 10%, 25%, 50%, and 75%. These thresholds include both partial and total body contact limits.

Discharge

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	20 cfs (0.57 cms)	Confident the branch will always exceed 10% MOS
25%	25 cfs (0.71 cms)	Confident the branch will always exceed 25% MOS
50%	50 cfs (1.4 cms)	5 cfs (0.14 cms)
75%	75 cfs (2.12 cms)	12 cfs (0.34 cms)

Precipitation

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	4 mm	Confident the branch will always exceed 10% MOS
25%	7 mm	Confident the branch will always exceed 25% MOS
50%	8 mm	Confident the branch will always exceed 50% MOS
75%	10.5 mm	0.5 mm

Table 3. The *E. coli* exceedance thresholds for both discharge and precipitation for the North Branch of the Clinton River based on margins of safety (MOS) of 10%, 25%, 50%, and 75%. These thresholds include both partial and total body contact limits.

Discharge

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	60 cfs (1.70 cms)	Confident the branch will always exceed 10% MOS
25%	150 cfs (4.25 cms)	20 cfs (0.57 cms)
50%	260 cfs (7.36 cms)	60 cfs (1.7 cms)
75%	360 cfs (10.19 cms)	150 cfs (4.25 cms)

Precipitation

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	29 mm	Confident the branch will always exceed 10% MOS
25%	31 mm	Confident the branch will always exceed 25% MOS
50%	32 mm	7 mm
75%	33 mm	23 mm

Table 4. The *E. coli* exceedance thresholds for both discharge and precipitation for the Red Run Branch of the Clinton River based on margins of safety (MOS) of 10%, 25%, 50%, and 75%. These thresholds include both partial and total body contact limits.

Discharge

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	Confident the branch will always exceed 10% MOS	Confident the branch will always exceed 10% MOS
25%	Confident the branch will always exceed 25% MOS	Confident the branch will always exceed 25% MOS
50%	30 cfs (0.85 cms)	Confident the branch will always exceed 50% MOS
75%	150 cfs (4.25 cms)	Confident the branch will always exceed 75% MOS

Precipitation

Exceedance Threshold	Partial Body Contact (1000 MPN/100 ml)	Total Body Contact (300 MPN/100 ml)
10%	2 mm	Confident the branch will always exceed 10% MOS
25%	3 mm	Confident the branch will always exceed 25% MOS
50%	5 mm	Confident the branch will always exceed 50% MOS
75%	8 mm	0.5 mm

Table 5. The *E. coli* partial body and total body contact limit discharge yields in cms/km^2 for all four sampling sites. These yields were created using the previously calculated partial and total body contact limit thresholds. When a branch always exceeded the threshold, it was designated with an N/A.

Partial Body Contact Yield (*cms/km^2*)

Exceedance Threshold	Clinton Main Branch	Middle Branch	North Branch	Red Run Branch
10%	0.0056	0.0054	0.0071	N/A
25%	0.0105	0.0067	0.0177	N/A
50%	0.0168	0.0132	0.0307	0.0063
75%	0.0228	0.0199	0.0425	0.0314

Total Body Contact Yield (*cms/km^2*)

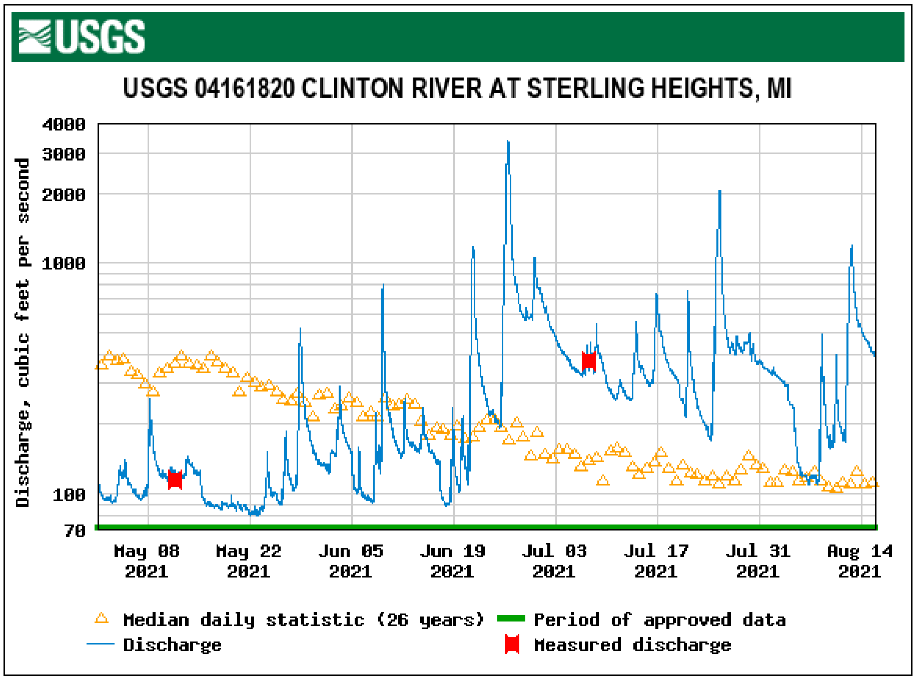
Exceedance Threshold	Clinton Main Branch	Middle Branch	North Branch	Red Run Branch
10%	N/A	N/A	N/A	N/A
25%	N/A	N/A	0.0024	N/A
50%	0.0046	0.0013	0.0071	N/A
75%	0.0095	0.0032	0.0177	N/A

Discussion

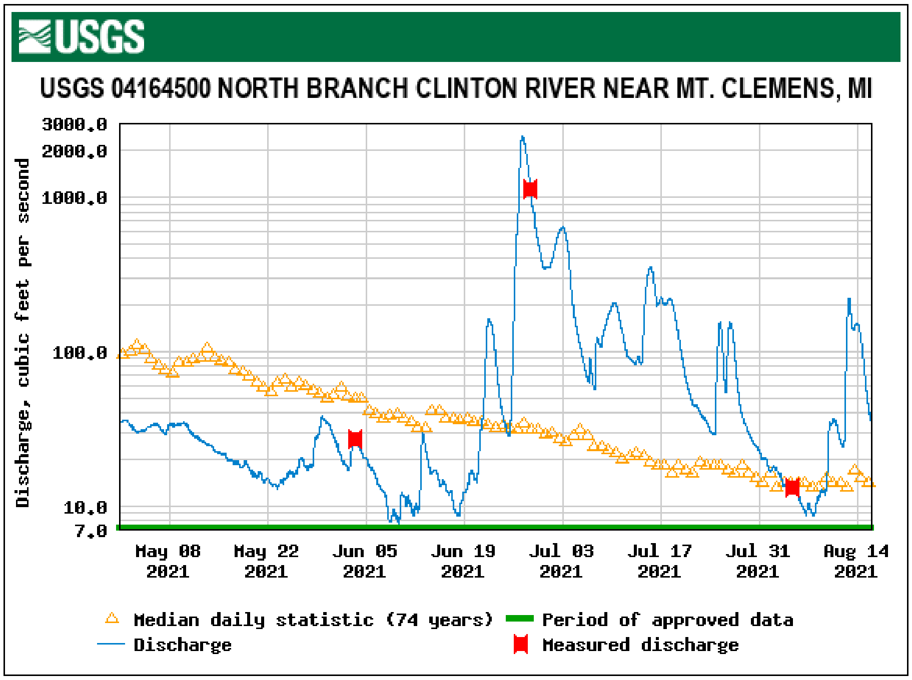
E. coli Dynamics during baseflow and storm conditions

Escherichia coli dynamics within the Clinton River Watershed were distinct for each sampled site and its respective sub-catchment. Heterogeneous patterns of precipitation, land use, and surface geology (form and texture) together shaped the watershed dynamics of streamflow and *E. coli* responses. Watershed urbanization has been directly linked with increases in *E. coli* concentrations in rivers, with models that predict a twenty-time increase if land use is transformed from non-urban to fully urban (Piyapong et al., 2021). Pathogens are the most common cause of impairment of the Clean Water Act section 303d. In Michigan, *E. coli* is the third most common overall impairment. (EPA, 2022). Certain pathogens such as *E. coli* can be used as an indicator of the presence of other pathogens (Chen & Chang, 2014). Although our study measured total *E. coli*, source tracking and differentiation could help management officials identify and possibly limit the sources of *E. coli;* from human, bovine, or avian origins. The variability of *E. coli* throughout the watershed has been measured in various other studies, with human sources being prevalent in suburban land types, and wildlife sources dominant in open land and forested zones (Wu et al., 2011). The true base flow for our data was difficult to define. Frequent precipitation events during the summer, the time interval between precipitation events, and how long specific reaches took to return to a base flow or near baseflow state all affected stream levels, so typical base flow levels might not have been reached or were higher for 2021. Once a branch had seen a few days between precipitation events and looked like it was going to level out, another storm would follow, quickly disturbing the baseflow of the reach.

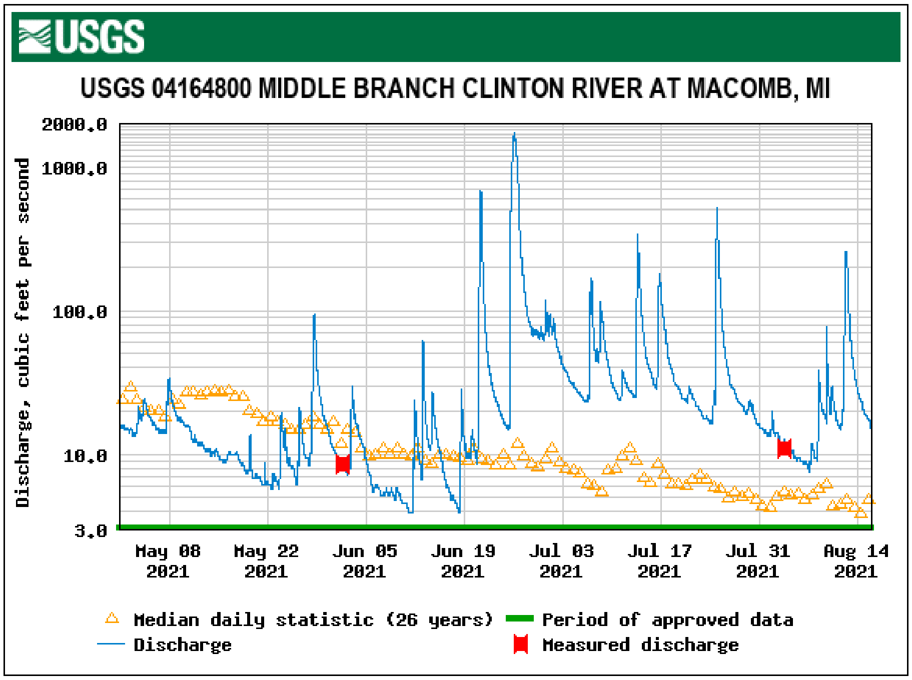
Temporal discharge measurements at our sites have changed over time and seem to affect watershed dynamics and the transport of *E. coli*. Historical medians of discharge for the previous 26 years were higher in May and early June for precipitation events. Select discharge events rose above the median daily statistic during this time frame, but after June 19th, all median daily discharges were far exceeded throughout the rest of the summer, and even after we had ceased sampling. Historical trends also indicate discharge was highest during the late spring and continues to decline through the summer, which was almost the opposite of the summer of 2021 trends (Figure 10). During precipitation events, the speed at which baseflow increased varied between sites. In July, the base flow was naturally higher due to this phenomenon. Both the Middle Branch and Red Run had flow responses to a storm event within a few hours, whereas the North Branch and Clinton Main Branch had a delay of at least 12 hours after precipitation started before a significant increase in flow could be seen. This time lag is due to the size of the catchments and the time it takes water to accumulate flow into the streams from surface flow (Saghafian et al., 2002). Branch peak flows also had wide variability across the watershed, possibly due to these variations in the size of catchment, amount of precipitation in each catchment, impervious surface percentage, and channel widths (Saghafian et al., 2002).


USGS
USGS 04161820 CLINTON RIVER AT STERLING HEIGHTS, MI
Discharge, cubic feet per second
4000
3000
2000
1000
100
70
May 08 2021
May 22 2021
Jun 05 2021
Jun 19 2021
Jul 03 2021
Jul 17 2021
Jul 31 2021
Aug 14 2021
Median daily statistic (26 years)
Period of approved data
Discharge
Measured discharge

a)


USGS
USGS 04164500 NORTH BRANCH CLINTON RIVER NEAR MT. CLEMENS, MI
Discharge, cubic feet per second
3000.0
2000.0
1000.0
100.0
10.0
7.0
May 08 2021
May 22 2021
Jun 05 2021
Jun 19 2021
Jul 03 2021
Jul 17 2021
Jul 31 2021
Aug 14 2021
Median daily statistic (74 years)
Period of approved data
Discharge
Measured discharge

b)



c)

Figure 10. USGS gages at a) Clinton Main Branch, b) North Branch, and c) Middle Branch showing hourly discharge for the period of May 1st to August 14th, 2021 in blue and 26-year median discharge in yellow triangles in cubic feet per second (U.S. Geological S, 2016)

The concentration of *E. coli* is known to be directly related to precipitation events. As precipitation increases, *E. coli* colonies drastically increase in number (McCarthy et al., 2007) and vary seasonally due to *E. coli* survivability rates at different temperatures (Mancini, 1978). Within each reach, the size of the watershed affected peak flow and the concentrations of *E. coli*, where either the *E. coli* was diluted due to high flow, or more *E. coli* was flushed down the stream network at different rates, peaking well before peak discharge and rising concentrations. At the North Branch site, our maximum *E. coli* concentration was the highest with a value of 23845.84 MPN/100 ml, followed closely by the Main branch with 22329.90 MPN/100 ml, Red Run with 20270.01 MPN/100 ml, and then Middle Branch with a max of 11722.48 MPN/100 ml, most likely because it has the smallest area of the four watersheds. Overall, Red Run averaged the highest geometric means of our sampling data. These values are extremely high when compared to the water quality standards for body contact of 300 and 1000 MPN/100 ml, making any contact with the water unsafe during these storm events and for hours and days following. These levels also indicate the need for management-based mitigation and comprehensive source tracking of *E. coli* accumulation. Routine large discharges from the George W. Kuhn retention basin, which can hold up to 124 million gallons of water, influence flow and pathogen concentrations throughout the Red Run. This and other such stormwater infrastructure can deliver extremely high concentrations of pathogens and pollutants in times when precipitation might not be the driving influence of exceedances. In addition, we observed geese and ducks close upstream of the sampling location at the Red Run, which may contribute to high *E. coli* concentrations under no precipitation conditions.

While *E. coli* concentrations have been known to be high in the past throughout the river system, our data brings to light how easily the current limits are exceeded with very little precipitation. The only reach that had some resilience to larger amounts of precipitation was the North Branch. This branch is much less urbanized and has different surface geology than the other reaches, with the majority of the North Branch subwatershed consisting of Lacustrine clay and silt, whereas the other reaches, besides Red Run, had subwatersheds with more gravel, sand, and fine to coarse till which have much greater pore size and therefore infiltration rates. Land cover in the Red Run subwatershed is almost completely developed, with surface geology of Lacustrine clay and silt, as well as Lacustrine sand and gravel, but little infiltration or even soil interaction due to the large amounts of impervious surfaces. Previous studies have demonstrated that soil type and moisture content directly influence not only the survival and fecundity of *E. coli* but also its ability to withstand environmental fate and transport (Lang & Smith, 2007). Soils that can retain more moisture will have *E. coli* for longer periods before pathogen decay begins due to the desiccation of soil. Point source contamination could be a reason for high *E. coli* concentrations during dry-weather periods, however, determining these sources was not within the scope of our study.

Integration of *E. coli* dynamics into the Decision Support System

To assist with public awareness of watershed dynamics and associated *E. coli* risks, we worked with the Institute of Water Research at Michigan State University to incorporate our information into an online decision support system (DSS). The DSS is an online tool that aims to provide local decision-makers with a visualization of current stormwater management challenges in the Clinton River watershed and future impacts from urbanization and climate change. Health risks from *E. coli* were of particular importance to stakeholders, and thus, our discharge and precipitation threshold values were incorporated into the *E. coli* section of the DSS tool. With other modeling techniques being utilized in this system to predict watershed dynamics with changes in climate and land cover, the thresholds we created for *E. coli* exceedance based on precipitation and discharge were put in the Soil and Water Assessment Tool (SWAT) models to predict future *E. coli* exceedances under different scenarios. Our data also helped characterize *E. coli* dynamics during individual storms, which can be influenced by surficial geology, land use, and catchment size. This information became its own module within the DSS so that the public and local water managers can visualize these dynamics and make informed management decisions.

Study Limitations

As with all scientific work, there are limitations of this study that could be addressed in future research. We assumed the locations of the USGS gages were close enough to our sampling sites to use the discharge data obtained from USGS to represent the streamflow of our sampling sub-watersheds. However, the USGS gage at the North Branch is six miles downstream of our sampling site, and the network picks up additional tributary flows, so the discharge values we used for the North Branch represent a larger and more varied catchment area than our sampled sub-watershed.

An additional limitation is that the sample size of our *E. coli* data collected over the summer of 2021 is relatively small, which leads to uncertainties illustrated by the large confidence intervals in the logistic regression models (Figure 9). We obtained historical *E. coli* data to increase the sample size, however we did not comprehensively analyze these data due to time constraints. The historical *E. coli* data were collected on random sampling days over a year with a single grab sample every time, which may not fully capture *E. coli* responses during an entire storm event. Thus, in our limited analyses we found no clear correlation between historical *E. coli* data and historical streamflows. Future research may consider seasonal variation in the historical data because *E. coli* cells grow in temperatures ranging from 20 to 37°C with a positive relationship to temperature (Farewell & Neidhardt, 1998), which indicates *E. coli* concentrations may be higher in summer months. We focused only on characterizing *E. coli* responses during the summer of 2021 because we suspect *E. coli* during the colder seasons would be less active.

Due to time constraints, we did not include dry hours before sampling events as a parameter to the logistic regression model for characterizing the relationship between *E. coli* concentrations and precipitation. A longer antecedent dry period before rain may result in more *E. coli* cells building up in the landscape and then flushing into the streams. Conversely, a short dry period between storms may have a smaller first flush effect (Gupta & Saul, 1996; Charlebois, 2021) and may result in relatively high baseline *E. coli* concentrations because *E. coli* concentrations have not had time to recede to baseline levels.

Another potential limitation of our study is that we did not consider the time lag between peak streamflow and peak *E. coli* concentrations during a storm event at each branch when we studied the relationship between streamflow and *E. coli* concentrations. Instead, we used the instantaneous streamflows, which may not correctly represent the relationship. Specifically, there was a long time lag for North Branch. For example, the time lag for North Branch at a storm from July 25th to July 26th was about 30 hours, indicating the instantaneous streamflow could still be low while we observed a high *E. coli* concentration, and vice versa. The long time lag for North Branch may explain the weak correlation we found. Identifying the specific time lag in hours for each branch and building it to the model were hard because they varied depending on the intensity and duration of the precipitation events. Instantaneous streamflow could tell the water managers about the water level and flow rate at specific *E. coli* levels, while more systematic research may be needed to identify the time lags for the relationship.

Implications for Management

The thresholds that we created have the capability to be utilized as a proxy for *E. coli* concentrations to create a red/yellow/green light real-time risk warning system for the Clinton River, which would inform the public when it is safe to use the river. When the system indicates river discharge or precipitation is well below the thresholds we determined, the risk warning system would show the river is in a green light stage, meaning there is a very low risk of *E. coli* exceedance. A yellow light warning would occur when river discharge or precipitation is close to reaching the thresholds, and the public should be wary of using the river, as it is, or may soon, exceed *E. coli* contact limits. A red light warning would occur when river discharge or precipitation is at or exceeding the threshold. Several similar systems are already in place throughout the Great Lakes, such as the Michigan BeachGuard System and the Indiana Lake Michigan BeachAlert System. These systems, which are based on intensive, near-real-time qPCR testing, notify the public which beaches are closed or have an advisory, and the reason, such as high bacteria levels (Michigan Water Stewardship Program, 2021). The Indiana Lake Michigan BeachAlert System provides a graphical interface with red flags for closures, yellow flags for advisories, and green flags for open beaches (Indiana Department of Environmental Management, 2022). This type of user interface would work well if integrated into the DSS to provide real-time risk warnings.

Similar sampling projects can help water managers better understand stormwater and resulting *E. coli* dynamics within their watershed. Sampling *E. coli* during both baseline conditions and throughout individual storm events provides a direct and comprehensive understanding of *E. coli* dynamics. Having baseline samples to compare to our storm samples not only provided a way to statistically analyze how *E. coli* dynamics were changing, but also resulted in striking data and visuals that could be strategically used by water managers. Graphics and data, such as the threshold panels we created, can be used by water managers to help strengthen their case for the need for more extensive research programs, such as microbial source tracking. Microbial source tracking would also lend itself well to a similar methodology as our *E. coli* work. Sampling systematically throughout the entire watershed under multiple stream conditions, such as during baseflow and throughout storm events, would help support qPCR source tracking projects by helping pinpoint when and where certain microbial sources are prevalent throughout a watershed. Sampling throughout storm events (storm chasing) necessitates long hours from dedicated personnel and is expensive, making it relatively rare. However, our study graphically showed the value of capturing the dynamics of individual storms. Sampling and analyzing nutrient concentrations, turbidity, dissolved oxygen, and other water quality parameters in a similar way to our *E. coli* work would help water managers understand the conditions in which water quality parameters are altered. These data could also be used to create streamflow thresholds for other water quality parameters of interest.

Having a sampling plan that considered all four branches of the Clinton River was crucial in our understanding of the entire watershed, as the four branches accumulate to form conditions in the lower river mainstem. Many factors influence the heterogeneity of the landscape within the watershed. Political boundaries split the watershed, resulting in different counties managing different portions of the river. Geologic history impacts soil characteristics, causing different areas in the watershed to have great infiltration capacities, or to be better suited for agriculture, thus impacting the composition of runoff in these areas. Socioeconomic factors influence population density, urbanization, and imperviousness, impacting the amount of runoff into the river. Through our sampling, we attempted to capture as much of this heterogeneity as we could. Only sampling the river after all branches had converged or leaving out one of the branches would have severely diminished our understanding of the individuality of the sub-watersheds of the four branches. If water managers were to only sample and create management plans from data collected in the more urban areas of the watershed, the more rural areas of the watershed would not be properly understood.

Of the four branches of the Clinton River, the North Branch was the most resilient to influences from increased discharge and precipitation, with response rates roughly 400 times lower than Red Run. The North Branch is the least urbanized, consisting mainly of cropland and natural areas such as forests (Figure 3). These croplands and forests may act as a riparian buffer zone, helping to filter out the *E. coli* contaminated runoff before it reaches the river. Studies have shown that riparian buffers can help to reduce the amount of fecal bacteria in both urban (Casteel, 2005) and rural (Sullivan, 2007) areas by more than 99%. As a result of the North Branch's ability to filter *E. coli*, it is imperative the North Branch subwatershed be protected from development and urbanization, as they may lead to a loss of its important filtering properties. Unfortunately, there are already mounting pressures for increased developments in the area. Thankfully, some projects exist that are aiming to limit damage from increasing development of the North Branch. One such project is the North Branch Greenway, which will provide public access to the floodplain, as well as ensure the creation and preservation of greenways along the North Branch (Macomb County Government, 2019). We recommend county managers look to the work being done in the North Branch, and consider establishing similar riparian buffers on the other branches to decrease the concentration of pathogens entering the Clinton River.

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Assistance to the Hydrologic Modeling Team

Authored by: Timothy Marchman and Daniel Dominique

Introduction

Within the overall Clinton Smart Stormwater Management Project, the University of Michigan Hydrologic Modeling Team, led by Dr. Valeriy Ivanov, was tasked with creating hydrologic and climate models to provide whole-systems understanding and projections for integration into Michigan State University's online Decision Support System (DSS). The main goals of the modeling team were to identify areas within the Clinton River Watershed that are vulnerable to flooding due to increased urbanization, quantify the hydrologic response to land use development, and to quantify the hydrologic response to climate change within the watershed at both sub-watershed and watershed levels. However, these models often required the creation, updating, and management of various GIS files, and due to the graduation of the modeling team's former GIS expert, a void existed within the team. Therefore, we joined the modeling team to provide the GIS support they needed. To help the modeling team, we performed GIS duties including familiarizing ourselves with the watershed, mapping stream channel widths, updating the watershed boundary file, analyzing the impact of a water retention and treatment basin on the watershed, and creating a file containing all of the 303(d) impairments of the Clinton River. A summary of all the created files, for both the modeling team and our own *E. coli* work is included in the next section, "Metadata".

Summary of GIS Work

The first, and most important step was familiarizing ourselves with the watershed in regards to its spatial, geologic, municipal, and other attributes. As our predecessor had left us with hundreds of gigabytes of GIS files associated with the Clinton River Watershed, our main task for the first few weeks was to determine what types of files we had and did not have. Thanks to our predecessor's meticulous file management system, we were able to determine what the holes in our data library were. The most important files that we were missing were high resolution LiDAR data.

LiDAR (Light Detection and Ranging) data was critical for mapping stream channel widths. LiDAR data were obtained from the Southeast Michigan Council of Governments (SEMCOG) and compiled for project use. Digital Elevation Model (DEM) data were provided in small grids, which had to be mosaiced into one comprehensive DEM that was used for various watershed modeling components, such as updated flow direction, flow accumulation, and stream delineation processes. The DEMs were also used to gather stream channel cross sections. These were first determined at USGS streamflow gage sites, and then later on in areas of interest such as the Red Run Branch. These channel cross sections assist with calculating discharge, are useful inputs for various watershed models,, and are used to predict frequency of overbank flooding.

A problem that the modeling team had discovered was that the Clinton River Watershed boundary file that they had was severely outdated. There were many issues with the file that they were using, for example, it contained subwatersheds for sections of the Clinton River that do not exist any more, it did not account for much above or below ground drain infrastructure, and it had large holes in the geometry of the shapefile that would cause model failures. To remedy the issue of subwatersheds for nonexistent stream reaches, we used current satellite imagery and elevation data to merge and redraw these subwatersheds, ensuring that each subwatershed was associated with the downstream node of a specific stream reach. To address the infrastructure issue, we used current and historic county infrastructure GIS files and maps to find and redraw the watershed around storm drains inputs and outputs, and where there might be breaks in a subwatershed, such as a culvert passing through a major highway. Finally to address the geometry problem, we painstakingly looked at the boundaries of all subwatersheds to find areas where there were gaps. When there were gaps, we had to edit the shapefile so that everything connected the way that it should.

As the modeling team progressed through their work, they began to realize the uniqueness of the Red Run Branch, mainly that the stream dynamics are heavily influenced by the George W. Kuhn Retention Treatment Basin (GWK) which is designed to store, screen, and disinfect flood water, which is eventually pumped into the Red Run Branch (citation or link?). The modeling team understood that the design and operation of the GWK impacts the dynamics of the discharge and shape of Red Run subwatersheds, and that these needed to be taken into account. To assist them, we obtained GWK Basin's discharge records from January 1, 2000 to September 1, 2021, with the facility's permission, through our contact at the Clinton River Watershed Council. In the form received, the modeling team was unable to integrate these data into their models. To fix this, we translated the data from individual discharge release dates and amounts into a continuous time series. We also needed to address how the subwatersheds of the Red Run Branch were impacted by the GWK Basin. To do this, we had to research previously constructed watershed maps and translate them into GIS form, while taking into consideration the previous edits we had made based on the infrastructure of the region.

During the summer, Michigan State University's Dr. Glenn O'Neil, lead designer of the DSS and its interface with the modeling work, requested us to create a GIS file of the 303(d) impairments and the most recent impairment date of each stream reach in the Clinton River. We obtained an EPA shapefile of the Clinton River Watershed that contained the stream reach ID for each reach in the watershed, as well as a link to the EPA's website which contains all 303(d) impairments and impairment dates. Since there are over 600 individual reaches in the watershed, going through each individual reach to identify impairments would have been far too time consuming. We found that many reaches had the same URLs linked to the EPA's 303(d) impairment site associated with them, so we were able to group the reaches that shared URLs to expedite the process.

Discussion

Our assistance to the modeling team was beneficial, as it allowed them to not focus on the creation of GIS files and finding data, and focus on creating, running, and troubleshooting their models. GIS processes can be very time consuming and hardware intensive. We had access to a powerful PC, so any intensive GIS process took much less time than for a standard desktop PC.

As a result of our integration with the modeling team, we learned many skills and gained valuable experience that will translate well to our future careers. Through our collaboration with them, we were able to hone our GIS skills. Both of us have had prior experience with GIS, but not doing the specific tasks that the modeling team asked of us. Throughout our time working with the team, we had to learn how to do GIS work that we had never done before, which helped increase both of our GIS repertoires. For example, the remapping of subwatersheds based on elevation and infrastructure data was something that neither of us had done before. A skill that we became better at through our collaboration with the modeling team was sourcing and managing files and data. When we first started working with the modeling team, we were overwhelmed with the amount of data and files that we now had to be experts on. This forced us to create systems to organize and understand our data, such as the creation of our own test maps and directories to help us find the data we needed. When we needed data that we didn't have, we scoured the internet to find it. If we couldn't find what we needed, we contacted parties that would be able to help us, such as getting LiDAR data from SEMCOG and discharge data from the GWK through the Clinton River Watershed Council.

Finally, we learned how to work with professionals from different disciplines. Prior to joining the team, we had no knowledge of hydrologic modeling. At first, it was difficult to follow exactly what was needed by us, due to this inexperience. However, by attending weekly meetings and asking questions, we were able to gain a basic understanding of hydrologic models such as tRIBS (TIN-based Real-time Integrated Basin Simulator) and SWAT (Soil Water Assessment Tool). Having this knowledge of hydrologic modeling, we were able to create GIS files so that they would be able to be integrated into the models more effectively. Also, we were able to better translate our knowledge of GIS to the modelers, so they could direct us to what they needed more effectively.

Metadata

Compiled by: Timothy Marchman, Daniel Dominique, and Huayile Zhang

Metadata Overview:

We created various files, including GIS files and data files for both the UM Hydrologic Modeling Team and for our own *Escherichia coli* sampling project. The UM Hydrologic Team used the files we created to make their models more accurate. For example, we edited Clinton River subwatershed files to better reflect below and above-ground infrastructure, and provided them to the modeling team. For our own *E. coli* subproject we created time series, GIS files, and R code to better understand the influence of precipitation and streamflow on *E. coli* dynamics. Our time-series data is based on baseline and storm sampling we conducted in the summer of 2021. We used GIS files to explore the subwatersheds of our *E. coli* sampling locations. Finally, we created R code to help us visualize and analyze the data.

Metadata File Inventory:

Title: CM_Watershed

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Sources: SEMCOG LiDAR data, Clinton Boundary File

Description: Shapefile of the watershed of Clinton main branch, created from SEMCOG LiDAR data. Watershed tool from flow accumulation and direction processes clipped to boundary file.

Discipline: Hydrologic Modeling

Keywords: Watershed; LiDAR; DEM; Flow Accumulation; Flow Direction; Spatial Analyst

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Title: Clinton River Summer 2021 E. coli monitoring data logistic regression

Included Files: CM_Ecoli_Flow_Precip_Relations.csv; MB_Ecoli_Flow_Precip_Relations.csv; NB_Ecoli_Flow_Precip_Relations.csv; RR_Ecoli_Flow_Precip_Relations.csv

Release Date: 4/19/2022

Authors: Huayile Zhang; Timothy Marchman; Fariborz Daneshvar

Contact Information: huayilez@umich.edu; tjmarchm@umich.edu; fdanesh@umich.edu

Sources: USGS 04161820 Clinton River Gage for the Clinton Main (CM) Branch discharge values, USGS 04164800 Middle Branch (MB) Gage for the Middle Branch discharge values; USGS 04164500 gage for the North Branch (NB) discharge values; Red Run (RR) discharge values were synthesized using ERA5 data; Precipitation data was synthesized using NLDAS Primary Forcing Data

Description: CSV files containing the date and time of *E. coli* triplicate sample being taken, as well as the geometric means of the triplicates in MPN/100 ml. These geometric means were translated into binary to determine whether they violated contact limits of 300 and 1000 MPN/100 ml. A violation was designated with a 1, while a non-violation was designated with a 0. Also included are discharge in cfs at sampling time, precipitation in mm at sampling time, the number of dry hours since the last precipitation event, and historical sampling data. All student sampled data is designated with “2021” under the notes column.

Discipline: Water quality

Keywords: Clinton River; E. coli

Title: Clinton River Summer 2021 E. coli raw monitoring data

Included Files: Clinton_Main_TimeSeries_Ecoli.csv; Middle_Branch_TimeSeries_Ecoli.csv; North_Branch_TimeSeries_Ecoli.csv; Red_Run_TimeSeries_Ecoli.csv

Release Date: 4/19/2022

Authors: Huayile Zhang; Timothy Marchman; Fariborz Daneshvar

Contact Information: huayilez@umich.edu; tjmarchm@umich.edu; fdanesh@umich.edu

Sources: USGS 04161820 Clinton River Gage for the Clinton Main (CM) Branch discharge values, USGS 04164800 Middle Branch (MB) Gage for the Middle Branch discharge values; USGS 04164500 gage for the North Branch (NB) discharge values; Red Run (RR) discharge values were synthesized using ERA5 data; Precipitation data was synthesized using NLDAS Primary Forcing Data

Description: Hourly time series of E. coli concentrations in MPN/100ml for two dilutions gathered from 5/11/2022 to 7/27/2021. Time series of discharge data gathered from 5/6/2021 to 8/3/2022 in cubic feet per second, and time series of precipitation data in mm compiled from 5/6/2021 to 8/14/2021. Also included are error bars based on the *E. coli* triplicates.

Discipline: Water quality

Keywords: Clinton River; E. coli

Title: ClintonBoundary

Release Date: 03/22/2022

Authors: Kevin Murphy; Daniel Dominique

Contact Information: kvmurph@umich.edu; djdom@umich.edu

Sources: University of Michigan Department of Civil Engineering

Description: Shapefile of the watershed boundary of the Clinton River Watershed.

Discipline: Hydrologic Modeling

Keywords: Watershed; Boundary

Title: Clinton_River_Subwatersheds

Release Date: 4/19/2022

Authors: Timothy Marchman, Kevin Murphy, Fariborz Daneshvar

Contact Information: tjmarchm@umich.edu; kvmurph@umich.edu; fdanesh@umich.edu

Sources: Macomb County Public Works

Description: ArcGIS layer package of the subwatersheds of the Clinton River edited to take into account above and below ground infrastructure, no longer existing stream reaches, and the George W. Kuhn Retention Treatment Basin.

Discipline: Hydrologic Modeling

Keywords: Clinton River; Subwatershed

Title: Clinton_Streams

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Sources: University of Michigan Department of Civil Engineering

Description: Shapefile containing all stream reaches for the Clinton River Watershed.

Discipline: Hydrologic Modeling

Keywords: River; Stream; Clinton River

Title: Ecoli_TimeSeries.R

Release Date: 4/19/2022

Authors: Huayile Zhang

Contact Information: huayilez@umich.edu

Description: R script for time-series plots showing *E. coli* concentrations overlaying the streamflow and precipitation hyetograph.

Discipline: Water quality

Keywords: Clinton River; E. coli

Title: EcoliflowPrecip_Relation.R

Release Date: 4/19/2022

Authors: Huayile Zhang

Contact Information: huayilez@umich.ed

Description: R script for summer 2021 logistic regression models and generalized linear regression models of E.coli, precipitation, and streamflow relationships

Discipline: Water quality

Keywords: Clinton River; E. coli

Title: GWK_Catchment_Clinton

Release Date: 4/19/2022

Authors: Timothy Marchman

Contact Information: tjmarchm@umich.edu

Description: ArcGIS layer package containing the catchment of the George W Kuhn Retention Treatment Basin.

Discipline: Hydrologic modeling

Keywords: Retention Basin; George W Kuhn; Discharge; Clinton River

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Title: GWK_Time_Series_Clinton.csv

Release Date: 4/19/2022

Authors: Timothy Marchman

Contact Information: tjmarchm@umich.edu

Sources: George W Kuhn Retention Treatment Basin

Description: A time series of daily discharge from the George W Kuhn Retention Treatment Basin from 1/1/2000 to 9/30/2021 in cubic meters per day.

Discipline: Hydrologic modeling

Keywords: Retention Basin; George W Kuhn; Discharge; Clinton River

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Title: Main_branch_site

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Description: Shapefile of the *E. coli* sampling site at the Clinton Main Branch.

Discipline: Water Quality

Keywords: Clinton River

Title: Middle_branch_site

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Description: Shapefile of the *E. coli* sampling site at the Middle Branch of the Clinton River.

Discipline: Water Quality

Keywords: Clinton River

Title: NB_Watershed

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Sources: SEMCOG LiDAR data, Clinton Boundary File

Description: Shapefile of the watershed of the North branch, created from SEMCOG LiDAR data. Watershed tool from flow accumulation and direction processes clipped to boundary file.

Discipline: Hydrologic Modeling

Keywords: Watershed; LiDAR; DEM; Flow Accumulation; Flow Direction; Spatial Analyst

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Title: North_branch_site

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Description: Shapefile of the *E. coli* sampling site at the North Branch of the Clinton River.

Discipline: Water Quality

Keywords: Clinton River

Title: Quaternary_Geology_Map_Clip

Release Date: 03/08/2022

Authors: Daniel Dominique, Christine Purdy

Contact Information: djdom@umich.edu

Sources: Michigan State University (Dr. Glenn O'Neil)

Description: Michigan Quaternary Geology clipped to the Clinton River Watershed Boundary

Discipline: Geology

Keywords: Geology; Surface Geology; Quaternary Geology; Soil

Title: RR_Watershed

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Sources: SEMCOG LiDAR data, Clinton Boundary File

Description: Shapefile of the watershed of the Red Run branch, created from SEMCOG LiDAR data. Watershed tool from flow accumulation and direction processes clipped to boundary file.

Discipline: Hydrologic Modeling

Keywords: Watershed; LiDAR; DEM; Flow Accumulation; Flow Direction; Spatial Analyst

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Title: Red_run_site

Release Date: 4/19/2022

Authors: Daniel Dominique

Contact Information: djdom@umich.edu

Description: Shapefile of the *E. coli* sampling site at the Red Run Branch of the Clinton River.

Discipline: Water Quality

Keywords: Clinton River

Title: Umich_Nodes_Clinton

Release Date: 4/19/2022

Authors: Timothy Marchman

Contact Information: tjmarchm@umich.edu

Description: ArcGIS layer package of all University of Michigan's stream nodes in the Clinon River as of 2021.

Discipline: Water Quality

Keywords: Clinton River

Appendix A

Original Project Factsheet from March 2021 by Tori Graves

SMART STORMWATER MANAGEMENT FOR THE CLINTON RIVER

PROJECT OVERVIEW & UPDATE: March 2021

The Clinton River Watershed in Southeast Michigan (Figure 1) faces stormwater challenges related to urbanization and climate change. Urbanization, including impervious surfaces and drainage infrastructure, has contributed to excessive stormwater runoff with degraded water quality including elevated nutrients, sediments, pathogens, and other pollutants. Effects of climate change, such as shifting precipitation patterns and increased frequency and intensity of storm events, further exacerbate challenges to, and uncertainties in, stormwater management.

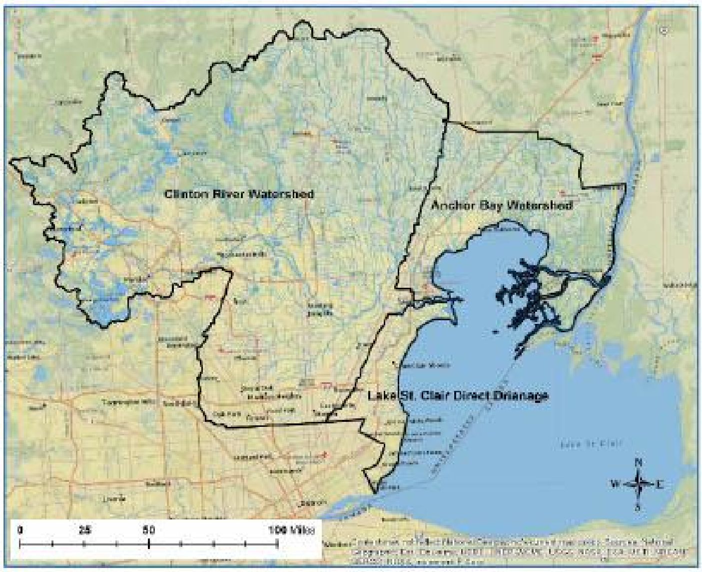
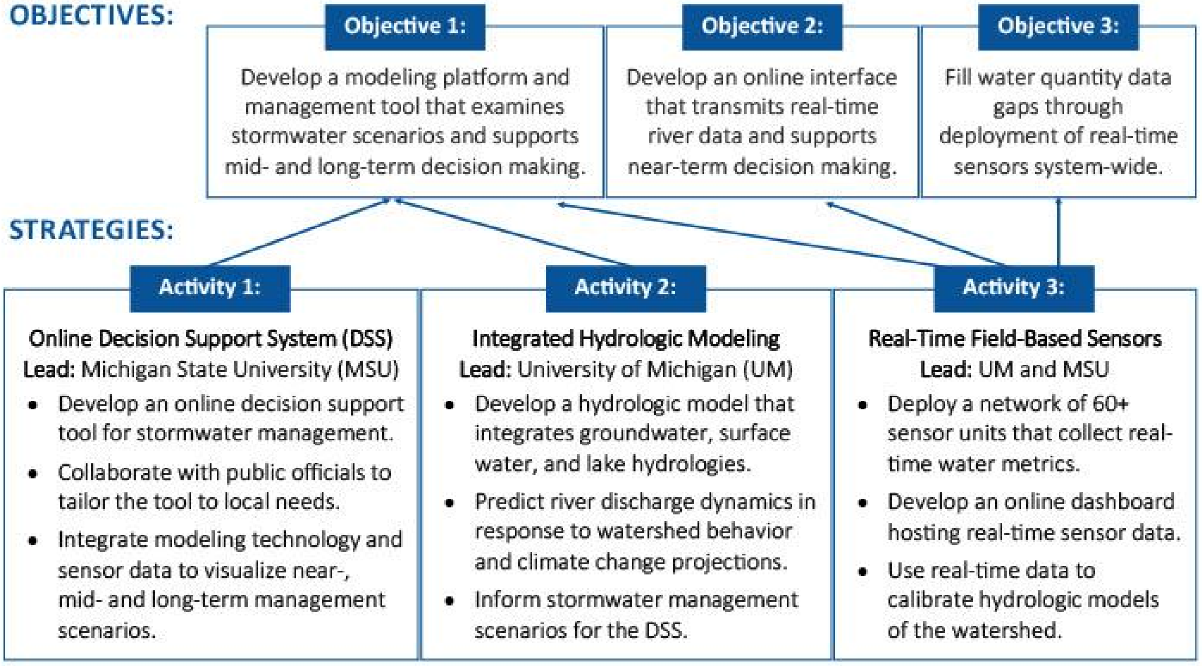


Figure 1. Clinton River Watershed | **Source:** Clinton River Watershed Council

Existing and emerging technologies, such as satellite communication, web-based tools, sensors, and advanced computer modeling, offer promising solutions but are not often applied to stormwater problems at the watershed scale. Since 2018, a team of interdisciplinary researchers, scientists, and local water managers have been collaborating to provide technological resources for proactive and informed stormwater decision making within the Clinton River Watershed. Project deliverables will serve as an innovative template for urban stormwater management across the Great Lakes Basin.

PROJECT GOAL: To assemble and deliver available technologies in the form of a holistic stormwater management toolkit by leveraging partnerships between the science community and management professionals in the Clinton River Watershed.



OBJECTIVES:

Objective 1:

Develop a modeling platform and management tool that examines stormwater scenarios and supports mid- and long-term decision making.

Objective 2:

Develop an online interface that transmits real-time river data and supports near-term decision making.

Objective 3:

Fill water quantity data gaps through deployment of real-time sensors system-wide.

STRATEGIES:

Activity 1:

Online Decision Support System (DSS)
Lead: Michigan State University (MSU)

- Develop an online decision support tool for stormwater management.
- Collaborate with public officials to tailor the tool to local needs.
- Integrate modeling technology and sensor data to visualize near-, mid- and long-term management scenarios.

Activity 2:

Integrated Hydrologic Modeling
Lead: University of Michigan (UM)

- Develop a hydrologic model that integrates groundwater, surface water, and lake hydrologies.
- Predict river discharge dynamics in response to watershed behavior and climate change projections.
- Inform stormwater management scenarios for the DSS.

Activity 3:

Real-Time Field-Based Sensors
Lead: UM and MSU

- Deploy a network of 60+ sensor units that collect real-time water metrics.
- Develop an online dashboard hosting real-time sensor data.
- Use real-time data to calibrate hydrologic models of the watershed.

ACTIVITY #1: ONLINE DECISION SUPPORT SYSTEM

Project collaborators from MSU are leading the development of an online decision support system, or DSS, that will visualize certain stormwater management scenarios. The project team is actively collaborating with future DSS users to guide development of a system that is responsive to the needs of local decision makers in Oakland and Macomb counties.

RESPONDING TO LOCAL MANAGEMENT NEEDS

To date, the iterative engagement process has involved workshops, regular meetings, and a two-part online survey. Initial stakeholder feedback was analyzed to identify a preliminary set of the most pressing stormwater management needs in the watershed. The following needs will set the stage for management scenarios incorporated into the DSS.

Vulnerability Assessment	Provide access to information and maps detailing locations in the watershed susceptible to flooding, rapid runoff, erosion, and poor water quality.
Climate Response	Enhance planning for climate change and response to local weather conditions including emergency response to flooding and spills.
BMP Evaluation	Evaluate effectiveness of all best management practices (BMPs), including green infrastructure, considering specific watershed locations under various management scenarios. BMPs should incorporate adaptive management techniques that address future emergency response needs.
Stormwater Peak Shaving	Understand which BMPs best address peak shaving under different storm conditions using volume and rate controls.

NEXT STEPS - *Convene Stakeholders & Integrate Hydrologic Models*

The project team is currently organizing a subcommittee of key stakeholders to test management scenarios and inform future iterations of the DSS. Through this process, the MSU team will make continued progress toward a refined version of the tool to be launched in 2022. Additionally, project members from UM and MSU continue to collaborate to develop hydrologic models that will be integrated into the DSS to visualize the identified management needs above.

PROJECT APPLICATIONS - *Enhance Stormwater Decision Making*

Stormwater managers are typically tasked with making important decisions with a limiting set of supporting data. The DSS will visualize current challenges within the watershed and future impacts of climate change, ultimately allowing managers to gain confidence in their near- and long-term decision making. Once the DSS is complete, decisions can be backed by historic and real-time data, leading to a greater ability to address issues such as flooding, erosion, and runoff contamination. This type of knowledge also allows for more effective allocation of time and financial resources put toward stormwater projects.

ACTIVITY #2: INTEGRATED HYDROLOGIC MODELING

Project collaborators from UM are developing multiple model scenarios that will be integrated in an innovative way that visualizes both groundwater and surface water hydrology. Outputs from two different models, SWAT and tRIBS, will be paired with a global circulation climate model of the Great Lakes region to develop a fully integrated hydrologic model that predicts a range of watershed behaviors and climate change scenarios. These model outputs will directly inform the final DSS.

INNOVATIVE MODEL SELECTION

The team is integrating two innovative modeling tools, each selected for their ability to visualize and address different watershed parameters and challenges.

	SWAT	tRIBS
Stands For	Soil and Water Assessment Tool	TIN-Based Real-time Integrated Basin Simulator
Scale	Large scale, long term	Small spatial scale, short- to medium-term
Primary Focus	Land surface processes	Physical process interactions of surface-subsurface
Simulates	Water quantity impacts related to land use, land management, and climate change	Continuous hydrologic responses to both wet and dry weather conditions
Predicts	Hydrologic outcomes related to management practices and climate change scenarios	Runoff, infiltration, stream flow, and saturation scenarios in relation to weather events
Data Inputs	Weather inputs, elevation, soils, vegetation	Weather inputs, soils, vegetation, land cover, channel morphology
More Info	https://swat.tamu.edu/	http://vivoni.asu.edu/tribs.html

DATA SHARING & ACQUISITION

A large component of model development has involved compiling data to feed into the models. To ensure the most up-to-date and relevant data are utilized in model creation, data has been collected from federal and state-level sources including the USGS, USDA, NOAA, NASA, and MI DNR. Additionally, local project stakeholders from Oakland and Macomb Counties have shared watershed-specific data files. To improve data access, the UM team is creating a centralized data dictionary that outlines all available files and their sources. While many of these data are historic, the team is also aiming to integrate new, real-time data from the project's sensor network to calibrate the model and assess how the model is performing.

NEXT STEPS - *Reduce Model Uncertainty & Run Simulations*

Because of the novelty and weight of this modeling approach, the team has undergone extensive training and research to discern best practices. The last step before they can begin running the model is to develop tools that remove uncertainty in the data and simplify model outputs. These preliminary steps are nearly complete, and the team will begin integrating and running the full model in the coming year. Model simulations must be run multiple times to ensure an accurate representation of model outputs, which will represent hydrologic outcomes in different climate scenarios. Once model simulations are complete, the highly technical model outputs will be simplified and integrated into the DSS in a way that is accessible and applicable to end users.

PROJECT APPLICATIONS - *Understand Watershed Behavior*

Watershed modeling activities provide unique insights into the current and future behavior and management of stormwater. Modeling also adds clarity and certainty to decision making in a seemingly complex and uncertain future. This insight allows decision makers to effectively address local needs and apply management practices that allow for the best use of natural and financial resources.

ACTIVITY #3: REAL-TIME FIELD-BASED SENSORS

To date, team members from UM have developed and deployed over 60 sensor units, also referred to as nodes, across the Clinton River watershed (Figure 2). Along with these nodes, MSU has developed and piloted a handful of smaller-scale sensor nodes within the network. Node placement is determined with the help of recommendations from local water officials. Some of the nodes are strategically located in close proximity to USGS gage stations or in sub-watersheds of interest.

SENSOR NODE TECHNOLOGY

Each solar powered node contains a battery, a microprocessor, wireless technology, and depth sensors (Figure 3). A handful of the planned nodes will be able to collect flow velocity and sediment load, which will be utilized in developing discharge rating curves for the project's modeling efforts. Sensor nodes are designed with cost in mind, making the technology accessible for communities of all sizes.

For more information on UM sensor technology, visit open-storm.org.

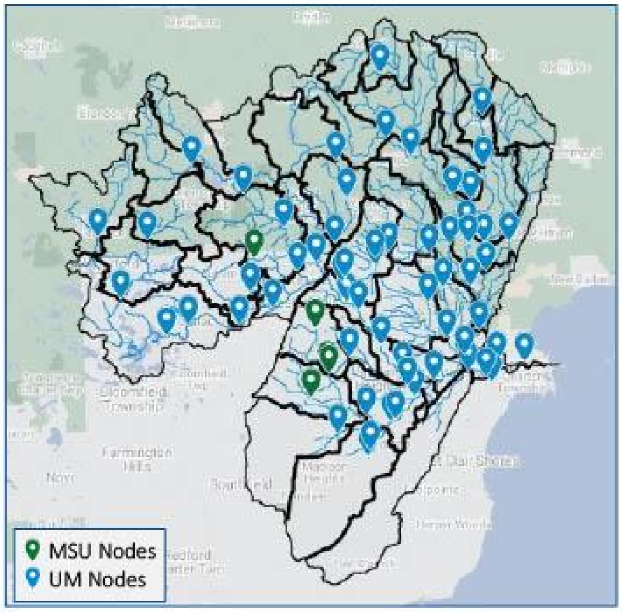


Figure 2. Clinton River Sensor Network | Source: UM Project Team

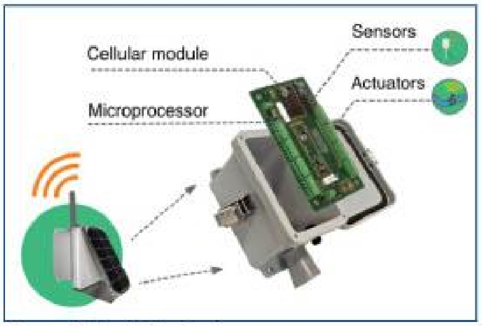


Figure 3. Node Technology
Source: open-storm.org

REAL-TIME DATA DASHBOARD

A team from UM has launched, and continues to develop, a web-based platform to share real-time sensor data with local water managers in the Clinton River, project contributors, and other interested parties. The dashboard displays real-time water depth data for each of the nodes in the network and shows trends in fluctuating water levels over time (Figure 4). This dashboard gathers a tremendous amount of data from across the entire network. For this reason, the team continues to develop quality control measures to identify and remove abnormalities that may arise. The dashboard has already shown its ability to be an efficient and accessible platform for translating real-time data to a broader network of stakeholders and the UM team continues to collaborate with primary users to make adjustments to the dashboard to better fit real-time management needs.

The dashboard is publicly accessible at: http://maps.open-storm.org.s3-website.us-east-2.amazonaws.com/

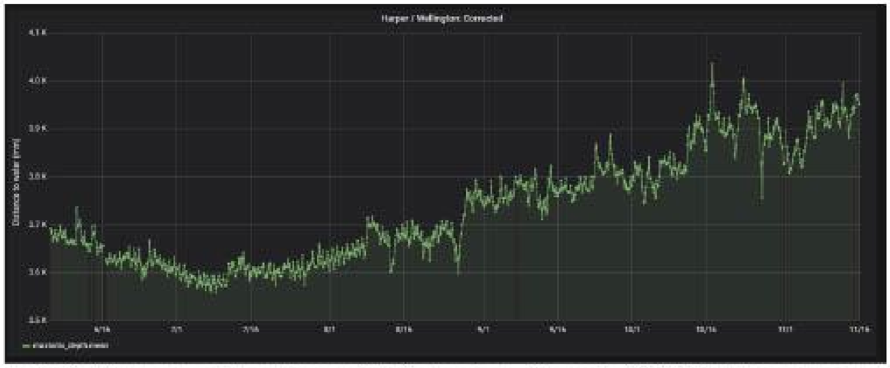


Figure 4. Real-time sensor data at Harper / Wellington June - November 2020 | Source: open-storm.org

NEXT STEPS - *Maintain / Upgrade Existing Infrastructure & Deploy Additional Nodes*

Figure 5. UM student servicing sensor node
Source: UM Project Team

Currently, the university teams are the primary caretakers of the sensor network and continue to upgrade the nodes with more reliable firmware and 4G networking capabilities (Figure 5). Moving forward, long-term maintenance responsibilities will be transitioned to county officials who will soon be trained on how to repair and maintain the sensor nodes. After maintenance is fully transitioned, university team members will continue to provide technical support as needed.

In addition to maintenance, the teams aim to further collaboration with County officials to deploy additional sensors in the southeast portion of the watershed where data gaps exist, as seen in Figure 2. The UM and MSU teams both plan to deploy a set of new sensor nodes in the coming year.

PROJECT APPLICATIONS - *Deliver Real-Time Insights & Network-Wide Response*

When managers have access to real-time water quantity and quality data across the river system, they are able to understand flow capacity in their drainage network and react in real-time to stormwater events. Prior to this sensor network, decisions were based on only a few USGS streamflow gages, plus in-person field observations. The network data allow for more timely and effective response to pressing issues like potential localized flooding during major storm events. Over time, continued real-time data collection throughout the watershed will begin to show patterns that, together with modeling outputs, will allow water managers to visualize and respond to local challenges related to land use practices, urbanization, and climate change. The data collected and shared through the dashboard and DSS will ultimately allow managers to address applicable needs that benefit both near- and short-term planning.

ADDITIONAL RESOURCES

- Michigan State University Institute of Water Research - https://www.egr.msu.edu/iwr/
- University of Michigan Real-Time Water Systems Lab - http://www-personal.umich.edu/~bkerkez/

PROJECT CONTACTS

MI Department of Environment, Great Lakes & Energy: Michelle Selzer, Project Officer, SelzerM@Michigan.gov
University of Michigan: Kate Kusiak Galvin, Project Manager, kkusiakg@umich.edu
Michigan State University: Jeremiah Asher, Assistant Director - Institute of Water Research, asherjer@msu.edu

PROJECT CONTRIBUTIONS

This project is made possible through funding from the Great Lakes Restoration Initiative along with multidisciplinary collaborations from the following organizations:

MICHIGAN STATE UNIVERSITY
UNIVERSITY OF MICHIGAN
OAKLAND COUNTY MICHIGAN
MACOMB COUNTY MICHIGAN
CRWC CLINTON RIVER WATERSHED COUNCIL
EGLE MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
EPA
Great Lakes RESTORATION

Appendix B

August, 2021 update of project factsheet

SMART STORMWATER MANAGEMENT FOR THE CLINTON RIVER

PROJECT OVERVIEW & UPDATE: November 2021

The Clinton River in Southeast Michigan (Figure 1) faces stormwater challenges related to urbanization and climate change. Urbanization produces increased impervious surfaces and drainage infrastructure which contribute to excessive stormwater runoff, flooding, and degraded water quality (elevated nutrients, sediments, pathogens, etc.). Southeast Michigan has seen shifting precipitation patterns as a result of climate change, including increased frequency and intensity of storm events. These changes further exacerbate challenges to, and uncertainties in, stormwater management. These problems threaten the ecological integrity of the Clinton River system and cause human health concerns.

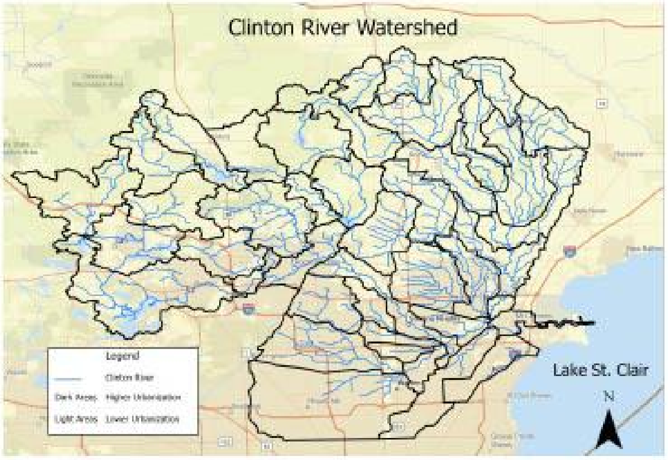


Figure 1. Clinton River system and its waterways
Source: Tim Marchman, University of Michigan

Existing and emerging technologies, such as satellite communication, web-based tools, hydrologic sensors, and advanced computer modeling offer promising solutions to stormwater problems, but they are not often applied at the watershed scale. Since 2018, a team of interdisciplinary researchers and scientists from University of Michigan (UM) and Michigan State University (MSU) have collaborated with local water managers and the Michigan Department of Environment, Great Lakes, and Energy (EGLE) to provide technological resources for proactive and informed stormwater decision-making for the Clinton River. Project deliverables will serve as an innovative template for urban stormwater management across the Great Lakes Basin.

THE WATERSHED

The Clinton River Watershed covers 760 square miles in four different Michigan counties, and it is comprised of thousands of bodies of water and hundreds of miles of streams. As the most populated watershed in Michigan, the area is home to 71 communities, 1.5 million people, and a range of diverse plants and wildlife. River headwaters begin in rural Northern Oakland County, and the system ultimately drains into Lake St. Clair, which is part of the Great Lakes system.

Figure 2. Clinton River Restoration project at Yates Cider Mill
Source: Clinton River Watershed Council

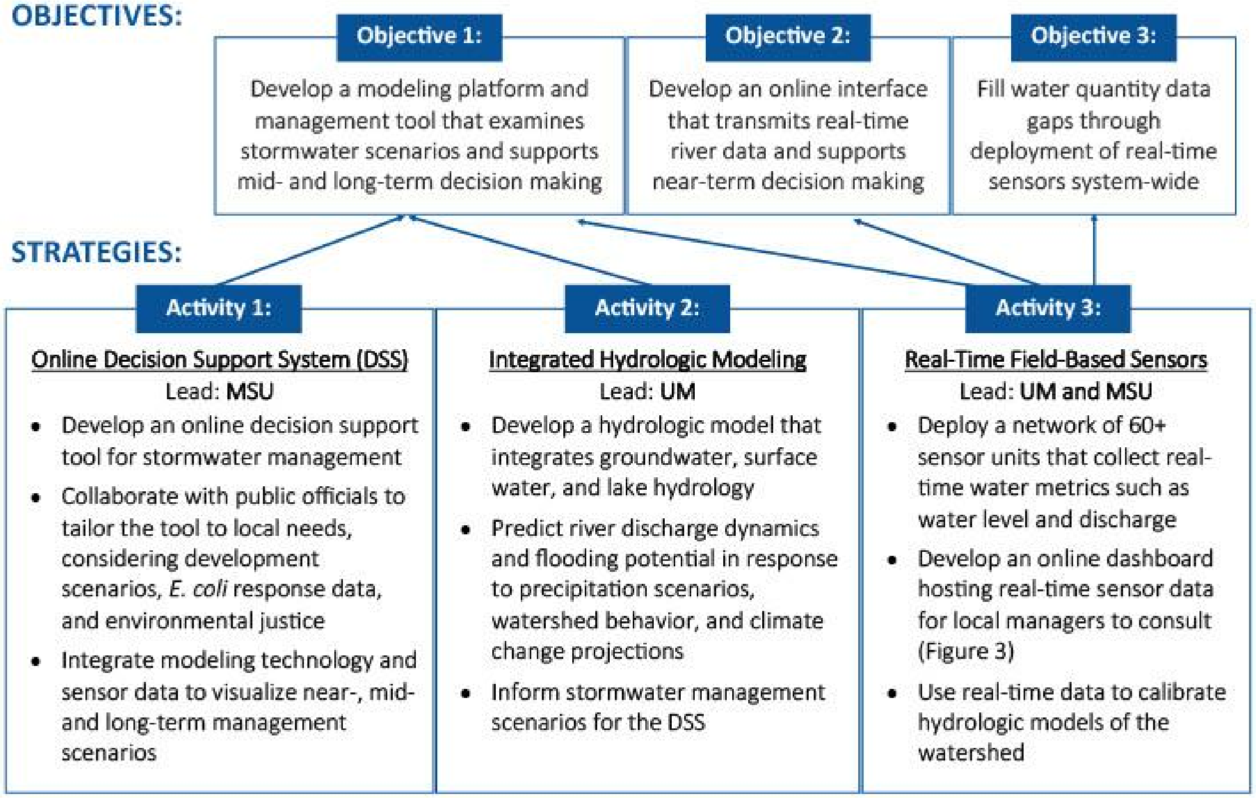
The Clinton River system was designated an Area of Concern (AOC) by the EPA in 1987. Since then, the Great Lakes Restoration Initiative (GLRI) has provided more than $43 million to fund projects and restoration initiatives with the goal of delisting the Clinton River as an AOC. Local and regional communities and non-profit organizations also contribute significantly to improving and protecting the river through watershed management, restoration efforts, green infrastructure installation, and community engagement. For example, the Clinton River Watershed Council (CRWC) is restoring a 500-foot section of the Clinton River at Yates Cider Mill in Rochester Hills (Figure 2). This project will improve degraded aquatic and riparian habitats and make the area more enjoyable to the public.

THE PROJECT

The Clinton River Smart Stormwater Management Project is a partnership between EGLE, UM, and MSU. The project, funded by GLRI, will demonstrate an ecologically based approach for managing rivers and streams in the Great Lakes Region impacted by urbanization and climate change. The project will provide a number of practical software tools and data sets to regional stakeholders, which can be used to effectively inform management actions needed to restore the Clinton River system.

PROJECT GOALS:

- To understand the hydrology of the Clinton River system and the stormwater management challenges facing local people, then apply this knowledge towards effective and equitable stormwater management
- To assemble and deliver a holistic stormwater management toolkit with innovative technologies to local water resource managers via partnerships between the science community and management professionals



OBJECTIVES:

Objective 1:

Develop a modeling platform and management tool that examines stormwater scenarios and supports mid- and long-term decision making

Objective 2:

Develop an online interface that transmits real-time river data and supports near-term decision making

Objective 3:

Fill water quantity data gaps through deployment of real-time sensors system-wide

STRATEGIES:

Activity 1:

Online Decision Support System (DSS)

Lead: **MSU**

- Develop an online decision support tool for stormwater management
- Collaborate with public officials to tailor the tool to local needs, considering development scenarios, *E. coli* response data, and environmental justice
- Integrate modeling technology and sensor data to visualize near-, mid- and long-term management scenarios

Activity 2:

Integrated Hydrologic Modeling

Lead: **UM**

- Develop a hydrologic model that integrates groundwater, surface water, and lake hydrology
- Predict river discharge dynamics and flooding potential in response to precipitation scenarios, watershed behavior, and climate change projections
- Inform stormwater management scenarios for the DSS

Activity 3:

Real-Time Field-Based Sensors

Lead: **UM and MSU**

- Deploy a network of 60+ sensor units that collect real-time water metrics such as water level and discharge
- Develop an online dashboard hosting real-time sensor data for local managers to consult (Figure 3)
- Use real-time data to calibrate hydrologic models of the watershed

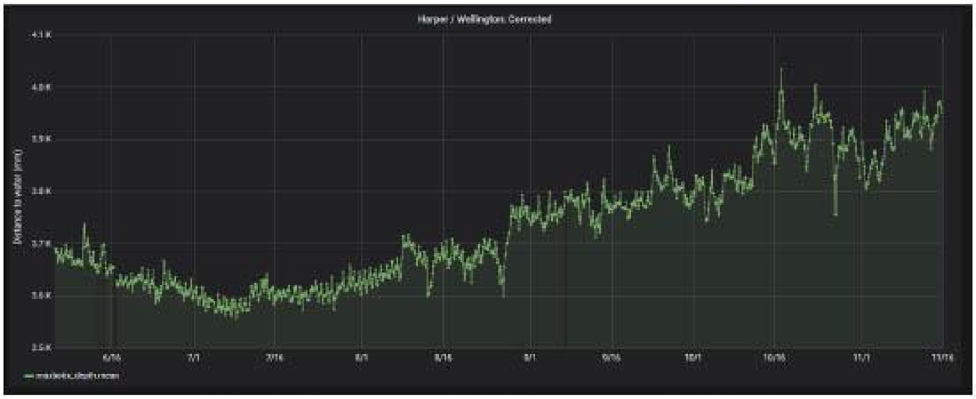


Figure 3. Real-time water level data from a sensor on the Clinton River at Harper Ave. and Wellington Cr. in Clinton Township (June - November 2020)
Source: open-storm.org

ACTIVITY #1: ONLINE DECISION SUPPORT SYSTEM

Project collaborators from MSU are leading the development of an online decision support system, or DSS, that will visualize certain stormwater management scenarios. The project team is actively collaborating with future DSS users to develop a system that is responsive to the needs of local decision makers in Oakland and Macomb counties. Responding to local management needs is an iterative engagement process that has involved workshops, regular meetings, and surveys. Stakeholder feedback was analyzed to identify the following most pressing needs for management scenarios to incorporate into the DSS:

Vulnerability Assessment	Provide access to information and maps detailing locations in the watershed susceptible to flooding, rapid runoff, erosion, and poor water quality
Climate Response	Enhance planning for climate change and response to local weather conditions including emergency response to flooding and spills
BMP Evaluation	Evaluate effectiveness of all best management practices (BMPs), considering specific watershed locations under various management scenarios
Stormwater Peak Shaving	Understand which BMPs best address peak shaving under different storm conditions using volume and rate controls

PROJECT APPLICATIONS - *Enhance Stormwater Decision Making*

Stormwater managers are typically tasked with making important decisions with a limited set of supporting data. The DSS will visualize current challenges within the watershed and future impacts of climate change, ultimately allowing managers to make more confident near- and long-term decisions about stormwater management and resource allocation. With the DSS, these decisions can be backed by historic and real-time data, leading to a greater ability to address issues such as flooding, erosion, and degraded water quality.

PHASE II ACCOMPLISHMENTS

A draft version of the DSS has been completed and was tested within the project team. A portion of this draft was presented to a subset of stakeholders for feedback, and revisions were made accordingly. In collaboration with the UM hydrologic modeling team, additional development and weather scenarios have been integrated into the DSS. Other additions to the DSS include consideration of county stormwater management plans and regulations, environmental justice concerns, and discussion of green stormwater infrastructure (GSI).

Stakeholders have indicated concern about the often high concentrations of *E. coli* in the Clinton River system; therefore, the DSS will now include information on *E. coli* dynamics for local managers to consider when making decisions about water safety. During Phase II, a team of UM researchers compiled and analyzed historical *E. coli* data and collected additional data in the field (Figure 4). This effort resulted in a better understanding of how *E. coli* responds to precipitation events in the Clinton River, including conditions when water quality standards are exceeded.

Figure 4. Sampling *E. coli* in the Clinton River
Source: UM Project Team

NEXT STEPS

The DSS development team will continue to integrate additional stakeholder feedback as it is received and make progress toward a refined version of the tool to be launched in 2022. Stakeholder testing of the finished tool is set to begin in early 2022, followed by appropriate revisions. Data from the real-time water sensor network will soon be integrated into the DSS, as will *E. coli* response information.

ACTIVITY #2: INTEGRATED HYDROLOGIC MODELING

Project collaborators from UM are developing multiple model scenarios that will be integrated in an innovative way to visualize hydrologic behavior of both groundwater and surface water. Outputs from two different models, SWAT and tRIBS, will be paired with a global circulation climate model of the Great Lakes region to develop a fully integrated hydrologic model that predicts a range of river discharge and climate change scenarios. These model outputs will inform the DSS. The team is integrating two modeling tools, which address different watershed parameters and challenges:

	SWAT	tRIBS
Stands For	Soil and Water Assessment Tool	TIN-Based Real-time Integrated Basin Simulator
Scale	Large scale, long term	Small spatial scale, short- to medium-term
Primary Focus	Land surface processes	Physical process interactions of surface-subsurface
Simulates	Water quantity impacts related to land use, land management, and climate change	Continuous hydrologic responses to both wet and dry weather conditions
Predicts	Hydrologic outcomes related to management practices and climate change scenarios	Runoff, infiltration, stream flow, and saturation scenarios in relation to weather events
Data Inputs	Weather inputs, elevation, soils, vegetation	Weather inputs, soils, vegetation, land cover, channel morphology
More Info	https://swat.tamu.edu/	http://vivoni.asu.edu/tribs.html

DATA SHARING & ACQUISITION

A large component of model development has involved compiling data to feed into the models. To ensure the most up-to-date and relevant data are utilized, data have been collected from multiple federal and state-level sources. Additionally, local stakeholders from Oakland and Macomb counties have shared watershed-specific data. To improve data access, the project team is creating a centralized data dictionary that outlines all available files and their sources. In addition to historic data, the team will also integrate new, real-time data from the project's sensor network to calibrate the model and assess model performance.

PROJECT APPLICATIONS - *Understand River Discharge Behavior*

Hydrologic modeling activities provide unique insights into the current and future behavior and management of stormwater. Modeling also adds clarity and certainty to decision-making in a seemingly complex and uncertain future. This insight allows decision makers to effectively address local needs and apply management practices that allow for the best use of natural and financial resources.

PHASE II ACCOMPLISHMENTS

The UM modeling team has obtained extensive hydro-meteorologic and physiographic data for the Clinton River Watershed and has used these data in model set-up, calibration, and validation. They have also successfully collected and processed trends in climate data for Southeastern Michigan to begin modeling climate change scenarios. After the team developed tools for uncertainty quantification and built a comprehensive GIS of the Clinton River Watershed, they built and tested a pilot hydrologic model for a small section of the Clinton River system. Results from this preliminary modeling were presented to stakeholders, and their feedback has been incorporated. Feedback will continue to be incorporated as the model is expanded from a sub-section of the watershed to the entire river system.

NEXT STEPS

The team will continue developing and running model simulations, which must be run multiple times to ensure an accurate representation of model outputs. In addition, collaboration with the MSU team will help identify which GSI scenarios can be represented in the hydrologic model. Once model simulations are complete, the highly technical model outputs will be simplified and integrated into the DSS in a way that is accessible to end users.

ACTIVITY #3: REAL-TIME FIELD-BASED SENSORS

In Phase I of the project, UM developed and deployed over 60 sensor units, also referred to as nodes, throughout the Clinton River Watershed. MSU also owns and maintains a handful of nodes in the river system (Figure 5). This network of real-time water level sensors is the largest in Michigan and one of the largest in the country. Node placement is determined with the help of recommendations from local water resource managers. Some of the nodes are strategically located in close proximity to USGS gage stations or in sub-watersheds of interest.

REAL-TIME DATA DASHBOARD

A team from UM has launched, and continues to maintain, a web-based platform to share open source real-time sensor data with local water resource managers, project contributors, and other stakeholders. The dashboard displays real-time water surface elevation and trends in fluctuating water levels for each of the nodes in the network (Figure 3). This dashboard gathers a tremendous amount of data from across the network, so the team continues to develop quality control measures to identify and remove abnormalities that may arise in the data. The dashboard has proven to be an efficient and accessible platform for translating real-time data to a broader network of stakeholders, and the UM team collaborates with these stakeholders to adjust the dashboard to better fit management needs. The dashboard is accessible at: maps.open-storm.org.

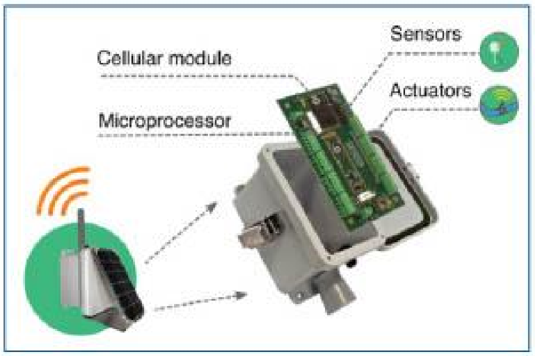


Figure 6. Node Technology | **Source:** open-storm.org

Figure 7. UM student servicing sensor node
Source: UM Project Team

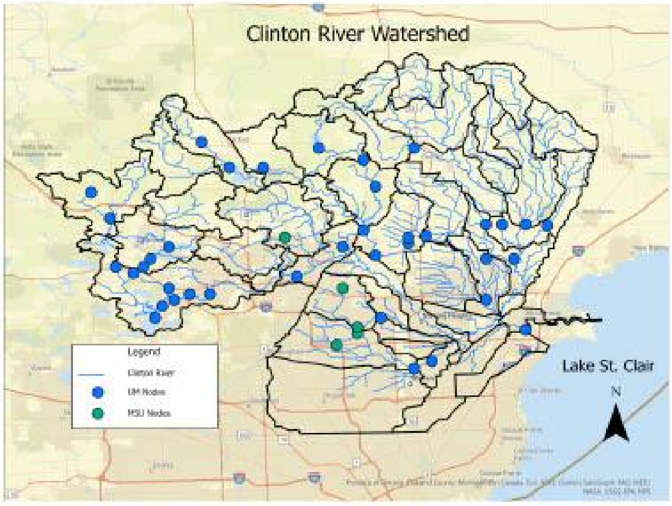


Figure 5. Clinton River Sensor Network | **Source:** Tim Marchman, UM

SENSOR NODE TECHNOLOGY

Each solar powered node contains a battery, a microprocessor, wireless technology, and depth sensors (Figure 6). A handful of the nodes can measure flow velocity and are being used in developing discharge rating curves, which will be used in the project's modeling efforts. Sensor nodes are designed with cost in mind, making the technology accessible for communities of all sizes. Currently, the university teams are the primary caretakers of the sensor network and continue to maintain and upgrade the nodes as needed. For more information on UM sensor technology, visit open-storm.org.

PROJECT APPLICATIONS - *Real-Time Insights*

When resource managers have access to real-time water quantity data, they can better understand flow capacity in their drainage network and react in real-time to precipitation events. Prior to this sensor network, decisions were based on only a few USGS streamflow gages and field observations. This sensor network allows for a more timely and effective response to pressing issues like potential localized flooding or spikes in *E. coli* concentrations. A long-term vision of this project is to employ further technologies alongside the sensor network that would allow managers to detain stormwater in real-time to manage the downstream flood peak. Additionally, Long-term continuous data collection from the sensors will begin to show patterns that, together with modeling outputs, will allow water resource managers to visualize and respond to long-term challenges related to land use practices, urbanization, and climate change.

ACTIVITY #3: REAL-TIME FIELD-BASED SENSORS *CONT.*

PHASE II ACCOMPLISHMENTS

During phase II, UM conducted maintenance work on the sensor network (Figure 7), which included swapping out 24 devices, firmware updates, battery replacements, modem upgrades, higher-performance SIM card installations, and a redesign to ensure batteries remain in place during transit of devices. These upgrades have resulted in greater connectivity, resiliency, and reliability of the network. The team also acquired, tested, and deployed a new stream flow and depth sensor into a Clinton River tributary to retrieve additional discharge data. The open-source dashboard website was published, so sensor data can now be easily viewed and accessed. Modifications to several core features of the server were made to accommodate updated software and the new node firmware. A real-time quality control engine was implemented into the dashboard, and most nodes are now reporting clean data with fewer data gaps and irregularities. MSU deployed additional nodes for a total of ten devices now in their network, and the team regularly visited each sensor for maintenance and data collection purposes. The MSU team also installed a weather station in the Clinton River Watershed in Bruce Township, which will collect additional weather data to support model calibration.

NEXT STEPS

The university teams will continue to maintain and monitor existing nodes and deploy additional sensors in new locations where stakeholders request further flow and discharge data. County partners will be asked to evaluate the dashboard for useability, and the team will continue to upgrade and make changes to the dashboard as evaluations are provided. Eventually, long-term maintenance responsibilities of the nodes will be transitioned to county officials who will be trained on how to repair and maintain the sensor nodes. After maintenance is fully transitioned, university team members will continue to provide technical support as needed.

ADDITIONAL RESOURCES

RELATED WEBSITES

- Michigan State University Institute of Water Research - https://www.egr.msu.edu/iwr/
- University of Michigan Real-Time Water Systems Lab - http://www-personal.umich.edu/~bkerkez/
- Clinton River Watershed Council - https://www.crwc.org/about/our-watershed/the-clinton-river-watershed

PROJECT CONTACTS

- MI Department of Environment, Great Lakes & Energy: Michelle Selzer, Project Officer, selzerm@michigan.gov
- University of Michigan: Kate Kusiak Galvin, Project Manager, kkusiakg@umich.edu
- Michigan State University: Jeremiah Asher, Assistant Director - Institute of Water Research, asherjer@msu.edu

This project is made possible through funding from the Great Lakes Restoration Initiative and collaborations with:

Appendix C

Final Phase II project factsheet from March 2021 by Megan DiCocco

SMART STORMWATER MANAGEMENT FOR THE CLINTON RIVER

PROJECT OVERVIEW & UPDATE: April 2022

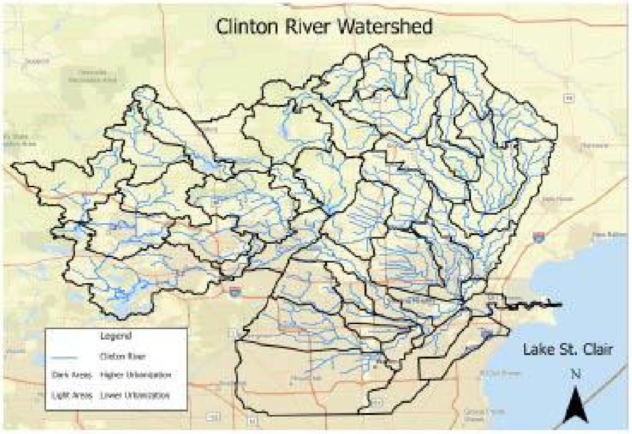


Figure 1. Clinton River system and its waterways
Source: Tim Marchman, University of Michigan

The Clinton River in Southeast Michigan (Figure 1) faces stormwater challenges related to urbanization and climate change. Urbanization produces increased impervious surfaces and drainage infrastructure which contribute to excessive stormwater runoff, flooding, and degraded water quality (elevated nutrients, sediments, pathogens, etc.). Southeast Michigan has seen shifting precipitation patterns as a result of climate change, including increased frequency and intensity of storm events. These changes further exacerbate challenges to, and uncertainties in, stormwater management. These problems threaten the ecological integrity of the Clinton River system and cause human health concerns.

Existing and emerging technologies, such as satellite communication, web-based tools, hydrologic sensors, and advanced computer modeling offer promising solutions to stormwater problems, but they are not often applied at the watershed scale. Since 2018, a team of interdisciplinary researchers and scientists from University of Michigan (UM) and Michigan State University (MSU) have collaborated with local water managers and the Michigan Department of Environment, Great Lakes, and Energy (EGLE) to provide technological resources for proactive and informed stormwater decision-making for the Clinton River. Project deliverables will serve as an innovative template for urban stormwater management across the Great Lakes Basin.

THE WATERSHED

The Clinton River Watershed covers 760 square miles in four different Michigan counties, and it is comprised of thousands of bodies of water and hundreds of miles of streams. As the most populated watershed in Michigan, the area is home to 71 communities, 1.5 million people, and a range of diverse plants and wildlife. River headwaters begin in rural Northern Oakland County, and the system ultimately drains into Lake St. Clair, which is part of the Great Lakes system.

Figure 2. Clinton River Restoration project at Yates Cider Mill
Source: Clinton River Watershed Council

The Clinton River system was designated an Area of Concern (AOC) by the EPA in 1987. Since then, the Great Lakes Restoration Initiative (GLRI) has provided more than $43 million to fund projects and restoration initiatives with the goal of delisting the Clinton River as an AOC. Local and regional communities and non-profit organizations also contribute significantly to improving and protecting the river through watershed management, restoration efforts, green infrastructure installation, and community engagement. For example, the Clinton River Watershed Council (CRWC) is restoring a 500-foot section of the Clinton River at Yates Cider Mill in Rochester Hills (Figure 2). This project will improve degraded aquatic and riparian habitats and make the area more enjoyable to the public.

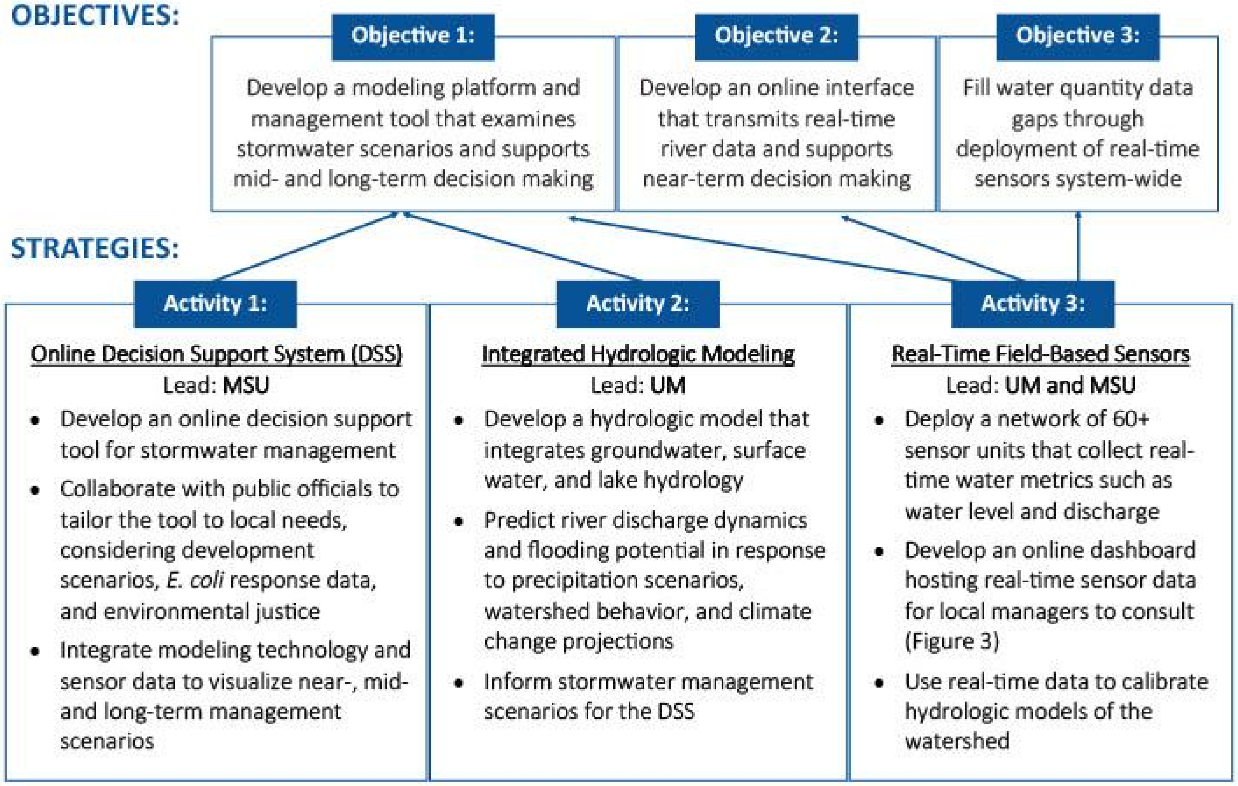
THE PROJECT

The Clinton River Smart Stormwater Management Project is a partnership between EGLE, UM, and MSU. The project, funded by GLRI, will demonstrate an ecologically based approach for managing rivers and streams in the Great Lakes Region impacted by urbanization and climate change. The project will provide a number of practical software tools and data sets to regional stakeholders, which can be used to effectively inform management actions needed to restore the Clinton River system.

PROJECT GOALS:

- To understand the hydrology of the Clinton River system and the stormwater management challenges facing local people, then apply this knowledge towards effective and equitable stormwater management
- To assemble and deliver a holistic stormwater management toolkit with innovative technologies to local water resource managers via partnerships between the science community and management professionals

OBJECTIVES:



Objective 1:

Develop a modeling platform and management tool that examines stormwater scenarios and supports mid- and long-term decision making

Objective 2:

Develop an online interface that transmits real-time river data and supports near-term decision making

Objective 3:

Fill water quantity data gaps through deployment of real-time sensors system-wide

STRATEGIES:

Activity 1:

Online Decision Support System (DSS)

Lead: **MSU**

- Develop an online decision support tool for stormwater management
- Collaborate with public officials to tailor the tool to local needs, considering development scenarios, *E. coli* response data, and environmental justice
- Integrate modeling technology and sensor data to visualize near-, mid- and long-term management scenarios

Activity 2:

Integrated Hydrologic Modeling

Lead: **UM**

- Develop a hydrologic model that integrates groundwater, surface water, and lake hydrology
- Predict river discharge dynamics and flooding potential in response to precipitation scenarios, watershed behavior, and climate change projections
- Inform stormwater management scenarios for the DSS

Activity 3:

Real-Time Field-Based Sensors

Lead: **UM and MSU**

- Deploy a network of 60+ sensor units that collect real-time water metrics such as water level and discharge
- Develop an online dashboard hosting real-time sensor data for local managers to consult (Figure 3)
- Use real-time data to calibrate hydrologic models of the watershed

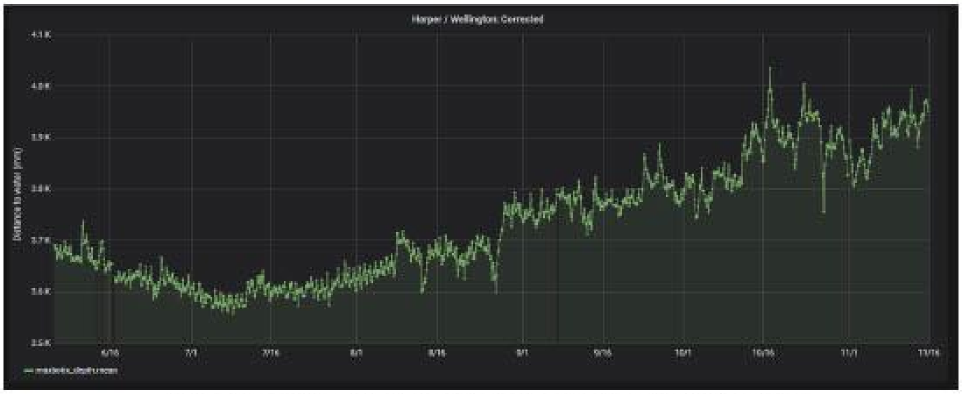


Figure 3. Real-time water level data from a sensor on the Clinton River at Harper Ave. and Wellington Cr. in Clinton Township (June - November 2020)

Source: open-storm.org

ACTIVITY #1: ONLINE DECISION SUPPORT SYSTEM

Project collaborators from MSU are leading the development of an online decision support system, or DSS, that will visualize certain stormwater management scenarios. The project team is actively collaborating with future DSS users to develop a system that is responsive to the needs of local decision makers in Oakland and Macomb counties. Responding to local management needs is an iterative engagement process that has involved workshops, regular meetings, and surveys. Stakeholder feedback was analyzed to identify the following most pressing needs for management scenarios to incorporate into the DSS:

Vulnerability Assessment	Provide access to information and maps detailing locations in the watershed susceptible to flooding, rapid runoff, erosion, and poor water quality
Climate Response	Enhance planning for climate change and response to local weather conditions including emergency response to flooding and spills
BMP Evaluation	Evaluate effectiveness of all best management practices (BMPs), considering specific watershed locations under various management scenarios
Stormwater Peak Shaving	Understand which BMPs best address peak shaving under different storm conditions using volume and rate controls

PROJECT APPLICATIONS - *Enhance Stormwater Decision Making*

Stormwater managers are typically tasked with making important decisions with a limited set of supporting data. The DSS will visualize current challenges within the watershed and future impacts of climate change and urbanization, ultimately allowing managers to make more confident near- and long-term decisions about stormwater management and resource allocation. With the DSS, these decisions can be backed by historic and real-time data, leading to a greater ability to address issues such as flooding, erosion, and degraded water quality.

PHASE II ACCOMPLISHMENTS

A draft version of the DSS has been completed and was *Alpha* tested within the project team. A portion of this version was presented to stakeholders for feedback, and revisions were made accordingly. In collaboration with the UM hydrologic modeling team, additional development and weather scenarios have been integrated into the DSS. Other additions to the DSS include consideration of county stormwater management plans and regulations, environmental justice concerns, and discussion of green stormwater infrastructure (GSI).

Stakeholders have indicated concern about the often high concentrations of *E. coli* in the river system; therefore, the DSS now includes information on *E. coli* dynamics for local managers to consider when making decisions about water safety. During Phase II, a team of UM researchers compiled historical *E. coli* data and collected additional data in the field (Figure 4). This work provided a better understanding of how *E. coli* responds to precipitation events in the Clinton River, including conditions when water quality standards are exceeded.

Figure 4. Sampling *E. coli* in the Clinton River
Source: UM Project Team

NEXT STEPS

The DSS development team will continue to integrate additional stakeholder feedback and make progress toward a refined version of the tool to be launched in 2022. Once the tool is launched, the project team will host a training webinar to introduce end-users to the DSS and showcase its features.

ACTIVITY #2: INTEGRATED HYDROLOGIC MODELING

Project collaborators from UM are developing multiple model scenarios that will be integrated in an innovative way to visualize hydrologic behavior of both groundwater and surface water. Outputs from two different models, SWAT and tRIBS, will be paired with a global circulation climate model of the Great Lakes region to develop a fully integrated hydrologic model that predicts a range of river discharge and climate change scenarios. These model outputs will inform the DSS. The team is integrating two modeling tools, which address different watershed parameters and challenges:

	SWAT	tRIBS
Stands For	Soil and Water Assessment Tool	TIN-Based Real-time Integrated Basin Simulator
Scale	Large scale, long term	Small spatial scale, short- to medium-term
Primary Focus	Land surface processes	Physical process interactions of surface-subsurface
Simulates	Water quantity impacts related to land use, land management, and climate change	Continuous hydrologic responses to both wet and dry weather conditions
Predicts	Hydrologic outcomes related to management practices and climate change scenarios	Runoff, infiltration, stream flow, and saturation scenarios in relation to weather events
Data Inputs	Weather inputs, elevation, soils, vegetation	Weather inputs, soils, vegetation, land cover, channel morphology
More Info	https://swat.tamu.edu/	http://vivoni.asu.edu/tribs.html

DATA SHARING & ACQUISITION

A large component of model development has involved compiling data to feed into the models. To ensure the most up-to-date and relevant data are utilized, data have been collected from multiple federal and state-level sources. Additionally, local stakeholders from Oakland and Macomb counties have shared watershed-specific data. To improve data access, the project team is creating a centralized data dictionary that outlines all available files and their sources. In addition to historic data, the team will also integrate new, real-time data from the project's sensor network to calibrate the model and assess model performance.

PROJECT APPLICATIONS - *Understand River Discharge Behavior*

Hydrologic modeling provides insights into the current and future behavior of stormwater, thereby adding clarity and confidence to management decision-making considering a complex and uncertain future. Decision makers can use models to effectively leverage natural and financial resources to address local needs.

PHASE II ACCOMPLISHMENTS

The UM modeling team obtained extensive hydro-meteorologic and physiographic data for the Clinton River Watershed and developed tools for uncertainty quantification in modeling. They then built a comprehensive GIS of the Clinton River Watershed and a pilot hydrologic SWAT model for a small section of the Clinton River system. Results from this preliminary modeling were presented to stakeholders, and their feedback was incorporated towards production of a model of the entire river system. This full model has been calibrated and validated. The team also collected and processed trends in climate data for Southeastern Michigan to model hundreds of future climate change scenarios at local and watershed scales.

NEXT STEPS

Once all model simulations are complete, the highly technical model outputs will be simplified and integrated into the DSS in a way that is accessible to end users. All climate change scenarios will also be analyzed and fed into the DSS. The UM team will collaborate with the MSU DSS team to identify which GSI scenarios can be represented in the hydrologic model down the line.

ACTIVITY #3: REAL-TIME FIELD-BASED SENSORS

In Phase I of the project, UM developed and deployed over 60 sensor units, also referred to as nodes, throughout the Clinton River Watershed. MSU also owns and maintains a handful of nodes in the river system (Figure 5). This network of real-time water level sensors is the largest in Michigan and one of the largest in the country. Node placement is determined with the help of recommendations from local water resource managers. Some of the nodes are strategically located in close proximity to USGS gage stations or in sub-watersheds of interest.

REAL-TIME DATA DASHBOARD

A team from UM has launched, and continues to maintain, a web-based platform to share open source real-time sensor data with local water resource managers, project contributors, and other stakeholders. The dashboard displays real-time water surface elevation and trends in fluctuating water levels for each of the nodes in the network (Figure 3). This dashboard gathers a tremendous amount of data from across the network, so the team continues to develop quality control measures to identify and remove abnormalities that may arise in the data. The dashboard has proven to be an efficient and accessible platform for translating real-time data to a broader network of stakeholders, and the UM team collaborates with these stakeholders to adjust the dashboard to better fit management needs. The dashboard is accessible at: maps.open-storm.org.

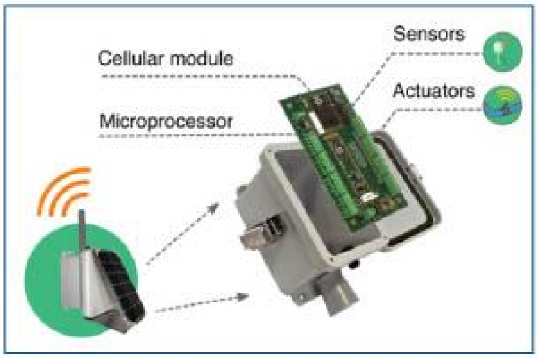


Figure 6. Node Technology | **Source:** open-storm.org

Figure 7. UM student servicing sensor node
Source: UM Project Team

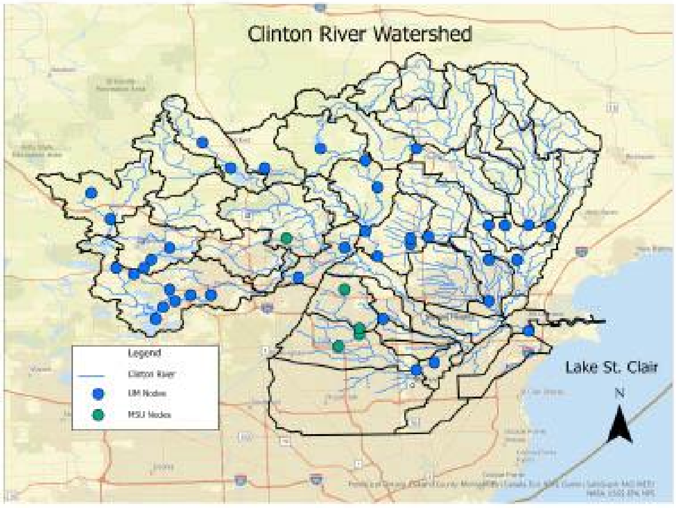


Figure 5. Clinton River Sensor Network | **Source:** Tim Marchman, UM

SENSOR NODE TECHNOLOGY

Each solar powered node contains a battery, a microprocessor, wireless technology, and depth sensors (Figure 6). A handful of the nodes can measure flow velocity and are being used in developing discharge rating curves, which will be used in the project's modeling efforts. Sensor nodes are designed with cost in mind, making the technology accessible for communities of all sizes. Currently, the university teams are the primary caretakers of the sensor network and continue to maintain and upgrade the nodes as needed. For more information on UM sensor technology, visit open-storm.org.

PROJECT APPLICATIONS - *Real-Time Insights*

When resource managers have access to real-time water quantity data, they can better understand flow capacity in their drainage network and react in real-time to precipitation events. Prior to this sensor network, decisions were based on only a few USGS streamflow gages and field observations. This sensor network allows for a more timely and effective response to pressing issues like potential localized flooding or spikes in *E. coli* concentrations. A long-term vision of this project is to employ further technologies alongside the sensor network that would allow managers to detain stormwater in real-time to manage the downstream flood peak. Additionally, Long-term continuous data collection from the sensors will begin to show patterns that, together with modeling outputs, will allow water resource managers to visualize and respond to long-term challenges related to land use practices, urbanization, and climate change.

ACTIVITY #3: REAL-TIME FIELD-BASED SENSORS *CONT.*

PHASE II ACCOMPLISHMENTS

During phase II, UM conducted maintenance work on the sensor network (Figure 7), which included swapping out 27 devices, firmware updates, battery replacements, modem upgrades, higher-performance SIM card installations, and a redesign to ensure batteries remain in place during transit of devices. These upgrades have resulted in greater connectivity, resiliency, and reliability of the network. The team also deployed a new high-tech stream flow and depth sensor into a Clinton River tributary to retrieve additional data. The open-source dashboard website was published, so sensor data can now be easily viewed and accessed. Modifications to several core features of the server were made to accommodate updated software and the new node firmware. A real-time quality control engine was implemented into the dashboard, and most nodes are now reporting clean data with few data gaps and irregularities. UM also created custom sensor data dashboards for partners in Oakland and Macomb Counties to increase dashboard useability, where the team has started to incorporate elevation data and legal lake level information. MSU deployed additional nodes for a total of ten devices now in their network, and the team regularly visited each sensor for maintenance and data collection purposes. The MSU team also installed a weather station in the Clinton River Watershed in Bruce Township, which will collect additional weather data to support hydrologic model calibration.

NEXT STEPS

The university teams will continue to monitor and upgrade existing nodes and to deploy additional nodes in locations where stakeholders request further data. County partners will be asked to evaluate the dashboard for useability, and project teams will continue to modify the dashboard as evaluations are provided. Eventually, long-term maintenance responsibilities of the nodes will be transitioned to county officials who will be trained to repair and maintain the nodes. After maintenance is fully transitioned, university team members will continue to provide technical support as needed.

ADDITIONAL RESOURCES

RELATED WEBSITES

- Michigan State University Institute of Water Research - https://www.egr.msu.edu/iwr/
- University of Michigan Real-Time Water Systems Lab - http://www-personal.umich.edu/~bkerkez/
- Clinton River Watershed Council - https://www.crwc.org/about/our-watershed/the-clinton-river-watershed

PROJECT CONTACTS

- MI Department of Environment, Great Lakes & Energy: Michelle Selzer, Project Officer, selzerm@michigan.gov
- University of Michigan: Kate Kusiak Galvin, Project Manager, kkusiakg@umich.edu
- Michigan State University: Jeremiah Asher, Assistant Director - Institute of Water Research, asherjer@msu.edu

This project is made possible through funding from the Great Lakes Restoration Initiative and collaborations with:

Appendix D

Evaluation Tools for the Clinton River Smart Stormwater Management Project:

External Interview Guide

Stakeholder Survey

Stakeholder Interview Guide

Internal Evaluation Interview Guide

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The University of Michigan, School for Environment and Sustainability

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1 External Interviews

1.1 Overview

Clients and researchers of the Clinton River Smart Stormwater Management Project are interested in potential extensions of the project to other watersheds in Michigan. The project has been very successful in the Clinton River, but more information is needed on the interest and applicability of this type of project in other areas. The following contains protocol and an interview guide for discussions with water management and conservation organizations outside of the Clinton River Watershed to assess the applicability of the Clinton River Smart Stormwater Management Project to other urbanized watersheds in Michigan.

Interview data are to be synthesized into a report for Michelle Selzer at the Michigan Department for Environment, Great Lakes, and Energy (EGLE). The interviews support the larger Clinton River Smart Stormwater Management Project funded by the Great Lakes Restoration Initiative (GLRI) and carried out by the Michigan EGLE, the University of Michigan, and the Michigan State University Institute for Water Research.

Interviews are to be held with other Southeast Michigan groups working on watershed-level management or conservation. They can be held via Zoom and recorded for later transcription and analysis

1.2 Research Questions

The following research questions are the main questions MI EGLE seeks to answer and the main topics they would like to better understand by completing the interviews. These are not the questions to directly ask any interview participant. Use these questions to frame your thoughts about the interview process - the questions to actually ask interview participants can be found in the interview guide in section 1.4.

1. Is this project and its deliverables applicable to other watersheds in Michigan (especially Southeast MI)?
    a. What tools do other watersheds currently use to manage stormwater challenges, and are these tools adequate?
    b. Would a Decision Support System or a sensor network similar to those in the Clinton be valuable to water resource managers in other watersheds?
        i. Specifically, which functions of the deliverables would be most useful or necessary to other watershed managers in addressing stormwater issues?

1.3 Potential Participants

In order to assess the applicability of this project to other watersheds in the state, the project team should leverage existing connections and networks to host conversations with local and regional organizations. Table 1 provides potential organizations to reach out to for interviews. The project already has contacts at some of these organizations, so interviewers should collaborate with Michelle Selzer, the project manager, and project Principal Investigators (PIs) to determine best interview candidates before reaching out with an interview invitation.

Organization
Great Lakes Water Authority (GLWA)
Alliance of Downriver Watersheds
Alliance of Rouge Communities (ARC)
Friends of the Rouge
Huron River Watershed Council
SEMCOG

Table 1. A list of suggested organizations to reach out to for external interviews. Project team members may have specific contacts at these organizations.

1.4 Interview guide

The following guide contains protocol for before, during, and after external interviews.

Before Interview:

- Reach out to potential participants via email
    - Explain who you are, why you are requesting an interview with them specifically, and how their participation can help watershed management and conservation in Michigan.
    - Let them know that results from this voluntary interview will not be made public and tell them exactly who will be seeing results.
    - Provide the project factsheet in the email.
- Obtain informed consent from the interviewee, schedule interview time and send calendar invite with Zoom info
- Ensure participants are okay with being recorded ahead of time, and let them know who will be seeing the recording or reading the transcription.

During interview:
Before beginning questions, confirm again that the participant is okay with being recorded, and remind them how long the interview may take (no more than an hour).

- Record meeting to the cloud or to personal computer
- Enable live transcript

Give brief introduction of the project and the purpose of today's interview

- Interview Purpose: "Thank you for agreeing to participate in this informal interview. My name is ____ and I am a _____. The purpose of this interview is to assess the applicability and potential value of the deliverables of the Clinton River Smart Stormwater Management Project to other watersheds in Michigan."
- Brief Project Intro: "I hope you had a chance to look over the Project Factsheet we provided in the initial email, but if not I will provide a brief introduction to the Clinton River Smart Stormwater Management Project.

Questions:

1. What kind of stormwater management challenges does your particular watershed face?
2. What tools are currently in use in your region to help water resource managers make short-term and long-term decisions about stormwater?
    a. Would you say these tools are adequate? Why or why not
    b. Probing questions: What are they doing well? What is lacking?

Explain to participants that you will now be demonstrating a stormwater management tool created for the Clinton River Watershed in Southeast Michigan and share your screen.
Clinton River Decision Support System

Briefly walk through tour feature giving overview and pulling out main examples of use

3. The tour feature provides narratives for the public and context about the watershed for water resource managers. How would a narrative tour feature like this of your watershed be helpful in your communication with the public or water resources managers?

Walk through managing water volume tool

4. This field-scale analysis helps managers explore how land cover change impacts runoff. How would a similar tool for your watershed be helpful to you in your work or for water resource managers in your region?

Walk through watershed-scale analyses of climate impacts

5. Would it be helpful to you or to water managers in your region to be able to visualize predicted climate change scenarios in this way? Why or why not?

Walk through the real-time monitoring dashboard, explaining the sensor network created by Dr. Branko Kerkez and its uses.

6. Could you see yourself or others at your organization using a real-time sensor network and dashboard like this, and how would this be helpful to you?

7. Overall, how well do you feel this DSS could be applied to your watershed?
8. Are there features of the DSS you would change to make it more usable or applicable to your watershed?
9. What other technologies would you like to see further developed or leveraged to help watersheds in Michigan and the Great Lakes Basin manage stormwater challenges?
10. We will now move into open discussion and feedback. Is there anything else you'd like to add about the applicability of this tool? Do you have any questions for me?

Tell the participant they can reach out to you via email if they have any remaining questions or comments in the coming days. Thank them.

Once recording and transcription has been exported, save it to a safe place for easy access during analysis and compilation for the final report.

-End of External Interview Guide-

2 Stakeholder Survey

2.1 Overview

The following contains protocol for conducting a survey of stakeholders for the Clinton River Smart Stormwater Management Project, which will assess the value and useability of project deliverables. Before taking this survey, stakeholders should already be familiar with the Decision Support System (DSS) and/or the real-time sensor network, or even already use these deliverables in their work. This survey should be sent to all stakeholders who participated in the stakeholder working group meetings or are known to be using project deliverables in their current work. A subset of these stakeholders who were most intimately involved in the development of the project, or who are actively using project deliverables most often, will be interviewed about similar topics (see section 3). These interviews will provide deeper insight and feedback about project deliverables in a more conversational setting.

Survey data are to be synthesized with stakeholder interview data into a report for Michelle Selzer at the MI EGLE. The survey and interviews support the larger Clinton River Smart Stormwater Management Project funded by the GLRI and carried out by the Michigan EGLE, the University of Michigan, and the Michigan State University Institute for Water Research.

2.2 Research Questions

The following research questions are the main questions MI EGLE seeks to answer and the main topics they would like to understand by surveying and interviewing stakeholders. These are not the questions to be built into the survey. Use these questions to frame your thoughts about the survey process - actual survey questions can be found in section 2.4.

1. Are the project deliverables helpful and valuable to users?
   a. Do users need these products?
   b. Do they see themselves using these products and how?
2. Were user expectations met?
   a. What functions were stakeholders expecting the DSS to have? Does it have them?
   b. What functionality and data were users expecting from the sensor network? Did it deliver?
3. Would an additional phase of this project be valuable to users?
   a. What features of the DSS or sensor network would users like to be added, refined, and/or polished if a future phase was developed?
   b. How could this team continue to transition products and deliverables to stakeholder management?

2.3 Potential Participants

The project team is seeking a population of survey participants who were involved in the stakeholder working group meetings throughout Phase I and Phase II of the project, or those who use the DSS or real-time sensor network in their work. This will include water resource managers from Oakland and Macomb Counties, officials at the Southeast Michigan Council of Governments (SEMCOG), municipal water managers, conservation practitioners, and more. Metrics and feedback from these populations will help assess the applicability, usability, and usefulness of deliverables. Interviewers should collaborate with the project manager, PIs, Michelle Selzer, and other clients to determine best survey candidates. A potential list can be found in this directory. Project team members have the most up to date directory and contacts.

2.4 Survey Questions

The survey questions (Table 2) can be built in a basic Survey Monkey template, or into Qualtrics. Qualtrics is suggested if approved and accessible. University of Michigan project team members can access Qualtrics at this link. When building this survey, title it "Clinton River Smart Stormwater Management" and be sure to add a description of the survey and its purpose on the title page. Note to respondents that the survey is anonymous and voluntary.

Table 2. Survey questions to be built into a survey platform such as Qualtrics or Survey Monkey. Table gives question type, answer options (if applicable), and other notes surveyors should know when building the survey.

#	Question	Type	Answer options (if applicable)	Notes
1	Your name (optional):	Short text box	N/A	Make this question optional
2	Your organization:	Short text box	N/A	
3	Your title:	Short text box	N/A	
4	How familiar are you with the Clinton River Decision Support System? (link to DSS)	Multiple choice	● Very familiar ● Somewhat familiar ● I have heard of the decision support system, but I have never used it ● Not at all familiar	Link to the DSS

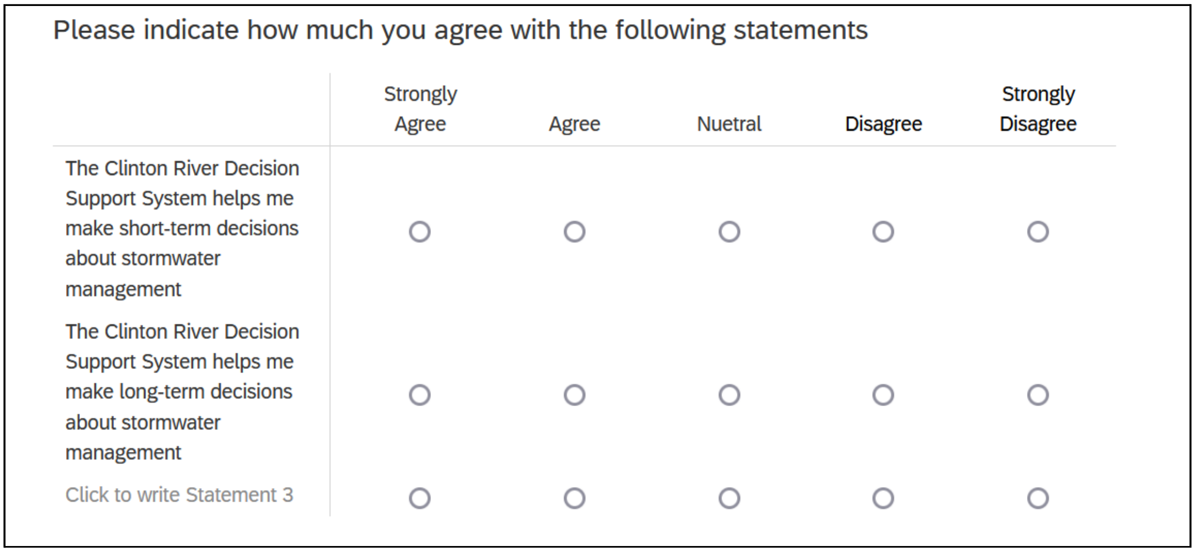
5	Which of the following features of the Clinton River Decision Support System have you used in your work? (check all that apply)	Checkboxes	● Field-scale analysis of runoff ● Urbanization sensitivity ● Watershed-scale analyses of climate impacts ● *E. coli* risk analysis and prediction ● Real-time monitoring dashboard ● Watershed tour ● Other (please describe)	
6	Of the features of the decision support system you have used, which one has been the most useful or valuable to you?	Multiple choice	● Field-scale analysis of runoff ● Urbanization sensitivity ● Watershed-scale analyses of climate impacts ● *E. coli* risk analysis and prediction ● Real-time monitoring dashboard ● Watershed tour ● Other (please describe)	
7	In a few words, please describe what the feature you chose in the question above helps you to accomplish.	Short text box	N/A	
8	Please indicate how much you agree with the following statements: -The Clinton River Decision Support System helps me make **short-term** decisions	matrix	Strongly agree Agree Neutral Disagree Strongly disagree N/A	Figure 1 Shows and example of this matrix for clarification

	about stormwater management -The Clinton River Decision Support System helps me make **long-term** decisions about stormwater management -The Clinton River Decision Support System is valuable to the work being done at my organization -The decision support system includes tools I have never before had access to in the Clinton River system -The decision support system helps me to better understand stormwater dynamics and processes in my watershed -The decision support system helps me communicate with **the public** about stormwater management challenges or decisions -The decision support system helps me communicate with **colleagues** about stormwater management challenges or decisions -The decision support system is user friendly and intuitive to navigate -I will use the decision support system in my future work to make stormwater management decisions			
9	Were you involved in the development of the Clinton River Decision Support	Multiple choice	● Yes ● No	

	System as part of the project's stakeholder working group?			
9a*	How much do you agree with the following statement? The Decision support system has the features and functions I was expecting it to have based on my prior communication with the development team	Multiple choice	● Strongly agree ● Agree ● Neutral ● Disagree ● Strongly disagree ● N/A	*If using Qualtrics, use a logic display so that this question only appears if the respondent answered YES to question #9.
10	What features or functions could be added to the decision support system to be more valuable or useful to you?	Open text box	N/A	
11	How familiar are you with the real-time sensor network in the Clinton River system? (link)	Multiple choice	● Very familiar ● Somewhat familiar ● I have heard of the sensor network, but I have never used it ● Not at all familiar	Link to the dashboard or Branko's open-storm.com site
12	Have you used the real-time sensor network to make water management decisions?	Multiple choice	● Yes ● No ● N/A	
13	Please indicate how much you agree with the following statements -The real-time sensor network provides valuable information to help me make water management decisions -The real-time sensor network	matrix	Strongly agree Agree Neutral Disagree Strongly disagree N/A	Just like question 8, see image below table to set up matrix

	provides information which I previously did not have access to in the Clinton River system -The locations of the sensors in the network are useful to me or my organization -The real-time sensor network provides clean, trustworthy data -The real-time sensor network dashboard/website is easy to access and navigate -I will use the real-time sensor network in my future work and/or decision making			
14	Were you involved in the development of the Clinton River real-time sensor network (including providing input on sensor locations)?	Multiple choice	● Yes ● No	
14a *	How much do you agree with the following statement? The real-time sensor network and dashboard have the features and functions I was expecting them to have based on my prior communication with the development team	Multiple choice	● Strongly agree ● Agree ● Neutral ● Disagree ● Strongly disagree ● N/A	*If using Qualtrics, use a logic display so that this question only appears if the respondent answered YES to question #14.
15	What features or functions could be added to the real-time sensor network and/or dashboard for them to	Open text box	N/A	

	be more valuable or useful to you?			
16	Are you interested in receiving further training or instruction on the use of the sensor network and/or decision support system?	Multiple choice	- Yes - No - N/A	
17	What further tools or technologies would you like to see applied in the Clinton River Watershed to aid in stormwater decision making and management?	Open text box	N/A	
18	Thank you for your time spent on this survey and the responses you provided! If you would like a project team member to follow-up with you about your responses, please provide your email below.	Open text box	N/A	



Please indicate how much you agree with the following statements

	Strongly Agree	Agree	Nuetral	Disagree	Strongly Disagree
The Clinton River Decision Support System helps me make short-term decisions about stormwater management	○	○	○	○	○
The Clinton River Decision Support System helps me make long-term decisions about stormwater management	○	○	○	○	○
Click to write Statement 3	○	○	○	○	○

Figure 1. Example of a matrix question in Qualtrics used in questions 8 and 13.

-End of Stakeholder Survey-

3 Stakeholder Interview Guide

3.1 Overview

The following contains protocol and an interview guide for discussions with a subset of stakeholders of the Clinton River Smart Stormwater Management Project to assess the value and useability of project deliverables. Before participating in an interview, stakeholders should already be familiar with the Decision Support System (DSS) and/or the real-time sensor network, or even already using these deliverables in their work. While the stakeholder survey in section 2 should be sent to all stakeholders who participated in the stakeholder working group meetings or are known to be using project deliverables in their current work, these interviews should be held with a subset of stakeholders who were most intimately involved in the development of the project or who are actively using project deliverables most often. These interviews will provide deeper insight and feedback about project deliverables in a more conversational setting.

Interview data is to be synthesized with stakeholder survey data (see section 2) into a report for the client at the Michigan Department for Environment, Great Lakes, and Energy. The interviews support the larger Clinton River Smart Stormwater Management Project funded by the Great Lakes Restoration Initiative and carried out by the Michigan EGLE, the University of Michigan, and the Michigan State University Institute for Water Research.
The interviews can be conducted via Zoom and recorded for later transcription and analysis.

3.2 Research Questions

See section 2.2, as research questions for the stakeholder survey also pertain to these interviews.

3.3 Potential Participants

While the stakeholder survey (found in section 2) should be sent to most or all of the stakeholder working group, these stakeholder interviews should only be held with a subset of the working group. Interviewers should collaborate with the project manager, PIs, and clients to select those interviewees most familiar with the DSS and the project in general (Phase I and/or Phase II) (Table 3).

Table 3. List of potential organizations and contacts to reach out to for stakeholder interviews.

Organization	Project contact
Oakland County Public Works or water resources division	Anne Vaara, Jim Wineka, Joel Kohn
Macomb County Public Works or water resources division	Jeff Bednar, Karen Czernel, Stacey McFarlane
Clinton River Watershed Council	Eric Diesing

SEMCOG	Kelly Karll

3.4 Interview guide

Before Interview:

- Reach out to potential participants via email
- Explain who you are, why you are requesting an interview with them specifically, and how their participation can help the project team assess the value of their deliverables and to further develop useful products for the Clinton River.
- Let them know that results from this voluntary interview will not be made public and tell them exactly who will be seeing results.
- Obtain informed consent from the interview, schedule interview time and send calendar invite with Zoom info
- Ensure participants are okay with being recorded ahead of time, and let them know who will be seeing the recording or reading the transcription.

During Interview:

Be prepared to share your screen and navigate the Decision Support System and real-time sensor dashboard if necessary.

Before beginning questions, confirm again that the participant is okay with being recorded, and remind them how long the interview may take (no more than an hour).

- Record meeting to the cloud or to personal computer
- Enable live transcript

Introduce yourself and reiterate the purpose of today's interview

- “Thank you for agreeing to participate in this informal interview. My name is ____ and I am a _____. The purpose of this interview is to assess the applicability, usability, and value of the deliverables of the Clinton River Smart Stormwater Management Project.”

Questions:

1. Can you please state your name, organization, and title for the recording
2. How familiar are you with the Clinton River Decision Support System (DSS)?
    a. Probing questions: do you use it in your work? How often do you use it? Have you been involved in the development and if so, since when?
3. Which tools/features of the DSS do you (or your organization) use most often and in what way?
    a. Be prepared to jog their memory of tools of the DSS and share screen if needed.
4. How is the information you receive from these tools/features valuable to your work or the work of your organization?
5. Does the DSS have the features and functionality you were expecting it to have based on your prior communication with the project team?

    a. If no - did you receive an explanation on why the project team wouldn't be able to integrate a particular tool or feature?
6. Do you feel the DSS is user-friendly and easy to navigate? If not, why?
7. What features or functions could be added to the decision support system to make it more valuable or useful to you or your organization?
8. How do you see the DSS as part of your, or your organization's, future?
9. How familiar are you with the real-time sensor network?
    a. If familiar - How often do you use it and how?
10. Are the data from the sensor network useful to you or your organization?
    a. If not, how could they be improved?
11. Are the locations of the sensors applicable to your work? Or what locations would be more useful to you to see real-time water height at?
    a. Be prepared to share sensor dashboard website and share screen if needed.
12. Is the real-time sensor dashboard easy to access and navigate? If not, please explain.
13. Does the sensor network have the features and functionality you were expecting it to have based on your prior communication with the project team?
    a. If no - did you receive an explanation on why the project team wouldn't be able to integrate a particular feature?
14. What features or functions could be added to the real-time sensor network and/or dashboard for it to be more valuable or useful to you?
15. How do you see the sensor network as part of your, or your organization's, future?
16. What further tools or technologies would you like to see applied in the Clinton River Watershed to aid in stormwater decision making?
17. Overall, what is your general impression of the Clinton River Smart Stormwater Management Project?
    a. Probing suggestion: "you could give a few words or feelings that come to mind when you think of the project or you could perhaps comment on the value of deliverables, the team's stakeholder engagement, the project's future potential, etc."
18. Is there anything else related to these topics that you would like to discuss today? Or do you have any questions for me?

Tell the participant they can reach out to you via email if they have any remaining questions or comments in the coming days. Thank them.

Once recording and transcription has been exported, save it to a safe place for easy access during analysis and compilation for the final report.

-End of Stakeholder Interview Guide-

4 Internal Evaluation Interviews

4.1 Overview

The following contains protocol and an interview guide for internal evaluation discussions with PIs and key team members of the Clinton River Smart Stormwater Management Project. These interviews will give insight into the way the project team runs and communicates to determine what can be improved. Interviews should be conducted by the project manager, someone from the project manager's team, or someone similarly positioned.

Interview data is to be summarized into a report for the project manager and Michelle Selzer at the Michigan Department for Environment, Great Lakes, and Energy.

A round of these interviews was conducted during Phase II of the project in December 2021 and January 2022 by M. DiCocco, University of Michigan, School for Environment and Sustainability. Findings from this first round of interviews can be found in the UM SEAS final capstone report entitled *Supporting project integration and translation: Clinton River Smart Stormwater Management* (which can be accessed through the Deep Blue at UM), as well as with the project manager Kate Kusiak-Galvin and the MI EGLE client Michelle Selzer. Results from subsequent rounds of interviews can be compared with the results from the first round of interviews if deemed helpful.

Interview questions found in section 4.4 may need modification depending on when the interviewee started on the project and their position on the team.

4.2 Research Questions

The following research questions are the main questions MI EGLE is interested in answering and the main topics they are trying to understand by interviewing project team members. These questions are not the questions to actually ask any interview participant. Use these questions to frame your thoughts about the survey process - actual survey questions can be found in section 4.4.

1. Were original project goals understood and achieved?
    a. Did the team progress through tasks efficiently and effectively?
    a. Were subteam members held accountable to the project overall, and how?
    b. Was the team able to make adjustments in the face of adversity to overcome setbacks and obstacles?
2. Is the project management team valuable to the PIs and other team members?
    a. Does the management team improve project communication, cohesion, and productivity?
3. What could be improved about project management or communication?

    a. Did any communication or intra-project connectivity issues impede the completion of tasks?

4.3 Potential Participants

Interviews should be conducted with all PIs as well as select key team members from each subteam and institution involved in the project. Table 4 shows potential participants based off of Phase II involvement, but as these involvements may change, interviewers should coordinate with the project manager and the client to determine the best interview participants.

Table 4. Shows potential participants in the internal evaluation interviews and their role within the project. It also denotes which individuals participated in the first round of these interviews in January 2022.

Name	Organization/subteam
Branko Kerkez, PI*	UM; sensor network
Valeriy Ivanov, PI*	UM; hydrologic modeling
Jeremiah Asher, PI*	MSU IWR; DSS & stakeholder engagement
Paul Seelbach	UM SEAS; project management
Kate Kusiak Galvin	UM SEAS; project management
Mike Thomas*	MSU IWR; DSS & stakeholder engagement
Glenn O'Neil*	MSU IWR; DSS & stakeholder engagement
Meagan Tobias*	UM; sensor network
Weichen Huang	UM; hydrologic modeling
Kevin Murphy	UM; hydrologic modeling

*Team member participated in the first round of interviews during Phase II.

4.4 Interview Guide

Before Interview:

- Reach out to potential participants via email
- Explain who you are if the team member does not know you, why you are requesting an interview with them specifically, and how their participation can provide vital feedback to the team to help improve project efficiency, communication, connectivity, and productivity.

- Let them know that results from this voluntary interview will not be made public and tell them exactly who will be seeing results.
- Obtain informed consent from the interview, schedule interview time and send calendar invite with Zoom info
- Ensure participants are okay with being recorded ahead of time, and let them know who will be seeing the recording or reading the transcription.

During interview:
Before beginning questions, confirm again that the participant is okay with being recorded, and remind them how long the interview may take (no more than an hour).

- Record meeting to the cloud or to personal computer
- Enable live transcript

Remind the participant that this discussion will be focused around team communication, connection, and project management. Responses will be anonymously synthesized into a report for clients at MI EGLE and the project manager.

Questions:

1. To start, please state which institution or team you work on for this project? And briefly describe your role and what deliverable you primarily work on?
2. When did you begin working on this project?

Inter-institution communication - this first set of questions all relate to communication with project members outside of your team. When I say “subteam” I mean the three teams working on the three different deliverables (modeling team, MSU DSS team, and UM sensor network team)

3. How often do you communicate with team members from the other subteams, especially the teams at the other institution (UM/MSU), about project tasks and in what form do you communicate with them?
4. Overall, how has this inter-institution communication been useful or impactful to your project work?
5. Do you feel that the project management team has had an impact on your connection with other subteam members?
    a. If yes, could you give a specific example of how the project management team impacted communication, connection, or productivity?
6. What would you change about the way the subteams communicate with each other, or what can we do as a team to communicate more effectively?

Progression through project work/tasks - This next set of questions relate to productivity and progression through tasks.

7. Within your subteam how were team members held accountable for progressing through tasks and milestones?
    a. Probing questions: Were deadlines for tasks or progress set and adhered to? How did the team keep track of milestones?
8. How were team members held accountable to <u>whole </u>project tasks and milestones <u>overall</u>?
9. Can you think of any situations during the current phase when a team communication or connectivity issue hindered your progress on this project?
    a. If yes, describe what happened and if/how it was resolved
        i. Could the project management team have helped with this? What could have been done differently, etc.
10. How did the project team overall make adjustments in the face of adversity to overcome setbacks and obstacles?

Stakeholder Interaction - this set of questions relates to stakeholder engagement

11. How often do you interact with stakeholders and in what way?
12. What have you learned about stakeholder needs through these interactions?
13. Do you feel that the project management team facilitates your engagement with the stakeholders and their interests? If yes, how?
14. What could be improved about the way the project team overall communicates and connects with stakeholders?

Reflection on Deliverables - This last set of questions will be a reflection on deliverables.

15. Thinking back to the beginning of this phase, can you reflect on what your subteam planned to deliver compared to what was actually created/completed
    a. (probing questions: How did your team's goals or deliverables change during phase II? Did timelines change? Were deliverables added or subtracted from the work plan?)
16. Based on your understanding of stakeholder concerns, how are your subteam's final deliverables useful to stakeholders?
17. From your perspective, how do all the project deliverables (DSS, modeling, & sensor network) address stakeholder needs?
18. In general, what do you think could be done or developed further to meet stakeholder needs?

Time for open dialogue/feedback about any topics discussed:

19. Is there anything else you would like me to know about any of the topics discussed?

Tell the participant they can reach out to you via email if they have any remaining questions or comments in the coming days. Thank them.

Once recording and transcription has been exported, save it to a safe place for easy access during analysis and compilation for the final report.

-End of Internal Interview Guide-