Electronic Water Level Sensors for Monitoring Scour Critical Structures University of Michigan

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Abstract

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16. Abstract

This report details a research project aimed at developing and deploying a cost-effective water level sensor network for monitoring scour critical bridges in Michigan. The project involved a comprehensive review of existing water level monitoring technologies, followed by the selection and pilot deployment of Open-Storm sensors on over 30 bridges across the state. Real-time water level data was collected and transmitted, and system performance was continuously monitored. The results demonstrated that the sensors provided valuable real-time information, enhancing bridge inspection efficiency and decision-making. Positive feedback from bridge engineers highlighted the benefits of the technology in improving situational awareness and resource allocation. The report concludes with recommendations for scaling the technology statewide and integrating it with predictive models and other data sources to further enhance bridge scour management practices.

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Executive Summary

The Michigan Department of Transportation (MDOT) faces significant challenges in managing bridge scour, a leading cause of bridge failures. Traditional methods, relying on infrequent inspections and non-site-specific data, often prove inadequate for timely detection and response to scour critical events. This research project aimed to address these challenges by developing and deploying a cost-effective water level sensor network for real-time monitoring of scour critical bridges in Michigan.

The project commenced with a comprehensive review of existing water level monitoring technologies, encompassing various sensor types, data logging technologies, and power consumption considerations. Following this review, the research team, in collaboration with MDOT, selected Open-Storm technology for a pilot deployment due to its cost-effectiveness, ease of deployment, reliability, and the existing expertise within the University of Michigan team.

While only 20 sensors were originally proposed, over 30 bridges across Michigan were instrumented with Open-Storm sensors, strategically placed based on bridge characteristics and site assessments. These sensors measured water levels at 15-minute intervals and transmitted data hourly for real-time monitoring. System performance was continuously monitored, and a quality control protocol was implemented to ensure data reliability and identify potential gaps or outages.

The pilot deployment demonstrated several key benefits of the water level sensor network:

- **Enhanced situational awareness:** Real-time water level data provided bridge inspectors with up-to-date information on site-specific conditions, enabling them to make more informed decisions about inspection timing and resource allocation.
- **Improved inspection efficiency:** By reducing unnecessary site visits and focusing efforts on bridges experiencing high-water events, the sensor network improved the overall efficiency of MDOT's bridge inspection program.
- **Data-driven decision-making:** The availability of real-time data supported a more proactive and data-driven approach to bridge scour management, allowing for timely responses to potential scour critical events and optimizing maintenance activities.

Bridge engineers provided positive feedback on the sensor network, highlighting its value in enhancing their understanding of bridge scour risk and improving their ability to respond effectively to high-water events.

Based on the successful pilot deployment and positive user feedback, this research recommends scaling the sensor network statewide. This could be achieved through further deployment of sensors or the identification of even more cost-effective solutions. Toward state-wide adoption, the results emphasize the use of non-contact water level sensors with built-in wireless connectivity to enable real-time data reporting and alerts in a datum adjusted format. The system should be designed for easy maintenance and replacement of devices to minimize field labor and costs. Additionally, the study calls for built-in data quality control measures, mobile-friendly dashboards, and embeddable website elements for seamless integration into MDOT's existing systems.

Future research could explore the integration of real-time water level data with predictive models and other data sources to further enhance the accuracy and timeliness of scour risk assessments. Overall, this research project demonstrates the potential of cost-effective water level sensor networks to significantly improve bridge scour management practices. By providing real-time data and supporting data-driven decision-making, these technologies can enhance the safety, resilience, and longevity of bridge infrastructure in Michigan and beyond.

Introduction

Background

Scour poses the biggest risk to structural failure to bridges. This is true in Michigan and the broader US, where the USDOT has classified an alarming number of bridges as scour critical. Scour critical bridges subjected to local and contraction scour are at a particularly high risk of failure during storms. Rainfall drives high water levels, which in turn drive erosive flows. Water elevation plays a major role in bridge management, as inspectors are required to visit each bridge during or after storm events. As such, availability of real-time water level information is critical to guiding the inspection schedule.

Bridge inspectors visit sites based on weather reports and other sources of non-site-specific data. Without measurements at the individual bridges, high water levels may be missed, or a site may be visited when water levels did not exceed critical thresholds. As such, significant indefinites may arise in inspection procedures. Given the number of scour critical structures, this creates a major pain point that can only be addressed through more on-the-ground data.

Increasing the number of measurement sites is non-trivial and cost-prohibitive. The major source of water data in the US is provided by the US Geological Survey (USGS). The USGS maintains approximately 8000 stream gages across the continental US, which approximates to an average of two or three gages per county. Many of these gages are confined to coastal zones, meaning that inland counties, including many in Michigan, have no measurements of water level. Increasing the number of gages is cost prohibitive. Installation of a USGS gauge often exceeds $20,000 per site and maintenance can easily exceed $10,000 per year. Given the sheer number of designated scour critical bridges, instrumentation via USGS gauges is impractical and unaffordable. Much of the cost relates to sensors, hardware, and data loggers that are not built for the purpose of measuring just water levels. Furthermore, maintenance of sites is carried out by scientific staff and requires the calibration of rating curves, neither of which is a core requirement of a much simpler water level measurement. As such, there is an opportunity to reduce cost with a built-for-purpose solution.

Objectives

The objectives for the project spanned a comprehensive set of steps, aimed at taking the water level sensing theologies from prototype to operationalization:

- **Objective 1**: review existing state-of the art sensing systems.

- **Objective 2:** identify operating conditions and recommendations for the proposed technologies
- **Objective 3:** work with MDOT and bridge owners to identify bridges for a pilot deployment
- **Objective 4:** deploy the sensor and work with MDOT on integration into the High Flow Monitoring system
- **Objective 5:** provide recommendations how to adopt monitoring technologies across more scour critical bridges in the state of Michigan.

Scope

The project involved a comprehensive review of existing water level monitoring technologies, including sensors, along with wireless data logging technologies and their power consumption. The project also involved reviewing other state DOTs' use of technology to provide insights into the use of real-time data for scour inspection. A robust sensing package was developed to operate effectively in diverse Michigan weather conditions, including satellite data transmission for remote regions, and a tamper-proof design to protect sensors. MDOT collaborated with our team to select over 20 bridges for sensor deployment over 18 months, measuring water levels and other performance metrics. System performance was monitored for at least 18 months, with quality control protocols to ensure data reliability. An analysis was developed to explore statewide sensor adoption based on pilot data, and a comprehensive research report documented all findings and provided a scaling plan for the entire state.

Statement of Hypothesis

The deployment of cost-effective water level sensors for monitoring scour critical structures would significantly enhance the efficiency and accuracy of bridge inspection processes by providing real-time water level data. We proposed that this real-time data would reduce the uncertainties associated with current inspection methods that relied on weather reports and non-site-specific data, leading to improved decision-making and resource allocation for bridge management in Michigan. The scalable deployment of these sensors across the state would be financially viable and operationally sustainable, promoting widespread adoption and integration into existing high flow monitoring systems.

Methodology

Experimental Design

This project involved extensive research and technological development to address the critical need for effective water level monitoring in Michigan's bridge infrastructure. The initial phase focused on a comprehensive review of existing water level monitoring technologies and an evaluation of their suitability for MDOT's needs. This included a detailed assessment of sensor types (ultrasonic, radar, lidar), data logging technologies, and power consumption factors.

The project then transitioned into a pilot deployment phase, where a selected sensing package was installed on 20 bridges across Michigan. These sensors were strategically placed based on bridge characteristics and site assessments to ensure optimal performance and data reliability. The deployment phase spanned 18 months, during which water levels were measured at regular intervals and transmitted for real-time monitoring.

Finally, the project culminated in a thorough analysis of the collected data and the development of recommendations for future implementation. This included an assessment of the system's performance, the effectiveness of the chosen technology, and the overall impact on bridge inspection efficiency and decision-making. The findings from this research were compiled into a comprehensive report, outlining a plan for scaling the technology statewide and promoting its widespread adoption within MDOT's bridge management practices.

Equipment

The water level monitoring equipment used in this project consisted of several key components:

- **Sensing Devices:** The project evaluated various sensing technologies, including ultrasonic, radar, and lidar, to determine the most suitable option for MDOT's needs. The selected sensors were designed to accurately measure water levels in diverse weather conditions.
- **Data Loggers:** Different data logging technologies, including open-source options, were considered for their compatibility with the chosen sensors and their ability to store and transmit data efficiently.
- **Wireless Communications:** The project explored cellular wireless communication methods for transmitting data from the sensors to a central database.

- **Databases:** A database was established to receive, store, and manage the data transmitted from the sensors. This database allowed for real-time monitoring of water levels and facilitated data analysis.

Figure 1: Open-Storm Device

Additional details are provided in the findings section of this report.

Procedures

Technology Review

Research Task 1: Conduct a comprehensive review of existing technologies for water level monitoring, focusing on sensors such as ultrasonic, radar, lidar, and other modalities. Evaluate various data logging technologies, including open-source options, and analyze the power consumption of each solution.

Research Task 2: Research how other state Departments of Transportation (DOTs) use real-time data for scour inspection. Collect information on various appraoches, which was to inform the refinement of the list of potential technologies from Research Task 1.

Technology Selection and Site Assessment

Research Task 3: Recommend the most appropriate technology for the Michigan Department of Transportation (MDOT) pilot program based on the findings from the first two tasks.

Research Task 4: Assess various bridge features to identify the most suitable bridges for sensor deployment. Consider practical factors such as wireless reception, specify mounting designs, and optimize enclosure orientations to maximize solar power recharging.

Site Selection

Research Task 5: Vet the selected sensing package to ensure it would operate effectively across diverse Michigan weather conditions and remote constraints. Design a tamper-proof package to protect sensors from harsh weather and vandalism, with improvements based on pilot deployment experiences.

Sensor Installation and Monitoring

Research Task 6: Collaborate with MDOT staff to select 20 bridges for instrumentation over a minimum span of 18 months. Deploy sensors to measure water levels at 15-minute intervals and transmit data every hour.

Research Task 7: Monitor system performance. Implement a quality control protocol to detect gaps or outages in the system. Analyze water level sensor data in real-time to filter out obstructions or noise in the sensor signals.

Analysis and Recommendations

Research Task 8: Develop a plan to promote the statewide adoption of sensors based on pilot data and experiences.

Research Task 9: Prepare a comprehensive research report documenting all project findings. Include a plan for scaling the findings to the entire state.

Findings

Summary of Data

Technology Review

In the fall of 2022, we conducted a technology review that outlined existing technologies for remote water level monitoring and their potential applications for the Michigan Department of Transportation (MDOT). It categorized technologies into four main components: sensing devices, data loggers, wireless protocols, and databases. Different sensing technologies such as ultrasonic, radar, and lidar are detailed, highlighting their operational functionality and suitability for various environmental conditions.

A list of several vendors and service providers that offer complete water level monitoring solutions are outlined in the review. Evigia Systems provides customizable flood monitoring platforms with various sensor options and communication methods. Campbell Scientific offers rugged, low-powered data logging and measurement systems suitable for environmental monitoring. High Sierra Electronics, part of One Rain, specializes in hydro-meteorological systems for weather threat protection. Other vendors like Hyfi, Intellisense, and StormSensor provide turnkey solutions with features like ultrasonic sensors, customizable alerts, and cloud-based data logging.

The document also reviews open-source and DIY options, such as the EnviroDIY Monitoring Station Kit from the Stroud Water Research Center, the FloodSense project from FloodNet, and the Open-Storm initiative from the University of Michigan. These solutions provide cost-effective and customizable options for water level monitoring but require more effort and technical expertise to assemble and deploy. The document concludes with a cost comparison of various vendor-supplied systems, emphasizing the trade-offs between initial costs, maintenance requirements, and data service fees.

The report was submitted and reviewed by key members of the MDOT scour team. Feedback was provided and incorporate in a final report.

Please Note: The complete review is provided in Appendix B. The above is a summary.

Other State Scour Strategies

Part of our research for this project included exploring scour monitoring solutions and methods employed by different state departments of transportation (DOTs) for monitoring and managing bridge scour.

Illinois

In 2012, the Illinois Department of Transportation contracted with USEngineering Solutions to provide a web-based bridge scour monitoring service called BridgeWatch. The BridgeWatch system monitors rainfall events in the drainage areas associated with the specified structures and predicts when the rainfall has created a predetermined storm event. Where available, stream gauge data is also monitored by the system for verification of stream flows and the magnitude of the events.

This monitoring service is intended to be used to help bridge owners and program managers to implement Plans of Action, when required. When BridgeWatch predicts the predetermined storm event has occurred, users will receive a Warning or Alert (via text, email, or fax) based on the following chart:

Scour Rating	Storm Event			
	10 Year	15 Year	50 Year	100 Year
4 or Less	Warning	Alert		
7			Warning	Alert

Warnings are notifications to users that a scour critical bridge in their inventory has passed the specified storm event. No response is required.

Alerts are notifications to users that a scour critical bridge in their inventory has passed the specified storm event. Users are required to inspect the structure to determine if it has been adversely impacted by the storm event and document the conditions at the site (date, time, water level, bridge condition, approach roadway condition, etc.). This information is then entered into BridgeWatch by the user.

The following maximum response times are recommended, but may be adjusted at the discretion of the bridge Program Manager:
Scour Rating of 4 or less: 2 hours
Scour Rating of 7: 48 hours

If users determine BridgeWatch has not adequately estimated the predicted storm event for a given rainfall, the Local Bridge Unit should be contacted so adjustments to the system can be made.

Ohio

Inspection of Bridges over Water

The Ohio DOT uses two methods for performing scour assessments:

1. Scour evaluation-Observed Scour for Bridges Methodology (uses observance of geomorphic, hydrologic, and hydraulic features at the bridge site)
2. Scour analysis-Theoretical Scour Calculations (uses theoretical scour calculations based on hydrologic and hydraulic analyses of the stream and bridge opening)

In addition, they perform underwater inspections of bridge substructure no less than 5 years (60 months).

High Water Inspections

Program managers are instructed to establish an internal procedure to monitor scour critical bridges during or immediately after periods of high water. The following elements are recommended for consideration as part of the procedures:

Monitoring

Program managers are instructed to create a monitoring plan that includes:

- Monitoring Plan Summary - Provides details of the extent of monitoring. What information the monitoring will provide, and what action will be implemented if the information indicates a scour problem?
- Monitoring Authority - Responsible agency identified for implementation and action of monitoring, including who is in charge of overseeing and carrying out the monitoring plan.
- Regular Inspection program - The frequency of the monitoring indicated and whether cross sections and comparison of historical cross sections be required. Items to watch for are indicated.
- Increased Inspection Interval - The need for and increased interval and items to watch for are indicated.
- Fixed Monitoring Devices - The type of instrument are identified. This type of monitoring can be dependent on increasing channel flows and an identified discharge that could potential cause scour concerns. The monitoring or interval is usually increased as discharge increases.

Wisconsin

Initial Underwater Profile Activity

All structures over water have an initial underwater profile activity taken during the Initial Inspection.

Follow-up Underwater Profile Activities:
Higher Risk Bridges, including bridges that are scour critical, having a code of 3 or less for NBI Item 113, have underwater profiles taken every 24 month on both the upstream and
downstream fascia. These profiles are compared with historical data to ascertain potential movement of the channel and risk of substructure undermining.

Underwater Dive Inspections
Underwater dive inspections are required if water conditions exist at the structure that prohibit access to all portions of an element by visual or tactical means. Scour critical bridges meeting this requirement are inspected at a minimum of every 24 months.

USGS Study: Bridge Scour Monitoring Methods at Three Sites in Wisconsin
John F. Walker and Peter E. Hughes

Between 1997 and 2004 USGS partnered with three Wisconsin counties and WisDOT to monitor bridge scour at three bridges in Wisconsin.

The equipment at two sites consisted of Datasonics PSA-916 sonar transducers. At one location transducers were installed both upstream and downstream and at a second location just one transducer was installed upstream. The "transducers were connected to a Campbell Scientific CR10 datalogger, which recorded distance to the streambed at the two locations using a 15-minute recording interval. Data from the Campbell datalogger was transmitted via phone." The cost of the equipment and installation at the time ranged from $9,000-$10,200. Annual cost of operation was $4,000.

The equipment at the third location was two manual wire-weight gages, installed on the upstream rail of the bridge. The gages contained "a calibrated reel which displays the distance from the reel to the weight using a series of counters. The gages [were] operated by lowering the weight to the water surface and then to the streambed, and the distances from the gage to each surface are recorded on a field form. The gages can be read to within 0.01 ft (0.3 cm), but the accuracy of distance to the streambed is probably on the order of 0.05 ft (1.5 cm). The measurement accuracy will depend upon the technique used to drop the weight to the streambed without allowing it to be carried a substantial distance downstream during high-flow conditions. A 10-lb (4.5 kg) downrigger ball was selected to minimize this problem." The cost of the equipment and installation was $3,000 and the annual cost operation was $3,300.

Method of Analysis

Sensor Installation and Monitoring

In the fall of 2021, a pilot deployment of five Open Storm depth sensors were installed on scour critical bridges in Southeast Michigan. These sites were chosen due to their proximity to Ann Arbor that would allow for easy maintenance, if needed. The locations included: MDOT 7079, MDOT 7166, MDOT 1072, MDOT 2471, and MDOT 2613.

After monitoring these sites throughout the 2021/2022 winter, it was determined that the network would be expanded to the planned upon 20 sites throughout the state in the summer of 2022. Our team worked with MDOT Scour Specialist, Andrew Zwolinski to gather priority sites from all regional bridge engineers. The bridge engineers provided a “wish list” of an additional 46 sites. 24 of those sites were considered “duplicates” as they included both sides of the bridge (upstream and downstream), so the potential sites were narrowed down to 34 sites. Using bridge plans, google street view, and physical site visits by our team or bridge engineers where 360° videos were taken, our team studied the viability of deploying sensors at these sites. 32 sites were deemed viable and in reviewing the project budget and timeline, our team planned on expanding the network from the planned 20 sites to a total of 37 sites. Deployment plans were developed for each site and shared with Mr. Zwolinski for review and approval.

During the pilot stage and during the full state-wide deployment, our team worked with Joe Rios, MDOT Right of Way Construction and Utility Permit Coordinator, to obtain the necessary permits to deploy the sensors at each of the sites. Mr. Rios and Mr. Zwolinski also assisted in the coordination of lane closures for three of the sites that had higher traffic.

Prevision Surveying

While not originally proposed, a bonus of our project was the surveying of all devices and water levels to NAVD88 elevation. Our team acquired a prevision surveying GPS unit, and trained in surveying sites to millimeter precision. These surveys were then referenced by our team with MDOT Bridge construction drawing to reference the water level data to deck elevation and levels that would pressure flow alerts.

Table 1. List of Scour Critical Sites with Sensors

SN	Region	LAT	LON	Bridge No	Route On	Feat Under	Stream Width (m)	Stream Depth (m)
1072	SOUTHWEST	41.9323	-85.0047	12031-B02	I-96 BL	Sauk River		
1091	SOUTHWEST	42.0329	-84.9769	12034-B04	I-69 NB	South Branch Hog Creek	14.5	
390	BAY	44.0477	-83.8564	06072-B03	US-23	Rifle River	29.3	
2471	BAY	42.9869	-83.7356	26031-B03	I-75	Swartz Creek	15.3	
2491	BAY	43.1832	-83.7687	25032-B03-1	I-75 NB/US-23 NB	Pine Run Creek	6.5	
2613	BAY	43.1112	-83.5189	25092-B01	M-15	Flint River	24.5	
2892	BAY	44.156	-84.2912	26032-B04	M-30	Tittabawassee River	9	
3082	BAY	43.3968	-84.6324	29011-B03-1	US-127 NB	Pine River	30.5	2.9
4240	BAY	43.6318	-84.7586	37014-B01-1	US-127 NB	Chippewa River	29.6	3.1
9178	BAY	43.3243	-83.7405	73131-B02	M-83	Cass River	54	
9734	BAY	42.9053	-84.0632	76023-B02-3	I-96 EB	Shiawassee River	30.5	1.7
10428	BAY	43.4836	-83.3868	79051-B01	M-24	Cass River	61.1	
5772	University	42.6073	-83.9659		I-96 WB	Shiawassee River		

SN	Region	LAT	LON	Bridge No	Route On	Feat Under	Stream Width (m)	Stream Depth (m)
7075	University	41.9831	-83.6783	58033-B02-1	US-23 NB	Middle Branch Macon River	7.5	
7079	University	42.0255	-83.6786	58033-B04-1	US-23 NB	N Branch Macon River	6	
7092	University	41.755	-83.6947	58034-B02-2	US-23 SB	N ranch Ten Mile Creek	7	
7166	University	41.8934	-83.3793	58151-B06-1	I-75 NB	Plum Creek	12.2	
488	SUPERIOR	46.8355	-88.4835		US-41	Little Carp River	7	
2954	SUPERIOR	46.405	-89.7792		US-2	Little Presque Isle River	50	1.5
6513	SUPERIOR	46.4076	-87.2441		US-41	Chocolay River	8.7	
8488	SUPERIOR	46.5347	-89.2763		M-28	S Br Ontonagon River	150	2
9682	SUPERIOR	46.3007	-86.4464		M-94	N Br Stutts Creek	8	
335	NORTH	45.075	-83.4486		US-23	Thunder Bay River	54.9	3
752	NORTH	44.6203	-86.2218		M-22	Betsie River	18.2	3.4
1500	NORTH	45.6463	-84.3949		US-23	Elliot Creek	8.5	0.5
6440	NORTH	44.23	-86.032		M-55	Pine Creek	8.2	0.6
8955	NORTH	45.4022	-83.8782		M-68	Trout River	12.2	1.2

SN	Region	LAT	LON	Bridge No	Route On	Feat Under	Stream Width (m)	Stream Depth (m)
3970	GRAND	42.9718	-85.0693	34032-B01	M-66	GRAND RIVER	53	
4011	GRAND	43.0007	-84.9214	34062-B03	M-21	MAPLE RIVER	45	
4706	GRAND	43.0631	-85.5799	41013-B02	M-44	GRAND RIVER	122.2	
4932	GRAND	42.9633	-85.6772	41081-B01	M-45, (FULTON ST)	GRAND RIVER	142.8	
7587	GRAND	43.4251	-86.3264	61075-B06	US-31 NB	WHITE RIVER	35	
8706	GRAND	42.8016	-86.0662	70023-B01	I-196BL EB	BLACK RIVER	54	
8767	GRAND	43.0744	-86.0521	70063-B02	I-96 WB	CROCKERY CREEK	24	
6140	METRO	42.5682	-82.8589		I-94	Clinton River Spillway	53.8	
6142	METRO	42.5902	-82.8571		I-94 NB	N&S RDS	60	
11328	METRO	42.3283	-83.2415		M-153 WB	Rouge River	39.4	

In the Spring and Summer of 2022, our team prepared and built the devices for the network. Afterwards, during July and August of 2022, two field technicians, Kenneth Ferrell and Mitchel Wojtowicz, traveled throughout the state and deployed the remaining 32 sensors. Following the initial deployments, Kenneth Ferrell continued to monitor performance and conducted necessary maintenance or swaps on sensors from August 2022-July 2023. In July 2023, a new field technician, Jacob Smith, took over management of the maintenance of the MDOT network.

Figure 2. Mitchell Wojtowicz, Field Technician, building an Open Storm Device

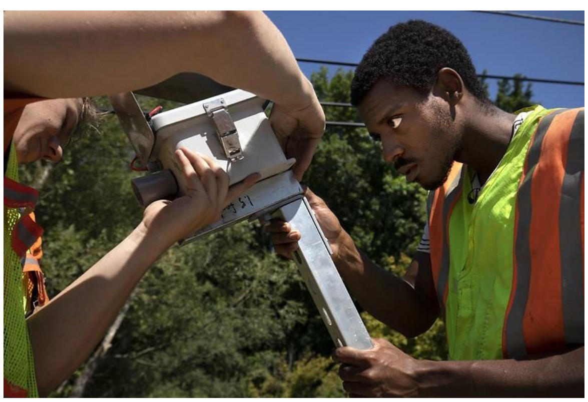

Figure 3. Mitchell Wojtowicz and Kenneth Ferrell deploying an Open-Storm Sensor

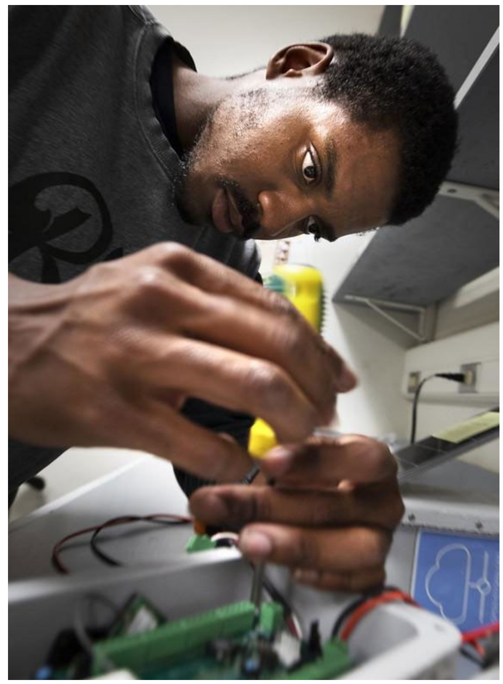

Figure 4. Kenneth Ferrell, Field Technician, building an Open Storm Device

Figure 5. Mitchell Wojtowicz and Kenneth Ferrell deploying an Open-Storm Sensor

Figure 6. Mitchell Wojtowicz and Kenneth Ferrell deploying an Open-Storm Sensor

Figure 7. Mitchell Wojtowicz and Kenneth Ferrell deploying an Open-Storm Sensor

Figure 8. Mitchell Wojtowicz and Kenneth Ferrell deploying an Open-Storm Sensor

Swapping

A unique feature of Open Storm devices is the ability to easily swap and replace devices that are not performing properly. Once deployed our team of field technicians have coordinated 43 maintenance tickets within the 36 months that the network has been active. 17 of these tickets were due to some type of obstruction - either plant or spider interference or the need to adjust the mounting due to bridge obstruction. Six of the tickets were due to one site, MDOT 11328, that appears to be in a location that does not provide consistent cell signal. Despite our attempts to swap it many times throughout the project, we were unable to get this site to perform consistently. The remaining 20 tickets were due to field conditions and sensors obstructions.

For sites that were further than a simple day trip for our field technicians (including sites in the North, Superior, and Bay regions), we coordinated with the Bridge Engineers in those regions to swap devices flagged for maintenance. Instructions (see Appendix E) and a video were provided for the Engineers prior to swapping devices. For devices retrieve from the field, the Engineer was able to use the packaging sent by our team and we provided a label for returning the device.

Data Streams and Alerts

In 2022, our team met members of the MDOT team who manage the ArcGIS HighFlow site, Joseph Thick, Cory Johnson, and Kyle Nelson, to discuss how to integrate the sensor data into HighFlow. Following that meeting, our team built an ArcGIS layer that was integrated into the site. We continued to refine this layer and update visualizations to work with MDOT needs. This layer was provided as a csv file with the agreed upon fields and was uploaded by Joseph Thick when provided.

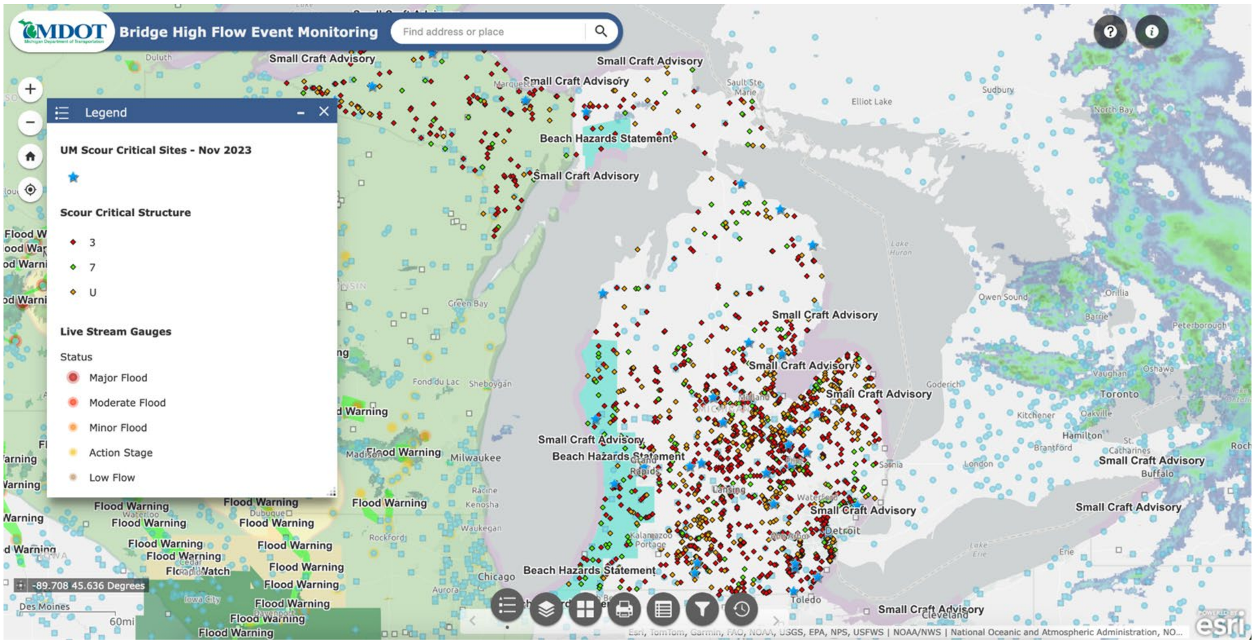

Figure 9. MDOT HIgh Flow Site: UM sites are marked with blue stars

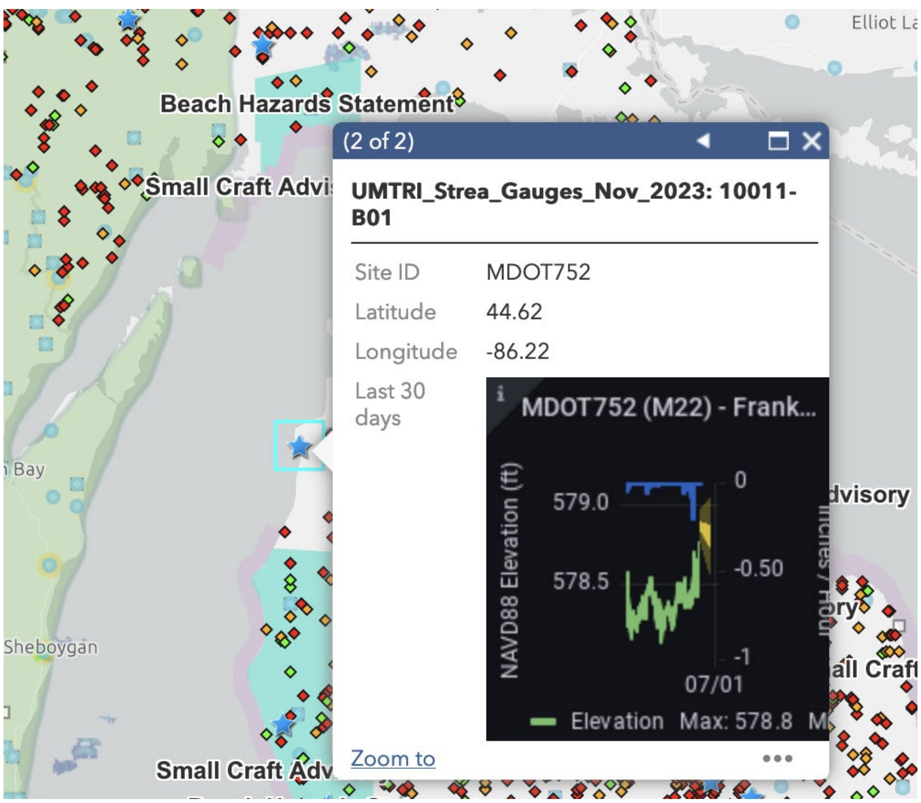

Figure 11. MDOT High Flow Site: Each UM site includes a live data stream and additional site information.

In addition to the integration of the data into High Flow, custom dashboards were created for each region to allow for the Bridge Engineers to be able to quickly view the live data from all the sensors within their respective regions. All custom dashboards can be found at: https://www.digitalwaterlab.org/mdot.

Figure 12. Screenshot of Dashboard Landing Page

During the summer of 2023, we hired an undergraduate student, Minyu Li, to focus on user experience design for the scour critical data with the goal of making the data easier and more functional for the Bridge Engineers. After conducting interviews with five of the bridge engineers and with Erik Carlon, MDOT Hydrologist, who were frequent users of the data. We analyzed those interviews and came up with a list of feature updates for the UM dashboards and High Flow layer. These feature updates included a cleaner interface with easier to find data in High Flow; integration of 25, 50, 100 year storm information for each bridge, images, pressure flow and forecasting data for each bridge. For the two sites where the data was available, a demonstration of how discharge curves could be integrated was provided. These updates were completed and shared with the Bridge Engineering team in late 2023.

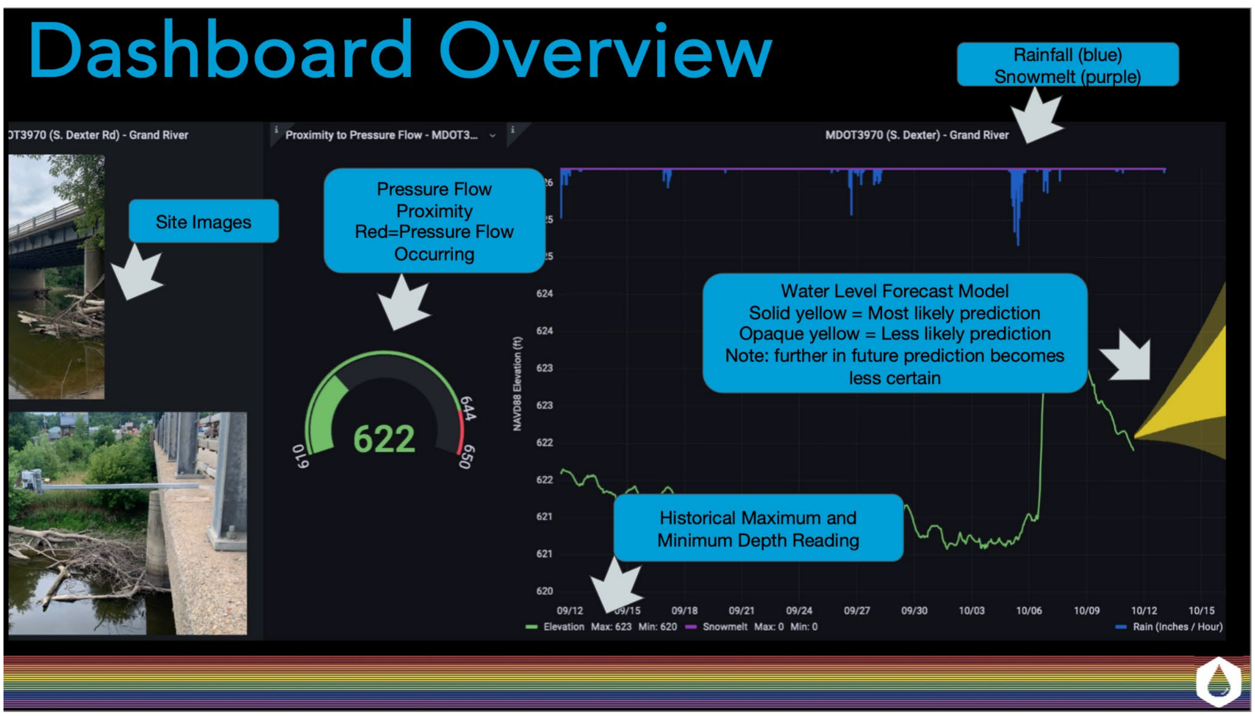

Figure 13. MDOT scour site data dashboard overview of features

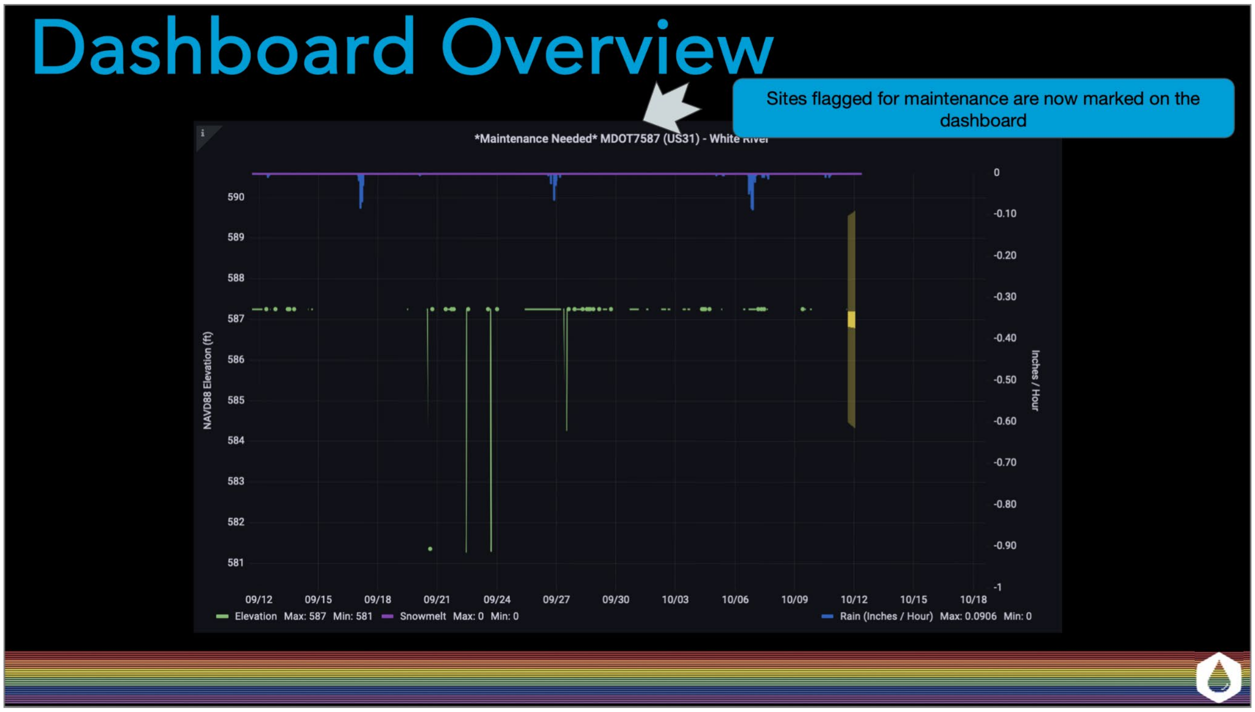

Figure 14. MDOT scour site data dashboard overview of features

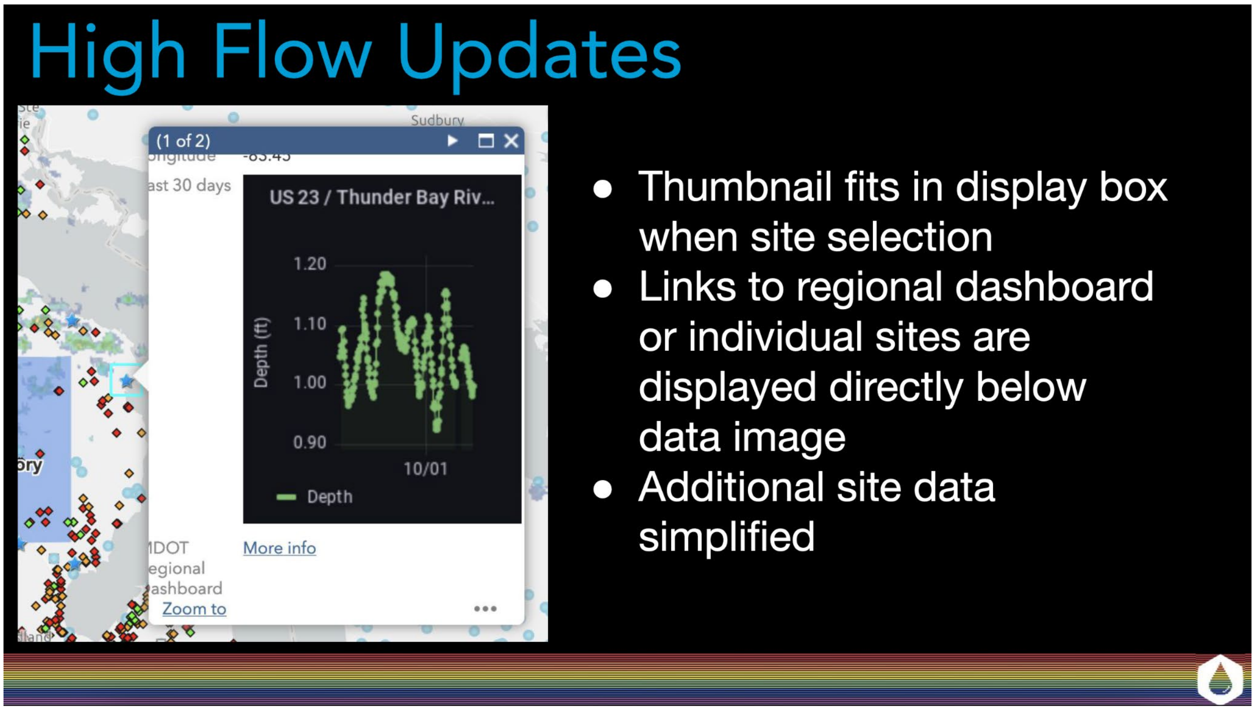

Figure 15. High Flow thumbnail example for scour critical site

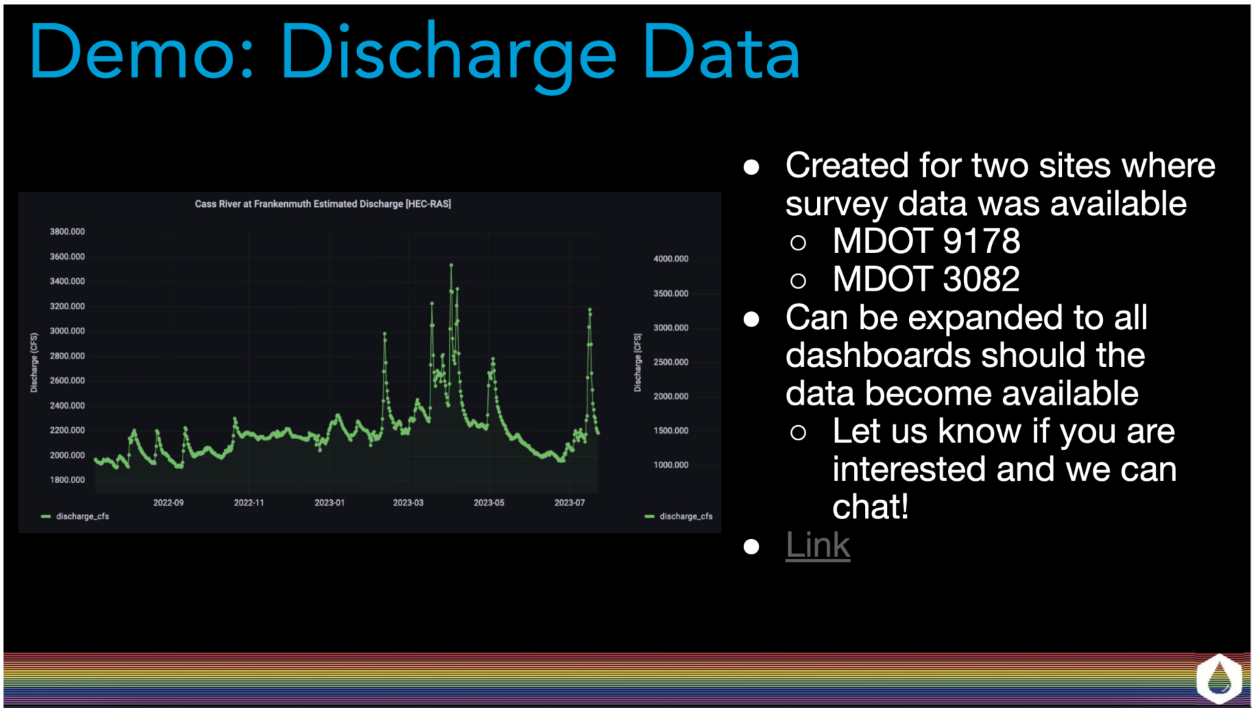

Figure 16. Example of discharge data

In addition to feature updates, we provided custom alerts for any Bridge Engineer that was interested in receiving alerts. Alerts can be received via email or SMS text and can be set for specific sites and customized to specific thresholds, when more than 3” of rain occurs within 24 hours at that site (a high flow event), or when pressure flow is reached.

It was critical to our team that the data felt useable and accessible. We held meetings and offered to provide additional trainings to acquaint each Bridge Engineer with the data. A training video was also recorded for those people who were unable to attend meetings with our team.

(https://www.loom.com/share/b6a36d9c7a004656ad0ed9c747323ad1?sid=57c8a31a-7d47-4565-8d2b-8ef57367154b)

All data is securing stored on University of Michigan AWS servers. If required, data can be provided to MDOT through an API key or Google Drive file.

Presentation of Results

System Performance

Open-storm has been providing open-source resources to enhance the accessibility of wireless water sensor networks. Here we give an overview of the architecture and describe several recent enhancements to the embedded operating system, hardware, and cloud services used in the sensor network operated by the Digital Water Lab (DWL) at the University of Michigan. Open-storm sensor nodes are custom low-power embedded computers which connect to online databases using cellular networks. A microcontroller is programmed with a non-preemptive operating system which wakes the device from sleep, downloads instructions from the server, records sensor readings and triggers control assets, transmits data to the server, and returns the device to sleep. The *open-storm* printed circuit board (PCB) was updated and accommodates diverse sensors and actuators though a Cypress PSoC5LP microcontroller. The system-on-chip (SoC) design allows control over analog and digital components, enhancing the platform's flexibility for integrating new sensors and actuators. Connectivity is provided by a 4G/LTE-capable Telit cellular modem. This MDOT work focused on nodes equipped with Maxbotix ultrasonic range finders that measure the distance between the sensor node and the water surface. This depth-sensor configuration is the default and requires minimal user setup beyond specifying a server endpoint to transmit data to. In the Digital Water Lab network, those distance readings are referenced to an elevation survey and reported to end-users as water depth above streambed or water surface elevation relative to the NAVD88 datum.

Open-Storm's hosting services are built around InfluxDB, a time series-optimized database facilitating efficient data storage and retrieval. InfluxDB's RESTful APIs allow for seamless interaction between sensors and external applications, supporting both data input and output. InfluxDB is implemented in open source, but can now also be purchased as a hosted commercial services on InfluxData.com, which significantly reduces the server maintenance burden on users. InfluxDB's primary role is to store sensor data transmitted via HTTP Post requests and enable adaptive sampling and real-time control through cloud-stored device settings, accessible to sensor nodes during server communication. This system supports bidirectional communication with field nodes and allows remote customization of measurement and transmission frequencies, thereby reducing the need for site visits. Beyond environmental monitoring, the sensor node is also equipped with internal diagnostics tools that track the device's operational health, including battery levels, cellular signal strength, and network connection attempts. An optional data quality module can also be activated to refine data and detect sensor defects or obstructions. More details regarding the nodes, available sensors and actuators, and the cloud architecture are available at https://www.digitalwaterlab.org/build.

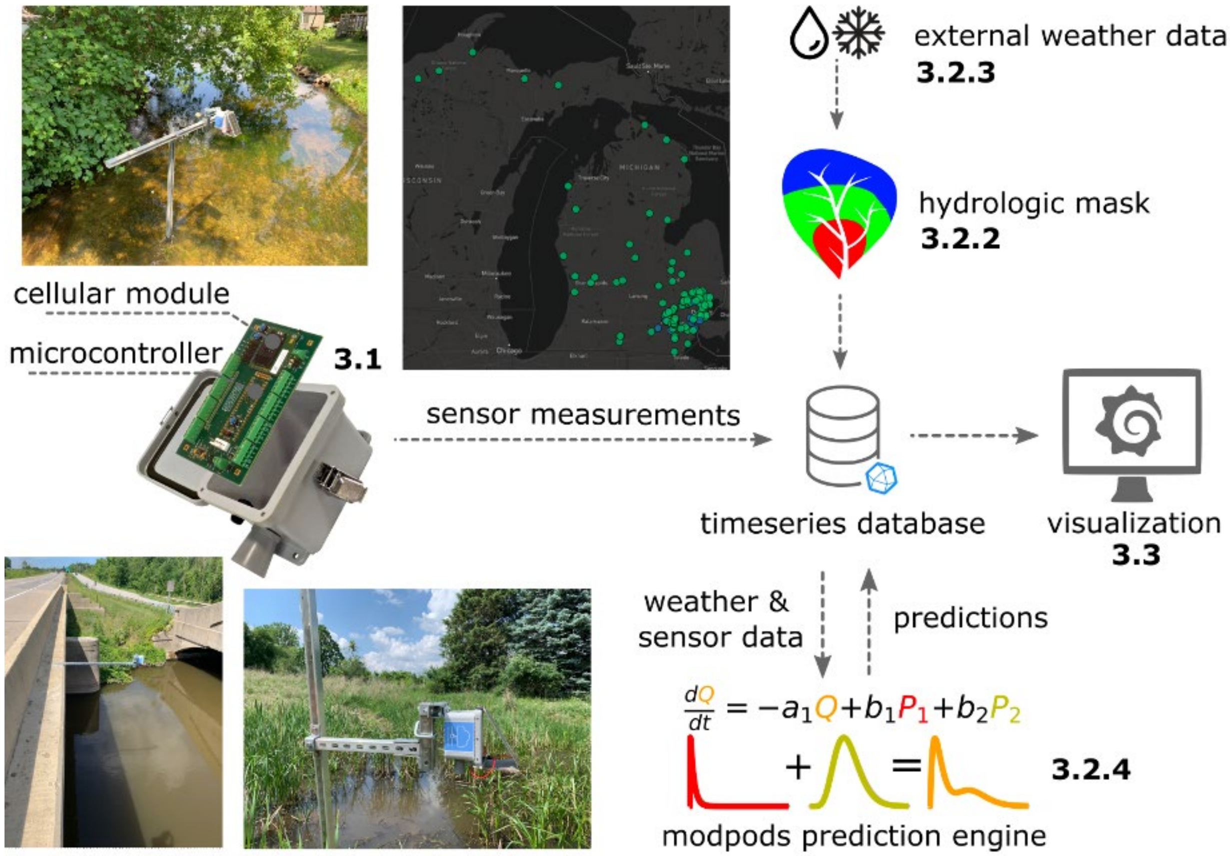

Figure 17. Automated and sensor-integrate hydrologic forecasting

The hydrologic sensor network and data services were energy efficient and reliable. Sensor nodes consumed only 50µA in their sleep state. The cellular modem's transmission, operating on a slow power cycle, was able to activate within a minute. During transmission the current consumption averaged 200mA with a peak of 2A. The network's sustainability was enhanced by solar power. With low power consumption, a measurement cycle of 10 minutes, and transmission cycle of 60 minutes, the devices were able to operate through a Michigan winter and recharge the lithium ion battery consistently. Transmissions were reliable (95% packet throughput) and aided by a buffering system in the devices that allowed for data to be sent later if connection failed during a given transmission attempt. There were a few network outages due to an issue with the domain service provider, but not the sensors or data services themselves. Maintenance of the devices was infrequent and generally only required because of physical damage to the node or sensor obstructions. The major challenge with the ultrasonic sensor data was noise caused by physical obstructions (e.g., plants and bridge decks) that blocked the sensor from making a measurement of water levels. The automated quality control system allowed these issues to be detected and addressed by trimming plants or adjusting the sensor's location on the bridge.

User Feedback

As our team worked to make the data more useable, we began tracking site views to each individual site (linked through the High Flow site) and regional dashboards. Anonymized user data is displayed in the two charts below, showing regular visits by users to the dashboard.

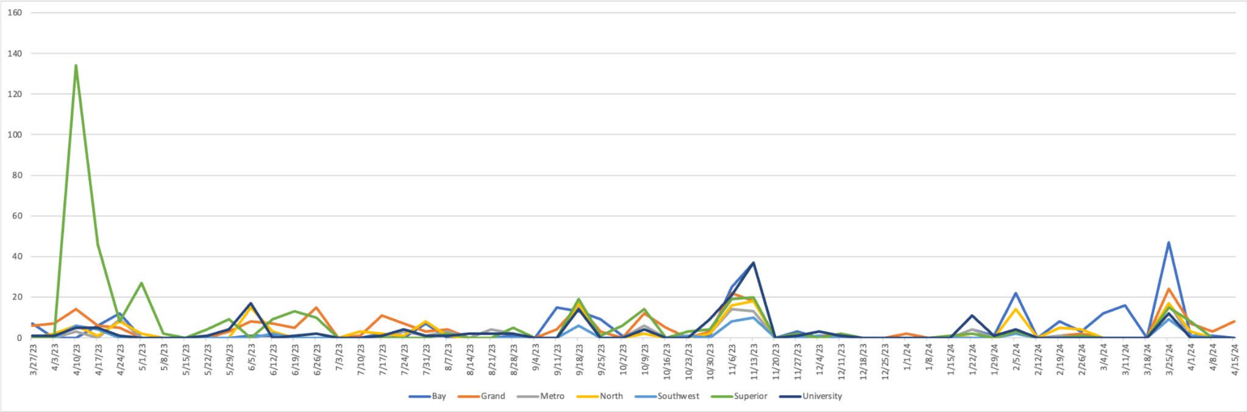

Figure 18. Weekly site views per region to individual sites

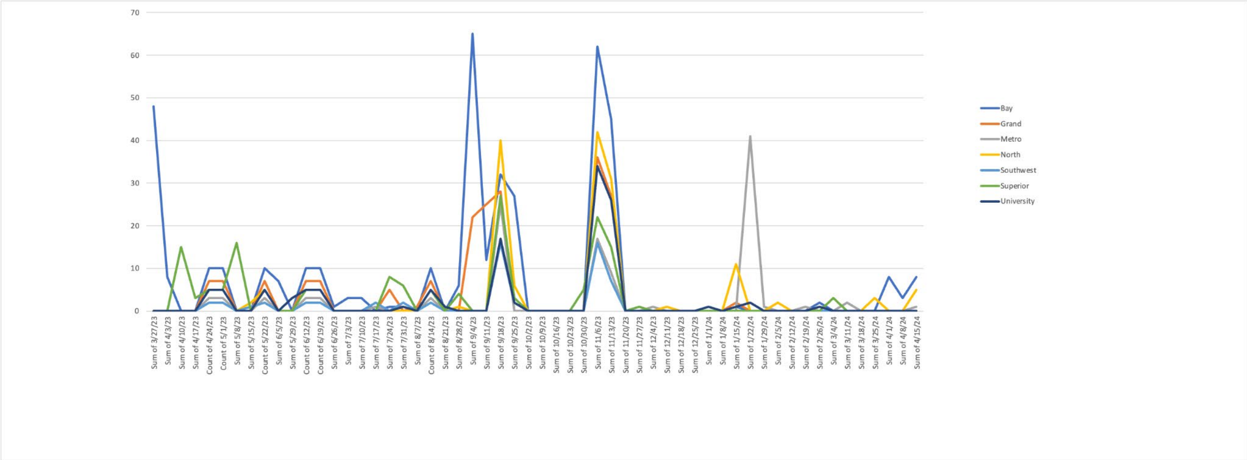

Figure 19. Weekly site views per region to regional dashboards

Feedback on the data and uses to better respond to high flow events has been positive. As noted by two Bridge Engineers:

Jordy Maloney, Bridge Engineers, Superior Region stated:

> *"One major benefit of the UM sensor network is being able to instantly monitor water levels region wide. In the past it was very difficult to perform in-person monitoring of scour critical assets after rain events because of the size of the Superior Region, where many bridges can be over six hours away from each other. The newark has allowed me to stay in tune to locations throughout the region at a*

greater scale than what the USGS gage data provides, and more importantly, provides a snapshot of the region and where to send resources. I see it as a helpful tool for the future.

One example where the network was particularly useful was at the end of April 2023 when the UP had over 3 feet of snow one week and 80 degree weather the next, which resulted in rapid snow melt. I used the network to determine if I needed to go into the field to assess the state of each bridge."

Chad Skrocki, Assistant Bridge Engineer, North Region stated:

"I would echo what Jordy has said about the network and particularly like the additional forecasting features. I feel like this project is moving in the right direction and would love to add additional locations to the network."

Forecasting

While not originally proposed, our team was able to make so much progress the core deliverables that we found time to research water levels forecasting. We ultimately integrated this into the final deliverables. Our *modpods*-based prediction engine takes in a depth or discharge time series (retrieved via RESTful API) and the corresponding sensor location. Then, the contributing area is delineated and weather data is sourced using publicly available datasets. Models are then trained. Once a day, trained models are fed weather forecasts and the resulting predictions are pushed to decision support dashboards. Computational expense is minimal as it takes thirty seconds to generate a one-week prediction on a consumer laptop.

A coarse flow direction grid with a resolution of 300 meters is used because there is no process-based modeling. The resolution need only be accurate enough to sample the right weather data. Weather data (liquid precipitation, snow depth, air temperature, and wind speed) are provided by the open-source project. The end-user software architecture only requires a time-series record of sensor measurements and the location of the sensor. The measurements targeted for prediction in this study are water level and discharge, but could be other parameters which have precipitation- and snowmelt-driven dynamics.

Using the sensor's location and the Hydrosheds flow direction grid, the contributing area of the catchment with pour point at the sensor location is delineated using *pysheds.* The flow distance for each grid cell is then calculated and used to divide the catchment into regions with short, medium, and long flow paths to the sensor. These flow-distance regions are used to aggregate rainfall. Once the total catchment is delineated and the flow distance regions are defined, the flow direction grid is no longer used. No other information about the catchment (e.g., average slope, landuse, topographic roughness index) is used by the model.

Evenly spaced points within each region are used to sample rainfall intensities at one-hour frequency. Those intensities are then averaged across each flow distance region. Snowfall is excluded because it generally does not immediately contribute to runoff. As weather stations are not ubiquitous and climate models often have spatial resolution of ten kilometers or more (NOAA), small catchments will often have identical data between different flow- distance regions. In this case the redundant data is omitted.

For estimating snowmelt, factors including albedo, insolation intensity, and humidity are important. However, to keep the model structure simple we coarsely represent the radiative and advective processes by making snowmelt a function of wind speed and air temperature. Because snow depth is only available at a daily resolution through Meteostat, it is linearly interpolated from daily to hourly frequency. As the underlying data is daily, the catchment is not segmented into flow distance regions for snowmelt estimates and these are instead aggregated across the entire catchment.

All trained models are loaded once per day and given historical and forecast weather with which to make a one-week prediction. A validation prediction over the past week is used to quantify the uncertainty of the prediction and generate bounds around the central estimate corresponding to the mean and maximum absolute percentage error over the validation interval. The predictions and weather data are then pushed to the server and fetched at the visualization endpoints.

The visualization interface built on Grafana is the primary way users interact with measurements and predictions. Grafana is an open-source analytics and monitoring platform, known for its ability to visualize and explore metrics from various data sources in a customizable dashboard format. It is widely used for tracking and visualizing time series data, such as performance metrics and IoT sensor data. Grafana’s hosted services (Grafana.com) offer a user-friendly solution, eliminating the need for installation and setup. This cloud-based approach simplifies the use of Grafana, allowing users to focus on data analysis and visualization without the complexities of managing server infrastructure. Grafana also features a built-in InfluxDB data source template which makes the generation of dashboards relatively quick and easy. Alerts can also be easily configured and delivered via channels including email and SMS.

Figure 20. Sample forecasting support dashboard. Estimated snowmelt and rainfall (across all flow-distance regions) are indicated on top of the graph in purple and blue respectively. Historical water surface elevation is in green. Predictions with uncertainty estimates are provided in yellow.

The figure below shows the cumulative density function of *training* Nash Sutcliffe Efficiency. The line indicates the percentile of a given NSE score, such that better overall performance lies in the bottom right, while worse performance goes to the top left. As numeric score metrics are always incomplete, the right side of the figure shows selected simulations to contextualize these scores.

Training records vary from several years to under a year (maximum) and from relatively clean (maximum) to obstructed and noisy (median). It seems the models are sufficiently complex to capture rainfall-runoff processes when sensor data is relatively clean and weather data is accurate (maximum). The prediction engine is also resilient to high noise levels, still finding a reasonable representation of the dynamics even when the observations are corrupted with measurement noise (median). Models also behave predictably due to their first-principles-based construction.

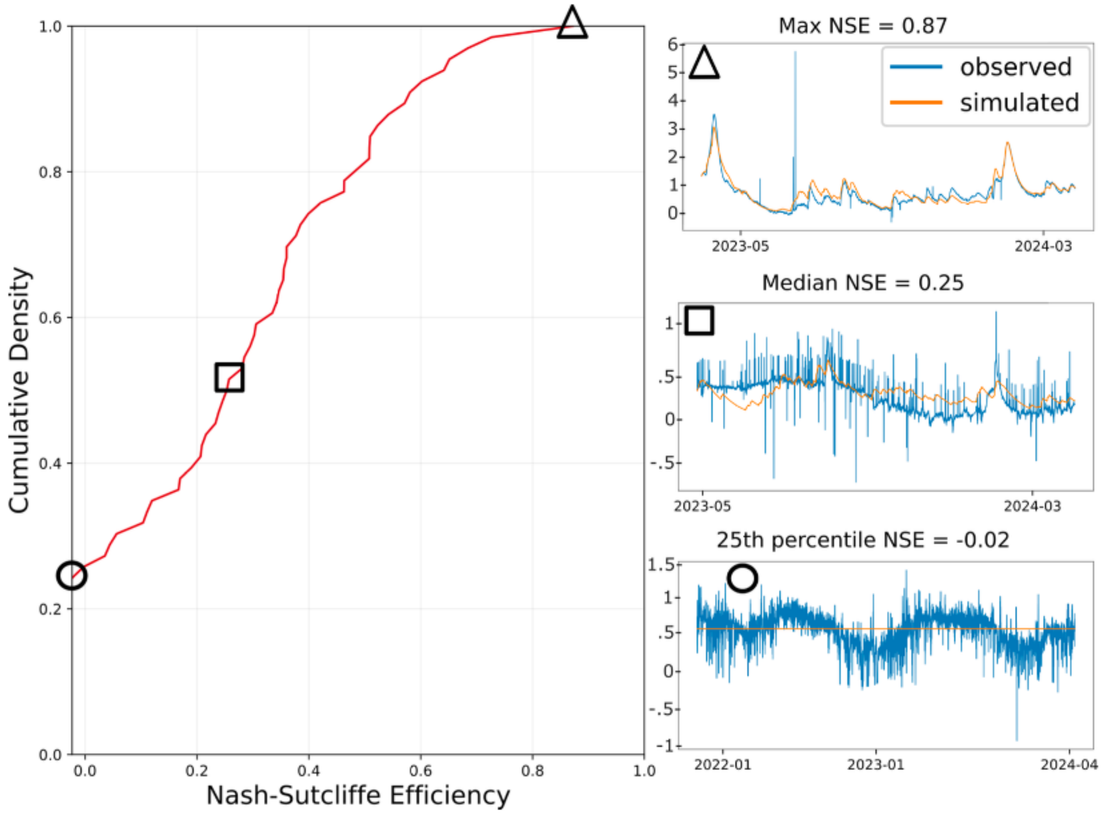

Figure 21. Cumulative density function of *training* Nash Sutcliffe Efficiency. The cumulative probability distribution of Nash Sutcliffe Efficiency is shown on the left. On the right are measured and simulated stage in meters for sites with training accuracy at the 25th percentile, median, and maximum of NSE (-0.02, 0.25, and 0.87 respectively).

Discussion

Validity of Hypothesis

The hypothesis was validated through a pilot deployment of the sensor technology on over 30 bridges in Michigan, strategically selected in collaboration with MDOT. System performance was continuously monitored, and a quality control protocol was implemented to ensure data reliability.

The results of the pilot deployment demonstrated that the real-time data provided by the sensors significantly enhanced the efficiency and accuracy of bridge inspection processes. Bridge inspectors were able to make more informed decisions about when and where to conduct inspections, reducing unnecessary site visits and ensuring that critical high-water events were not missed. This led to improved resource allocation and overall bridge management practices in Michigan. The successful pilot deployment and positive user feedback validated the hypothesis that cost-effective water level sensors could significantly improve bridge safety and management through real-time monitoring.

Factors Affecting Results

The technology review report (please see appendix) discusses the pros and cons of various technologies for water level monitoring, ultimately recommending Open-Storm devices for a pilot deployment by MDOT. The selected technology, Open-Storm, offers several advantages that make it well-suited for MDOT's needs. It is cost-effective on a per-device annual basis compared to both DIY and commercial solutions. The devices are ready for immediate deployment and can be easily scaled, and the University of Michigan team is already trained on the platform. Additionally, Open-Storm devices are designed for simple deployment and have been field-tested for reliability in Michigan's weather conditions. The expertise of the University of Michigan team allowed for customization and integration into MDOT's ArcGIS platform.

Implications

The pilot deployment of the water level sensors demonstrated significant benefits for bridge inspection and management. Real-time water level data allowed bridge inspectors to make more informed decisions about when and where to conduct inspections, reducing unnecessary site visits and ensuring critical high-water events were not missed. This improved resource allocation and overall bridge management practices. The positive feedback from bridge engineers highlighted the value of the technology in enhancing situational awareness and decision-making. The success of the pilot program suggests great potential for scaling the technology across the state, either by replicating the pilot's approach in other regions or by identifying an even more cost-effective solution. This would further improve bridge safety and management practices throughout Michigan.

Conclusions

In closing, we completed each proposed milestone, as summarized below.

- **Research Task 1: Technology Review**
  - Concluded that a wide range of water level monitoring technologies exist, each with strengths and weaknesses.
  - Identified ultrasonic, radar, lidar, camera, and pressure transducer sensors as potential options.
  - Highlighted factors like cost, accuracy, range, and maintenance requirements as key considerations.
- **Research Task 2: Other State DOT Practices**
  - Found that several state DOTs utilize real-time water level data for bridge scour inspections.
  - Noted variations in monitoring approaches, including the use of predictive models and fixed monitoring devices.
  - Showed that real-time data can improve decision-making and resource allocation for bridge inspections.
- **Research Task 3: Technology Recommendation**
  - Recommended Open-Storm technology for MDOT's pilot program.
  - Key factors in the decision were cost-effectiveness, ease of deployment, reliability, and the existing expertise of the University of Michigan team.
- **Research Task 4: Bridge Site Assessment**
  - Identified suitable locations for sensor deployment on bridges, considering factors like wireless reception, mounting design, and enclosure orientation.
  - Developed deployment plans for each site, ensuring optimal sensor performance and data collection.
- **Research Task 5: Sensor Package Development**
  - Vetted the selected sensing package (Open-Storm) for its ability to operate effectively in Michigan's weather conditions.
  - Designed a tamper-proof enclosure to protect sensors from harsh weather and vandalism.
- **Research Task 6: Sensor Installation and Monitoring**
  - Successfully deployed sensors over 20 bridges across Michigan in collaboration with MDOT staff.
  - Sensors collected water level data at 10-minute intervals and transmitted it hourly for real-time monitoring.

- **Research Task 7: System Performance Monitoring**
    - Implemented a quality control protocol to ensure data reliability and identify any gaps or outages in the system.
    - Developed real-time data analysis methods to filter out noise and obstructions in sensor signals.
    - Validated reliability of technology and power consumption.
- **Research Task 8: Adoption Plan**
    - All technologies of this project have been shared in an open-source format. Please see the "recommendations for implementation" section at the end of this report.
    - Commercial alternatives were provided in the technology report in the appendix.
- **Research Task 9: Research Report**
    - Prepared a comprehensive report documenting all project findings, including data analysis, user feedback, and recommendations for future implementation.

Conclusions from the Study

The pilot deployment of cost-effective water level sensors on scour critical bridges in Michigan demonstrated significant potential for enhancing bridge safety and management practices. Real-time water level data provided by the sensors enabled bridge inspectors to make more informed decisions regarding inspection schedules and resource allocation. This led to reduced unnecessary site visits and improved responsiveness to high-water events. The positive feedback from bridge engineers further validated the value of this technology in providing real-time situational awareness and supporting data-driven decision-making.

The success of the pilot program indicates that scaling this technology statewide could significantly benefit MDOT's bridge management practices. This could be achieved through further deployment of the existing sensor technology or the identification of even more cost-effective solutions. Additionally, integrating real-time water level data with predictive models and other data sources could further enhance the accuracy and timeliness of scour risk assessments.

This study highlights the potential of innovative, low-cost sensor technologies to address critical infrastructure challenges. By providing real-time data and supporting proactive maintenance strategies, these technologies can improve the safety, resilience, and longevity of bridge infrastructure in Michigan and beyond. Future research and implementation efforts should focus on refining these technologies, expanding their deployment, and integrating them with other data-driven tools to optimize bridge management practices.

Recommendations for Further Research

Future research could explore several avenues to further enhance the effectiveness and applicability of water level monitoring systems for bridge scour management.

First, research could focus on refining sensor technologies and data analysis methods to improve the accuracy and reliability of real-time water level measurements. This could involve investigating alternative sensor types, such as radar or lidar, and developing advanced signal processing algorithms to filter out noise and interference. Additionally, research could explore the integration of multiple sensor types to provide a more comprehensive and robust monitoring system.

Second, future research could investigate the development of predictive models for bridge scour risk assessment. By combining real-time water level data with other relevant factors, such as bridge geometry, streambed characteristics, and historical scour data, these models could provide more accurate and timely predictions of scour risk. This would enable bridge inspectors to prioritize inspections and maintenance activities based on the predicted risk level, optimizing resource allocation and reducing the likelihood of bridge failures.

Finally, research could explore the integration of water level monitoring systems with other bridge management tools and technologies. This could involve developing a centralized platform that combines real-time water level data with bridge inspection reports, maintenance records, and other relevant information. Such a platform would provide a comprehensive overview of bridge conditions and scour risk, facilitating data-driven decision-making and streamlining bridge management processes. Additionally, research could investigate the use of artificial intelligence and machine learning techniques to automate data analysis and identify patterns that could predict scour risk or detect early signs of bridge damage.

Recommendations for Implementation

Whether building a final scour monitoring system in-house, or contracting out to external parties, MDOT staff should take into considerations a set of recommendations when scaling the lessons of this research project across the entire state. Based on the insights of this study, the final solution should seek to apply the following requirements:

1. **Use non-contact water level sensors**: Sensors like those used this study (Ultrasonic or similar non-contact devices) should be used. Sensors placed in the water (e.g. pressure transducers) should be avoided to reduce maintenance

requirements due to biofouling. This will limit the amount of time that MDOT staff need to visit sites to repair compromised sensors.

2. **Require built-in wireless connectivity**: The final solutions should be connected to the internet and report data at least at hourly intervals. Simple data logging solutions will not address the problem, since events such as pressure flows need to be reported as soon as they occur.
3. **Datum-adjusted reporting and alerting**: The final data and dashboards should be displayed in real-time in NAVD88, or bridge engineer-preferred datum. This can be achieved by combining site surveys with the data collected by the devices. It should be possible for engineers to easily set these datum offsets, configure alerts and notifications to elevations expressed in this datum.
4. **Easy to switch out devices**: Bridge engineers and MDOT should not be required to conduct laborious maintenance in the field, such as repairing or troubleshooting equipment. As shown in this study, maintenance should only require a set of basic hand tools, so that staff can send back equipment for repair, while switching it out with a new unit during the same time. This will drastically reduce field labor, site visits, maintenance costs, and onus on field staff. A self-contained unit like the one used in this study, with all parts in one enclosure, should be prioritized.
5. **Built-in data quality control:** Bridge engineers should not be required to quality control the data. Rather, backend data services and staff should be dedicated to scanning for data problems as they occur to ensure that reliable data are always reliable. Maintenance tickets should be issues to flag sites for maintenance and send out new units for maintenance, after which relevant staff should be contacted. This will reduce outages and increase reliability.
6. **Mobile-friendly dashboards**: Many engineers use phones and tablets in the field. The data displays should be configured to render seamlessly on these devices, as well as on office desktops.
7. **Embeddable website elements**: To support integration into MDOT’s high flow website, the final solutions should make it easy to embed rendered images and *iframes* into external website. These need to be delivered via hypertext transfer protocol secured (https) channels.
8. **API access**: For easier integration into MDOT’s IT services and long-term storage, the final solutions should make it easy to pull in data via a secure application programming interface (API).

A note on open note on in-house, open-source adoption: Integrating open-source solutions into MDOT's existing workflows presents several significant challenges. Primarily, it necessitates a dedicated team of engineers and technicians with expertise in software development, data analysis, and hardware maintenance. This team would be responsible for customizing the open-source platform to align with MDOT's specific requirements, ensuring seamless integration with existing systems, and providing ongoing support and troubleshooting. Additionally, adopting open-source solutions may require a shift in MDOT's procurement and vendor management processes, as it involves working with a community of developers rather than traditional commercial vendors. This can introduce complexities in terms quality control. Furthermore, open-source solutions may not always offer the same level of user-friendliness and documentation as commercial products, potentially increasing the learning curve for MDOT staff.

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Appendices

A. List of Acronyms, Abbreviations, and Symbols
B. Technology Review
C. Deployment plan
D. Deployment plan - remaining network
E. Swap Instructions

Appendix A: List of Acronyms, Abbreviations, and Symbols

API: Application Programming Interface
DOTs: Departments of Transportation
DWL: Digital Water Lab
HTTP: Hyper text transfer protocol
MDOT: Michigan Department of Transportation
NOAA: National Oceanic and Atmospheric Administration
PCB: Printed circuit board
SoC: System-on-chip
SMS: Short message service
USDOT: United States Department of Transportation
USGS: United States Geological Survey

COLLEGE OF ENGINEERING
CIVIL & ENVIRONMENTAL ENGINEERING
UNIVERSITY OF MICHIGAN

Digital Water Lab

TECHNOLOGY REVIEW

October 2022

Our goal is to support MDOT's monitoring and management of scour critical bridges through the State of Michigan. To that end, we will bring to bear the latest sensing and data technologies. Sensor networks will aid MDOT engineers in prioritizing resources to address locations with the highest concerns or growing concerns.

This document provides a summary of existing technologies for remote water level monitoring. The specific objectives of this document are to:

1. Summarize existing technologies
2. Summarize existing vendors, suppliers, and service providers.
3. Compare and categorize all existing options that MDOT staff can use.

Technology Components

A water level monitoring solutions can be broadly categorized as:

1. Sensing – Devices that measure water levels
2. Data loggers – Devices that locally store measurements made by a sensor, and transmit the data to databases
3. Wireless protocols – Communication methods that are used to relay data to databases
4. Databases – Centrally located web services that are used to store data and share with clients on the Internet

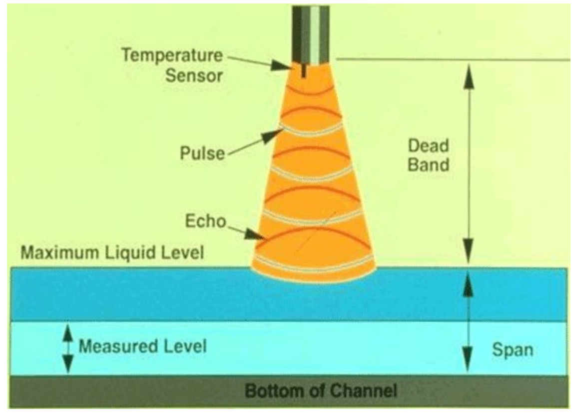
Sensing

I. Ultrasonic (sound)

Ultrasonic sensors measure the distance to an object by using ultrasonic sound waves. A transducer sends and receives ultrasonic pulses that communicate information back about the proximity of an object. Ultrasonic sensors are commonly used to measure water levels in both natural and built environments. As water levels change, the distance from the surface of the

Pros
Simple and Affordable
Cons
Environment can impact readings, limit on distance

water and the sensor changes and can therefore be detected. These types of sensors are typically simple and affordable.
It is important to note that air temperature, different materials, and even foam can impact the reading of the sound waves. They also have a blocking distance, or a limit to how far the sensor can be placed in order to get an accurate reading.



II. Radar (microwave)

Pros
Simple and Affordable
Cons
Environment can impact readings, limit on distance

Similar to ultrasonic sensors, radar measures the distance to an object by sending and receiving pulses, but in the case of radar -- electromagnetic waves, rather than sound waves -- are transmitted from the transducer.
The National Oceanic and Atmospheric Administration (NOAA) recently switched from using ultrasonic water level sensors to radar sensors at their sites in their National Water Level Observation Network (NWLON) due to errors in previous measurements due to temperature changes. It was found that the radar sensors were more resistant to temperature changes and more responsive to changes in distance, however, radar sensors were found to have a drop-off in accuracy during heavy rain or when floating ice and flotsam collected under the sensor. NOAA concluded that radar sensors were easier to maintain than ultrasonic sensors. [1]

III. Lidar (laser)

Lidar (Light Detection and Ranging) are sensors that use light as a pulsed laser, GPS, and inertial navigation system (INS) to measure distance. Similar to ultrasonic and radar sensors, a light

[1] Park, J., Heitsenrether, R., & Sweet, W. (2014). Water Level and Wave Height Estimates at NOAA Tide Stations from Acoustic and Microwave Sensors, *Journal of Atmospheric and Oceanic Technology*, *31*(10), 2294-2308. Retrieved Dec 3, 2021, from https://journals.ametsoc.org/view/journals/atot/31/10/jtech-d-14-00021_1.xml

Pros
Measures further distances than other sensors, energy efficient
Cons
Environment can impact readings

pulse is emitting and reflected back to a receiver to measure distance. Lidar sensors can measure distances much further than ultrasonic or radar sensors.

A 2020 study in the Water Resources Research journal found that one Lidar sensor (GARMIN LIDAR LITE) was "cost efficient," have "high energy efficiency," and have a "small measurement footprint."[2] Commercial products are not as readily available, however. Furthermore, the method requires more maintenance as laser lenses can become dirty and obstructed.

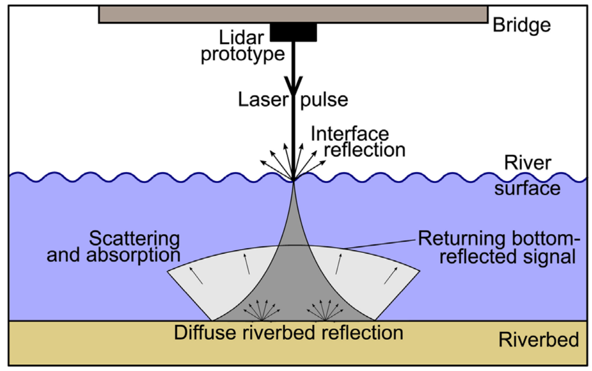


*Figure SEQ Figure * ARABIC 2: Schematic of lidar prototype experiment, where it is clamped to the underside of a bridge to measure river stage.*
Source: Water Resources Research

IV. Cameras

Pros
Customizable to identify unique environmental input
Cons
Not as rugged, need extensive resources to write necessary algorithms

Cameras can be used to take videos or images that are then analyzed by an algorithm for a specific data output. Using this type of sensor would require significant resources to develop the needed code to analyze the camera images and give useful data. However, done correctly, cameras can provide robust data.

Presently, cameras are used more for pedestrian or "people-counting". Using centroids and bounding boxes, the algorithm detects and tracks specific objects and then creates a data point to then be extrapolated into changes in environment. A similar technique would be applied to water sensing. USGS has just begun work to determine the usefulness of using cameras in sensing waterways and the surrounding environments. At the time of writing, this option is not readily deployable.

V. Pressure Transducers

Pros
Highly accurate
Cons
Significant maintenance required

Pressure transducers use strain gauges to measure the pressure of a fluid (water) and are often used to measure flow. These sensors are the only type that require contact with the water to collect data. Pressure transducers contain a force collector and a transduction element to generate an electrical signal. Pressure transducers can be highly accurate. However, because of the contact with water, maintenance can be quite extensive due to the need to clean off algae, ice, and other debris.

[2] Paul, J. D., Buytaert, W., & Sah, N. (2020). A technical evaluation of lidar-based measurement of river water levels. *Water Resources Research*, 56, e2019WR026810. https://doi.org/10.1029/2019WR026810

Data-logging

Microprocessors, or microcontrollers, are the “brain” of the computer, and serve as a central computing unit that take binary data (received from sensors) and provides an output. Most microprocessors are relatively affordable and consume low levels of power that allow them to be powered from solar panels and batteries, rather than requiring AC power. There are a number of DIY or “hobby”, low-cost options available, along with more rugged and higher processing options available. Since most dataloggers are not sold stand alone, and are part of an integrated solution, we have summarized the available options in the subsequent section of this report.

Wireless Protocols

Once the data is sensed and processed, it then needs to be communicated wirelessly.

I. Cellular Networks

Cellular networks offer broad coverage and are provided by purchasing SIM cards that connect with specific cellular carriers (i.e., Verizon, AT&T, T-Mobile, etc.). Costs for cellular network usually translate to monthly charges at a per-gigabyte price. However, since cellular towers are often placed in locations more central to residential and commercial areas, some more remote areas may not see as consistent coverage.

II. Wi-Fi

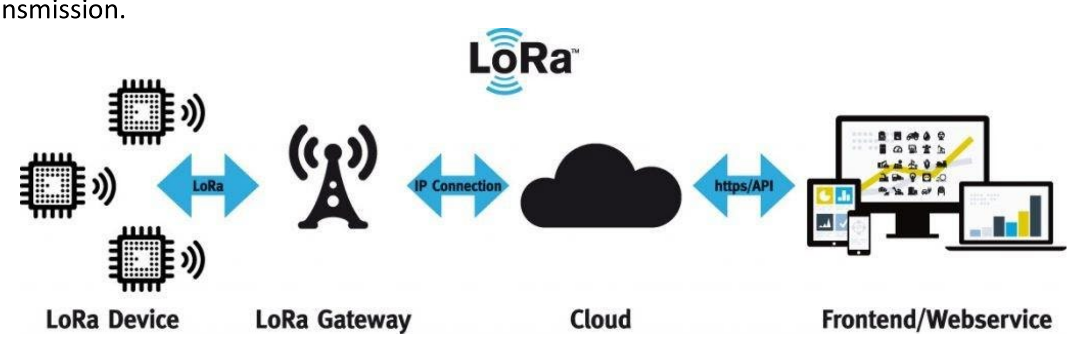
Wi-Fi networks typically offer a smaller area of coverage than cellular, but also typically do not have data limits and tend to have faster download and upload speeds. The smaller area is tied to a modem or wireless gateway that is hardwired through and provided by an internet service provider.

III. Mesh-based modems

Mesh-based modems provide the same speed and cost as Wi-Fi but also allow for broader Wi-Fi coverage through a series of nodes that communicate with each other. One node acts as the main Wi-Fi router and is connected directly to a modem or wireless gateway.

IV. Low-frequency/Long-range (LoRa) protocols

LoRa offers long range, low power data transmission for machine to machine (M2M) and Internet of Things (IoT) communication. LoRa uses wideband linear frequency modulated chirp pulses to encode information. However, they do have a limit on the quantity of data transmission.



V. Satellite

Satellite communication tends to have the highest coverage area, transmission costs do not depend on coverage area, and higher bandwidths are possible. Devices communicate with satellites using high frequency (GHz range) signals. There is a possibility for longer delays in transmission when using satellite. They require more power than their "terrestrial" options. Presently, satellite is also the most expensive option.

Databases and Servers

Once data is transmitted from the device it needs to be maintained and stored in a database system. While MDOT already hosts its own database, we provide a short summary here of alternative methods that may be used, if needed.

I. Cloud based solutions vs. locally maintained server-based solutions

Cloud based solutions are maintained off-site by a third-party vendor. They tend to be cheaper, as resources are not needed locally for maintenance; and they can offer lower storage rates due the volume of storage they provide to all consumers. However, there are certain elements that are out of control for users.

Local server solutions means that the end user is responsible for all elements of the database system, including, security, updates, etc. Scalability becomes a much larger issue with this option, and it requires many more resources. However, this option can be completely customizable, depending on the needs of the project.

II. Time series database vs. relational database solutions and schemas

Time series database are optimized to provide a quick response on queries. There are many "shelf-ready" visualization packages that have been designed to work specifically with time series databases. However, they cannot store non-time related data.

Relational database solutions and schemas require more resources in the initial setup and will require more time and processing power when queries are run. Although they can provide more options in how data is visualized, many of those visualizations would need to be custom built.

Equipment Stations and Sensor Options

DIY – Commercial

Depending on the customization and needs of the project, devices can be custom built ("DIY") using commercially available sensors, dataloggers, wireless communication, and database systems.

Below are the more commonly used components with pricing information. Prices are noted at the time of writing, with a general upward trends observed over the past five years.

Sensors

Type	Brand/Model	Features	Price (per unit)
Ultrasonic	Maxbotix MB7383 HRXL-MaxSonar-WRLST	• Resolution of 1mm • Accuracy of 1% • Maximum Range of 10m • Deadzone of 50cm • Operational Temperature: -40°C to 65°C • Operating Voltage: 2.7-5.5V • 2.9mA average current requirement	$131.95
	Senix ToughSonic 50	• Resolution of .34mm • Accuracy of 0.2% • Maximum Range of 15.2m • Operational Temperature: -40°C to 70°C • Operating Voltage: 0-10,0-5 VDC	$650.30
	APG Mid Range Sensor with Data Logging IRU-6429	• Resolution of 2.54mm • Accuracy of +/- 0.25% • Maximum Range of 9m • Operational Temperature: -40°C to 60°C • Operating Voltage: 12-28VDC	$588.82
	Judd Ultrasonic Depth Sensor	• Resolution of 3mm • Accuracy of 1 cm or .4 % distance to target • Maximum Range of 10m • Operational Temperature: -40°C to 85°C • Operational Voltage: 12-24VDC	$839.00
Radar	Sommer Non-Contact Discharge Radar RQ-30/RQ-30A	• Resolution of 1mm • Accuracy of +/-0.01m/s • Maximum Range of 16m • Operational Temperature: -35°C to 60°C • Operational Voltage: 12VDC	n/a
	Sommer Profiler RP-30	• Resolution of 1mm • Accuracy of +/-0.01m/s • Maximum Range of 15m or 35m (extended version) • Operational Temperature: -35°C to 60°C • Operational Voltage: 6-30VDC	n/a
	Miros RangeFinder	• Resolution of 1mm • Accuracy of <5mm • Maximum Range of 23-95m (depending on sensor chosen) • Operational Temperature: -30°C to 50°C • Operational Voltage: 12-36VDC	$16,000
Lidar	GARMIN LIDAR-lite v3	• Resolution of 1cm • Accuracy of 2.5cm distance >5m (~1%) • Maximum Range of 40m • Deadzone of 5cm • Operational Temperature: -20°C t	$129.99

	Benewake TF02-Pro LiDAR Mid-Range Distance Sensor	• Resolution: 1cm • Accuracy 5cm distance <5m • Maximum Range of 40m • Deadzone of 10cm • Operational Temperature: -20°C to 60°C • Operating Voltage • IP65 Protection	$96.95
	TeraRanger Evo 15m - The Medium-Range ToF Distance Sensor	• Resolution: 0.5cm • Accuracy of 4cm • Maximum Range: 15m • Deadzone: 50cm • Operational Temperature: not specified	$62.02
Cameras	Pricing is mainly dependent on the type of sensing required and is in human resource time to develop necessary code		
Pressure Transducer	Stevens SDX Analog Pressure Transducer	• Accuracy: +/-0.25% • Pressure Range: 0-45psi • Operational Temperature: -18°C to 85°C • Power Requirements: 9-26VDC	$295.00
	Omega Submersible Pressure Transducer with 4 Output Options	• Resolution: N/A • Accuracy: 0.08% • Pressure Range: 0-30psi • Operational Temperature: -18°C to 79°C	$876.85

Combined Sensors/Data-Logging

Brand/Model	**Features**	**Price (per unit)**
Ayyeka Wavelet V2, EX, 4R	• Battery powered, 33Ah • 3 ports, supports up to 12 3rd party sensors • 16 serial channels • Cloud-based platform integrates with SCADE or other platforms • Includes 2 SIM card ports	$2,999 for first 3 $1,400 for each after first 3

Campbell Scientific ALERT2	• Available with Wi-Fi, spread-spectrum radio, or cellular
	• 3 options available:
	  • The **canister** option includes six standard circular connectors for sensor I/O, as well as coax connectors for GPS, VHF radio, and optional integrated communications (Wi-Fi, spread spectrum, cellular).
	  • The **enclosure** option is built around the same platform as the canister option, but it is housed in a polycarbonate enclosure with cable glands and screw terminals for connecting external sensors.
	  • The **backplate** version is designed for applications where an enclosure will be provided, and it includes DIN rail terminals for easy sensor connections.
		n/a

Solinist AquaVent 5 Vented Water Level Datalogger	• Combines pressure and temperature sensors, hydrophobic filters and datalogger within a 22 mm x 173 mm (7/8" x 6.8") stainless steel housing • Ideal for shallow applications: up to 20 m (65 ft) submergence • Gauged pressure sensor for highly-accurate water level measurements: 0.05% FS • Multiple built-in hydrophobic filters and desiccants	$1,185
Telog PR-32A/32iA	• Single channel pressure recorder • Accuracy: ±0.075% of full scale at 73°F ±40 ppm/°F • **Temperature range:** 4° to 65°C • **Recording with PR-32 (no impulse option included)** • Sample Rate: 4 per second to 1 per 8 hours; programmable • Clock Accuracy: 0.01% • Memory Size :31,000 data values • Storage Method: Wrap around (first-in; first-out) • Cellular Internal: Telog WM2/L1 cellular modem LTE Category 1 certified Verizon Wireless. FirstNet available in the USA. • Factory installed, field replaceable Telog BP-4 lithium battery pack • Battery Life: Up to 2800 data calls to host computer	n/a

Telog Multi-channel RTUs	• **Recorder Channels:** 3 Pulse/event channels/4 Analog
	• **Analog Sampling**
	  ○ Sample rate: 1/sec to 1/8 hours for each channel
	  ○ Sample interval: 1 s to 8 h, synchronized to the hour, channel independent
	• **Event Sampling:** Event rate: 1 event/s maximum
	• Battery type: 9-volt lithium battery pack with MTA connector
	• Battery life: 6 months @ 73.4º F, with 1 sample every 5 s on all channels, no modem
	• External DC: Regulated 12 VDC; Unregulated 15-35 VDC
	• Cellular: Internal Telog WM2/L1 cellular modem LTE Category 1 certified Verizon Wireless
	• Modem upgradable to future communications technologies
	• Operating temperature: -15 to 60º C
		n/a

There are a number of microprocessors ranging from hobby-level (i.e. raspberry pi, Arduino) to more rugged options (i.e. Odroid). Depending on the processing needed and ruggedness, prices are typically under $100 and often $50 or less per unit.

Wireless

SIM Cards	$4-20/card
Cellular Providers	$5-30/month*
Satellite (Iridium)	$5-30/month*

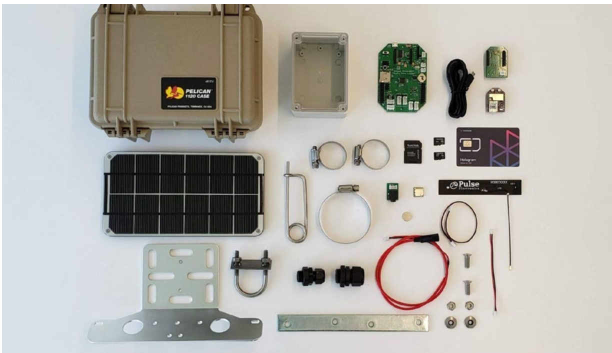
*pricing depends on the amount of data transferred per month and penalties for potential overages. Systems can be programmed depending on transfer needs (only transfer when there are changes in levels, etc.), however, these customizations require someone with programming experience.

DIY – Open Source

There are several open-source DIY sensor technology solutions available. These solutions require purchasing the parts and assembling them, but the instructions and manuals on how to do so are publicly available. Generally, these solutions are lower cost, but require more staff time to build and integrate into existing worksfolw.

Stroud Water Research Center – EnviroDIY

Founded in 1967 as a non-profit in Avondale Pennsylvania, Stroud Research Water Center's mission is to produce solutions for preserving and restoring fresh water. EnviroDIY (envirodiy.org) is an online community resource for DIY environmental science and monitoring. EnviroDIY is part of the WikiWatershed Toolkit, a Stroud Water Research Center initiative to help citizens, conservation practitioners, municipal decision-makers, researchers, educators, and students advance knowledge and stewardship of fresh water.[3] Members of the community forum can share their sensing projects and devices, along with tutorials and other resources, as well as be available for questions for those starting related projects. The platform also allows for resource to share data collected.



Through EnviroDIY, the EnviroDIY Monitoring Station Kit may be purchased for **$475** (when in stock).[4] This price does not include the water level sensor ($62-$876, see above), lithium ion battery (~$20), or the installation (price varies). The kit includes all other parts to build a solar powered, 4G cellular, and real-time data monitoring station.

3 https://stroudcenter.org/virtual-learning-resource/envirodiy-org/

4 https://www.envirodiy.org/product/envirodiy-monitoring-station-kit/

FloodNet

FloodNet is a cooperative between the New York City government and community, The City University of New York (CUNY), and New York University (NYU) to study flooding and its impact on the urban environment, specifically, New York City with the hope to reduce flooding risk. Through the FloodSense project, the team developed a water level sensor in order to generate real-time data on the frequency, depth, and duration of flooding events.

The sensor design and build instructions are available publicly through GitHub, allowing anyone to acquire, assemble, and deploy a similar sensor. The FloodSense sensor uses LoRa and ultrasonic sensors.

*Figure SEQ Figure * ARABIC 5: FloodNet Sensor Source: https://github.com/floodsense/floodsense_sensor*

Open-Storm

Open-Storm is a University of Michigan Digital Water Lab led initiative to provide open-source sensors, hardware and algorithms for the measurement and control of water systems. Open-Storm devices were designed using an industrially rated platform that allows for the simple deployment of sensors that transmit data wirelessly over a cellular network to a cloud-based database.

Currently, there are over 100 devices deployed in waterways in southeast Michigan that are collecting water-level data and available at maps.open-storm.org. The device design and build instructions are available publicly through GitHub and ifixit.com. The design and platform allows for additional customizations depending on the needs of the end user and has been vetted in a variety of different scenarios, including green infrastructure monitor to autonomous gage control. Compared to other open source options, Open-Storm was designed with "industrial quality" and automotive-grade components in mind, with the intent of support long-term, low maintenance applications.

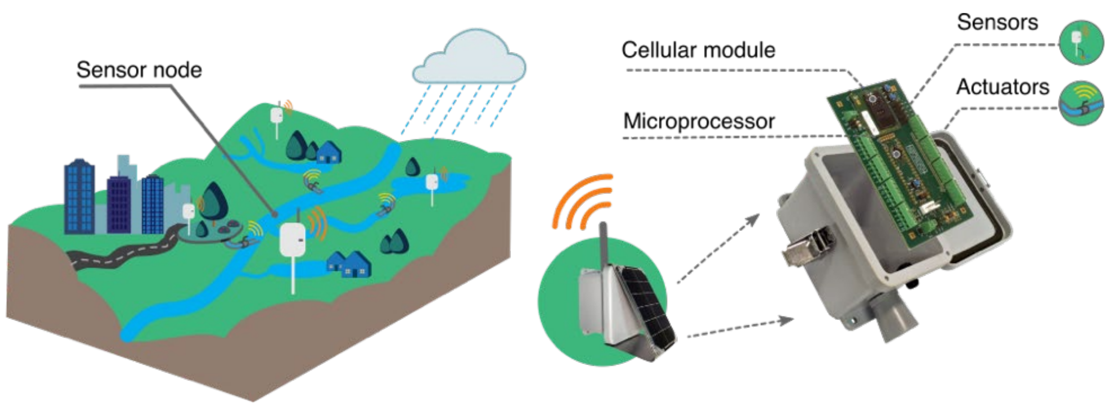


Figure 6: Open-Storm Node Source: Open-storm.org

Centers/Non-profits

Iowa Flood Center

Funded by the Iowa State Government, the Iowa Flood Center (IFC) was founded in 2009 at the University of Iowa's College of Engineering with the goal of providing Iowans with access to the latest technology and resources in helping with flood preparedness, decision making, and resiliency. All the work done at the center is accessible online through the Iowa Flood Information System (IFIS).

*Figure SEQ Figure * ARABIC 7: IFC Stream Sensor*

In partnership with the Iowa Department of Natural Resources, Iowa Department of Transportation, Iowa Homeland Security and Management Department, and Iowa Silver Jackets, IFC developed and maintains a network of over 250 stream sonar sensors to measure water depth and transmit data through a cellular network to the IFIS every fifteen minutes.

Vendor Supplied

For full-service, off-the-shelf products, there are a number of national and international vendors that provide sensing devices with wireless communication and database systems included.

*Figure SEQ Figure * ARABIC 8: SensiFlood hardware and software Source: Evigia*

Evigia

Evigia Systems provide IOT solutions for real-time data using wireless sensing, data analytics, and system integration technology. Based in Ann Arbor, MI, Evigia focuses on low-energy systems that have been used in in military, security, manufacturing, environmental, and general commercial applications.

Evigia's SensiFlood is a flood monitoring platform can be customized with pressure transducers, ultrasonic sensors, or radar sensors and uses either cellular or iridium satellite to communicate with their SensiFlood Web/Mobile Dashboard software.

Campbell Scientific

Campbell Scientific (Logan, Utah) designs and manufactures a variety of products including data loggers, data acquisition systems, and measurement and control products used worldwide in a variety of applications related to weather, water, energy, gas flux and turbulence, infrastructure, and soil.[5] Their products are intended as rugged and low-powered for monitoring and control.

Campbell Scientific has three turnkey solutions for flood monitoring including ALERT, ALERT2, hybrid ALERT, in addition to fully customizable systems. The platform is built around their own data logging products with optional integrated communications, encoders, and industry standard radio. Campbell Scientific's products may be purchased separately or as a complete system with maintenance support.

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5 https://www.campbellsci.com/about

High Sierra (One Rain)

Founded in 1992, High Sierra Electronics (which merged with One Rain in 2017) is a California-based environmental monitoring systems company. High Sierra Electronics designs, manufacturers, and builds complete hydro-meteorological systems with the goal of protecting lives and property from weather threats including flooding, dangerous road conditions, and vulnerable dams and levees. Depending on the needs of their clients, they provide both custom and standard packaged systems.

*Figure SEQ Figure * ARABIC 9: High Sierra Station Source: High Sierra Electronics*

High Sierra's Water Level Monitoring Station (Model 3466-00) is a packaged pressure transducer station that provides real-time data with the accuracy of 0.1%. The system is equipped with High Sierra's custom data transmitter and has an option to add a Radio Path Study for more remote location.

Hyfi

Hyfi is an Ann Arbor, MI-based environmental monitoring systems company that was founded in 2019 by University of Michigan environmental engineers. Still in the early and growth stage as a new company, Hyfi has been built on years of remote environmental monitoring both nationally and internationally.

*Figure SEQ Figure * ARABIC 10: Hyfi Flood Monitoring Station Source: Hyfi*

Hyfi's flood monitoring system is designed with reliable ultrasonic sensors for easy, local maintenance and provides customizable alerts, notifications, and flood visualizations. Hyfi's sensors are also designed to be installed and maintained with little effort.

Disclosure: Dr. Kerkez is the co-founder of Hyfi. No explicit recommendation is being made to consider Hyfi, nor that it is better than any of the other options.

Intellisense

Intellisense's Advance Warning Equipment (AWARE) Flood System is a rugged flood sensor that detects and automatically alerts users to flooding. Using a pressure transducer, the sensors can detect water levels, barometric pressure, air and water temperatures, and GPS location. AWARE IoT operations include *Iridium* satellite connection and cloud-based data logging. An added feature to the AWARE system is the option to add a camera to the device to visually monitor locations.

Intellisense, based in South Bay area of Los Angeles, also specializes in weather stations and meteorological sensors.

*Figure SEQ Figure * ARABIC 11: AWARE Flood System Source: Intellisense*

StormSensor

StormSensor provides sensor networks to monitor flooding, runoff, and rain in real-time. Currently, most of their clients are urban municipalities focused on monitoring storm sewer systems, but their products could be used in any infrastructure impacted by waterways and rain events. StormSensor's Networked Scute Sensors include an ultrasonic depth sensor, an ultrasonic doppler velocity sensor, and connects to their Terrapin cloud-based software via a LoRa network. StormSensor markets their product as an all-in-one, turnkey solution and must be purchased as a network, rather than single monitoring devices.

Vendor Cost Comparison

	Evigia	Campbell Scientific	High Sierra	Hyfi	Intellisense	StormSensor
						Equipment Costs
Water Level Station including sensor, battery, mounting, etc.	$3000	$4282	$3971	$1495 Annual Service Contract	$4995	min. 10 $1000
						Data Costs
Data Plan – Annual Per Station	$1000	$144	$102	Included in Service Contract	$84	$1000
Software / Dashboard - Annual Subscription Fee		$790 (one time cost)	$240 per station per year	Included in Service Contract	Included	Included
Data Sharing - Annual Service Fee		No Cost	$350 per station per year	No Cost	No cost	
						Additional Features
Warranty		3 years	2 years	Included with service contract	1 year	Included
Third Party Software Capability	No	Yes	Yes	Yes	Yes	No
Alert Notification Capability	Yes	Yes	Yes	Yes	Yes	Yes
Additional Sensors – third party sensors	Yes	Yes	Yes	Rainfall included	Yes	No
						Rounded Annual Cost per Device (5 year period)
	$1600	**$1200**	**$1500**	**$1500**	**$1500**	**$1200**

Technology Comparison

💧 =Less Effort & Resources 💧💧💧💧💧 = More Effort

	DIY – Commercial	DIY – Open Source	Vendor

Cost Comparison

	DIY – Commercial	DIY – Open Source	Vendor
Equipment (Per Site)	💧💧💧💧 *Depends on choices of sensors and will experience more waste of products through design iteration	💧💧💧	💧💧💧💧💧
Deployment	💧💧💧 *Costs increase as deployment is not included in pricing and parts and training are required	💧💧💧	💧💧
Internal Resources (People Time)	💧💧💧💧💧	💧💧💧	💧
Data	💧	💧💧	💧💧💧
Annual Maintenance	💧💧💧💧	💧💧💧	💧💧💧

Scalability

Ease of Scale	💧	💧 💧 💧 *Depends on system chosen	💧 💧 💧 💧 💧
Time	💧 💧 💧 💧	💧 💧 💧	💧
Annual Maintenance	💧 💧 💧	💧 💧 💧	💧

Reliability

Accuracy	Depends on robustness of custom system	💧 💧 💧 💧	💧 💧 💧 💧
Data Throughput		💧 💧 💧 💧	💧 💧 💧 💧
Latency		💧 💧 💧	💧 💧 💧
Security		💧 💧	💧 💧 💧
Tampering Issues		💧 💧 💧	💧 💧 💧

			Expertise
Who can build	In-house, requires someone comfortable with sensor tech, coding, and database systems	Can be built in-house or hired third party, using provided designs	Vendor
Who can maintain	In-house or hired third party. Maintenance requires less skilled resources than original design	Can be done in-house or hired by a third party. Some Open Source institutions provide more robust maintenance information or support than others	Vendor

Recommendation

Taken into consideration the vast array of options from DIY to off the shelf solutions that would allow MDOT engineers to collect data and monitor scour critical bridges, we recommend the the initial state-wide pilot deployment using Open-Storm devices for the following reasons:

1. Cost: When all the factors of cost are factored into the decision, Open-Storm devices are initially more cost effective on a per device annual basis than DIY or commercial solutions.
2. Speed of deployment: Open-Storm devices are designed and ready to be deployed immediately and scaled easily. Additionally, the University of Michigan team is trained on the platform.
3. Ease of deployment: Open-Storm devices, built at the University of Michigan, are designed to easily be deployed using a minimal amount of material and allow for a "plug-in-play" solution.
4. Reliability: Unlike an untested DIY device, Open-Storm devices have been tested in the field for a number of years and have received several rounds of upgrades to ensure reliability of performance through the variety of weather conditions in Michigan.
5. Expertise: Open-Storm dashboards, in partnership with the Digital Water Lab at the University of Michigan, can be customized and integrated in an ArcGIS platform. Open-Storm devices are designed to be easily swapped that do not require in-field expertise for maintenance, repairs, and replacements.

MDOT Pilot Deployment Proposal

September 1, 2021

MDOT 7080/7079 (map link)

US 23/North Branch Macon Creek (South of Milan)

DEPLOYMENT STRATEGY

Mount using upside down drilled cantilever mount, shown left, at the bridge crossing of North Branch Macon Creek and US-23 South Bound. Sensor will be mounted on the side wingwall of the western side of the Southbound bridge. However, this is subject to change to the Northbound side upon visiting the site, if one side provides a clearer line to the water.

ROAD CLOSURE CONSIDERATIONS

There is ample shoulder space on the side of US-23 beyond the guardrails of the bridge. Deployment team can pull over into the grass and walk along the outside of the guardrails to access wing walls.

MDOT 7166/7167 (map link)

Detroit-Toledo Expressway (I-75)/La Plaisance Creek (Southeast Monroe)

DEPLOYMENT STRATEGY

Mount using upside-down drilled cantilever mount on the corner of the bridge wall. A rebar locator will be used to avoid drilling into rebar. Sensor will be mounted on the side wingwall of the eastern side of the Northbound bridge.

ROAD CLOSURE CONSIDERATIONS

Team will park on the shoulder of I-75 NB, east side of the road near the bridge. From here it is only a short walk and step over the guardrail to access the wing of the bridge to mount. Due to proximity of wingwall to road, signage or road closure may be necessary.

MDOT 1072 (map link)

I-69/Sauk River (Coldwater)

DEPLOYMENT STRATEGY

Mount using upside down drilled cantilever mount at the bridge crossing of old 27 and Sauk River. Mount on the upper corner rather than lower edge to ensure sensor can capture high flow events that (indicated by the staff gauge) that would otherwise be in the dead zone of a lower node.

Note: this plan does not involve mounting on a wingwall.

ROAD CLOSURE CONSIDERATIONS

At location, Habitat for Humanity Restore is nearby and is only a short walk to the bridge of interest. Given that the installation will happen on the bridge, and not wingwalls, signage or road closure may be necessary.

MDOT 2471 (map link)

US 23/Swartz Creek

DEPLOYMENT STRATEGY

Mount using upside down drilled cantilever mount at the bridge crossing of Swartz Creek and SB I-75. Sensor will be attached on the West elevation, on the southern wingwall.

ROAD CLOSURE CONSIDERATIONS

Team will be able to park in the large grass space just after the bridge crossing on SB I-75. There is a large enough space to park entirely off the roadway and walk along the guardrail (on the opposite side of traffic) to access the bridge side wingwalls.

MDOT 2613 (map link)

MI 15/Flint River (North of Davison)

DEPLOYMENT STRATEGY

Mount using upside down drilled cantilever mount at the westside of the bridge crossing of 15 (N State) and the Flint River. Note that this installation is not on a side wingwall, but on the concrete wall on the bridge deck itself.

ROAD CLOSURE CONSIDERATIONS

Team can park at the Genesee County Park Canoe Launch. Getting to the site will require crossing the highway and although the shoulder is wide, signage or possible closure will be required.

MDOT Deployment Logistics

July 2022

Permit Number: 98000-086975-22-062422

Team Member	Title/Position	Contact Information (cell)	Emergency Contact	Contact Information
Ken Ferrell	Summer Temp	734-217-7188	Charletta(shar-let-uh) Stafford	734-678-1228
Mitchell Wojtowicz	`Summer Temp	734-717-3186	Angela Wojtowicz	734-657-5414
Branko Kerkez	PI	941.400.1617		
Kate Kusiak Galvin	Sr. Project Manager	708.525.5418		
Travis Dantzer	Grad Student	989.387.2663		

EMERGENCY RESPONSE PLAN>

FIELD HAZARD IDENTIFICATION PLAN>

SCHEDULE OVERVIEW

- **Wednesday, July 6:** University/Southwest: 7075, 7092, 1091 (perform maintenance on 1072)
- **Thursday, July 7:** Bay: 10428, 9178

- **Tuesday, July 12:** Superior: 2954, 8488, 488
- **Wednesday, July 13:** Superior: 6513, 9682
- **Thursday, July 14:** North: 1500, 8955, 335
- **Friday, July 15:** Bay: 2892, 390

- **Tuesday, July 19:** Grand: 3970
- **Wednesday, July 20:** Metro: 11328, 6142

- **Wednesday, July 27:** North: 752, 6440
- **Thursday, July 28:** Grand: 8767, 4932, 7587

Wednesday, July 6, 2022

University-Southwest: LOCAL
3 New, 1 Maintenance

NEW: MDOT 7075, MDOT 7092, MDOT 1091
Maintenance: MDOT 1072

TOTAL LIST OF SUPPLIES

QUANTITY	ITEM
4	4 or 5′ steel Strut Channel
4	Telespar Receivers
8	½″ Tapcons
8	Washers
4	Winged strut channel connector
4	Nodes

MDOT 1091 South Branch Hog Creek (I-69 NB)

Advance Notice Reference #:89875

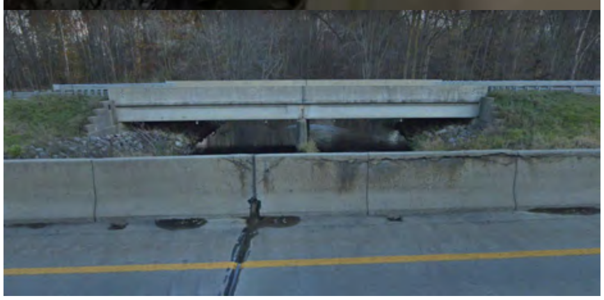
GOOGLE MAP LINK	PARKING ADDRESS
42° 1' 58.44" N 84° 58' 44.7384" W	Shoulder before structure. (~6 ft of room to operate on shoulder)

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Community Health Center of Branch County: Emergency Room	4′ steel strut channel ½′′ tapcons/washers (2) Winged strut channel connector Telespar receiver

ACCESS CONSIDERATIONS

Fence along grassed areas. Watch for poison ivy if operating in the river. Be cautious of traffic while operating

KEY PHOTOS (additional photos and 360 video in AirTable):



Video: https://www.youtube.com/watch?v=TwYn8FWNl8A

DEPLOYMENT STRATEGY

Cannot deploy on wing walls due to vegetation. Bridge mount, drill into concrete and mount cantilever straight out from road using tapcons and washers to secure a 4’ steel strut channel. (Northbound/Eastside)

MDOT 1072 Sauk River (I-69 BL)

Advance Notice Reference #:89879

GOOGLE MAP LINK	PARKING ADDRESS
https://www.google.com/maps/place/41%C2%B055'56.3%22N+85%C2%B000'16.9%22W/@41.9323056,-85.0046944,729m/data=!3m2!1e3!4b1!4m5!3m4!1s0x0:0x68bcafae89c61502!8m2!3d41.9323!4d-85.0047?hl=en&authuser=0	At location, Habitat for Humanity Restore is nearby and is only a short walk to the bridge of interest.

CLOSEST EMERGENCY ROOM

Community Health Center of Branch County: Emergency Room

DEPLOYMENT SUPPLIES REQUIRED

Strut

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://youtu.be/eCO2iolHGGw

DEPLOYMENT STRATEGY

Data is showing a solid obstruction. Cantilever will either need to be extended or relocated, if obstruction is not from the water.

MDOT 7092 North Ranch Ten Mile Creek (US-23 SB)

Advance Notice Reference #:89877

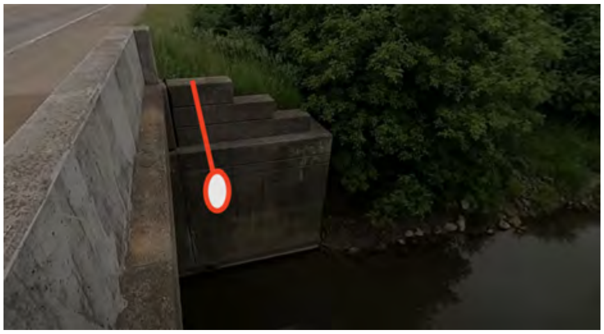
GOOGLE MAP LINK	PARKING ADDRESS
41° 45' 18" N 83° 41' 48.8184" W	Shoulder of road.

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
ProMedica Flower Hospital - Emergency Department	4' strut channel ½'' tapcons/ashers (2) Winged strut channel connector Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://www.youtube.com/watch?v=81c3Kq7zgfo

DEPLOYMENT STRATEGY

Drill into concrete, mount cantilever on wingwall parallel to the road using two tapcons and washers. Westside.

MDOT 7075 Middle Branch Macon River (US-23 NB)

Advance Notice Reference #:89864

GOOGLE MAP LINK

41° 58' 59.16" N 83° 40' 42.3919" W

PARKING ADDRESS

Shoulder of road.

CLOSEST EMERGENCY ROOM

Emergency Physicians Medical Grp

DEPLOYMENT SUPPLIES REQUIRED

4′ steel strut channel
½′′ tapcons/ashers (2)
Winged strut channel connector
Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://www.youtube.com/watch?v=RVyxvxNWkbg

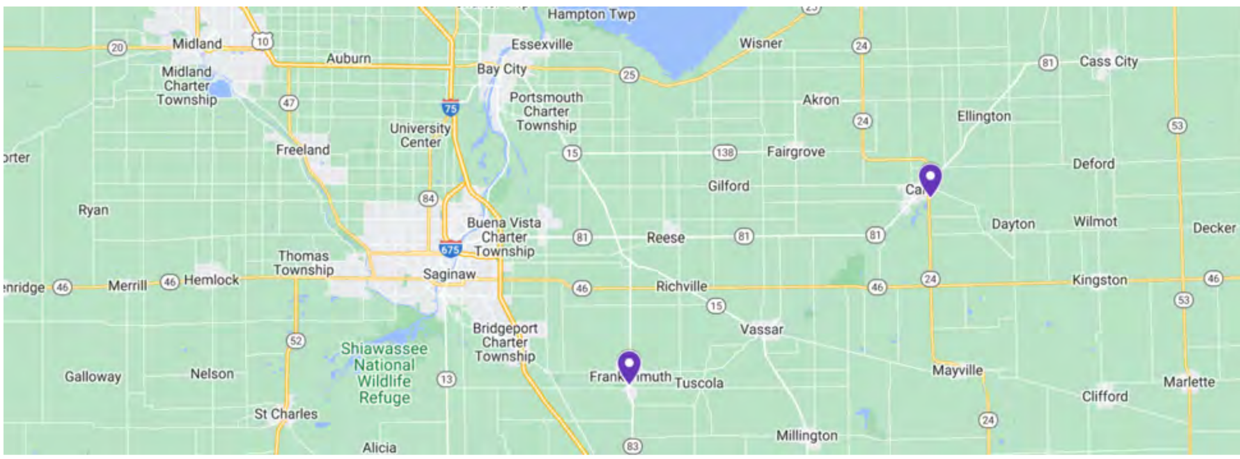
DEPLOYMENT STRATEGY

Drill into the concrete, mount the cantilever straight out from the overpass using two tapcons and washers. 4' strut channel should prevent the node from ever picking up soil readings if water levels drop significantly. (Eastside)

Thursday, July 7, 2022

Bay: LOCAL
2 New

NEW: MDOT 10428, MDOT 9178



TOTAL LIST OF SUPPLIES

QUANTITY	ITEM
2	Winged strut channel connector
2	Telespar receivers
2	4 or 5 ’ strut channel
4	½” Tapcons
4	Washers
2	Nodes

MDOT 10428 Cass River (M-24 NB)

Advance Notice Reference #:89880

GOOGLE MAP LINK	PARKING ADDRESS

43° 29' 0.974" N 83° 23' 20.3593" W

Tuscola County Recycling

CLOSEST EMERGENCY ROOM

McLaren Caro Region - Emergency Department

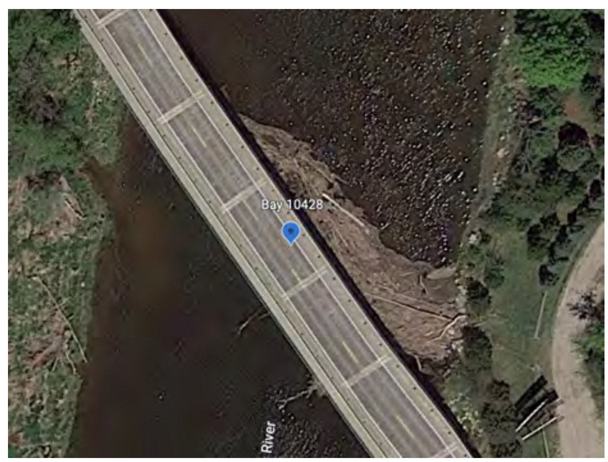
DEPLOYMENT SUPPLIES REQUIRED

Winged strut channel connector
4′ steel strut channel
½′′ tapcons/washers (2)
Telespar receiver

ACCESS CONSIDERATIONS

Downstream side has fencing that may inhibit deployment on that side. Upstream side appears to get clogged with driftwood based on google images.

KEY PHOTOS (additional photos and 360 video in AirTable):



DEPLOYMENT STRATEGY

Drill into the bridge more toward the north end on the upstream side. Mount cantilever straight out from the bridge using tapcons and washers to secure the steel strut channel. (Eastside/Northbound)

MDOT 9178 Cass River (M-83 NB)

Advance Notice Reference #:89881

GOOGLE MAP LINK

43° 19' 27.494" N 83° 44' 33.6793" W

PARKING ADDRESS

Open lot at gift shop. (North side of bridge)

CLOSEST EMERGENCY ROOM

Emergency - Ascension St. Mary's Hospital

DEPLOYMENT SUPPLIES REQUIRED

Winged strut channel connector
4' steel strut channel
U-bracket
½'' tapcons/washers (2)
Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

	Video: https://www.youtube.com/watch?v=buoWJqkYXCw

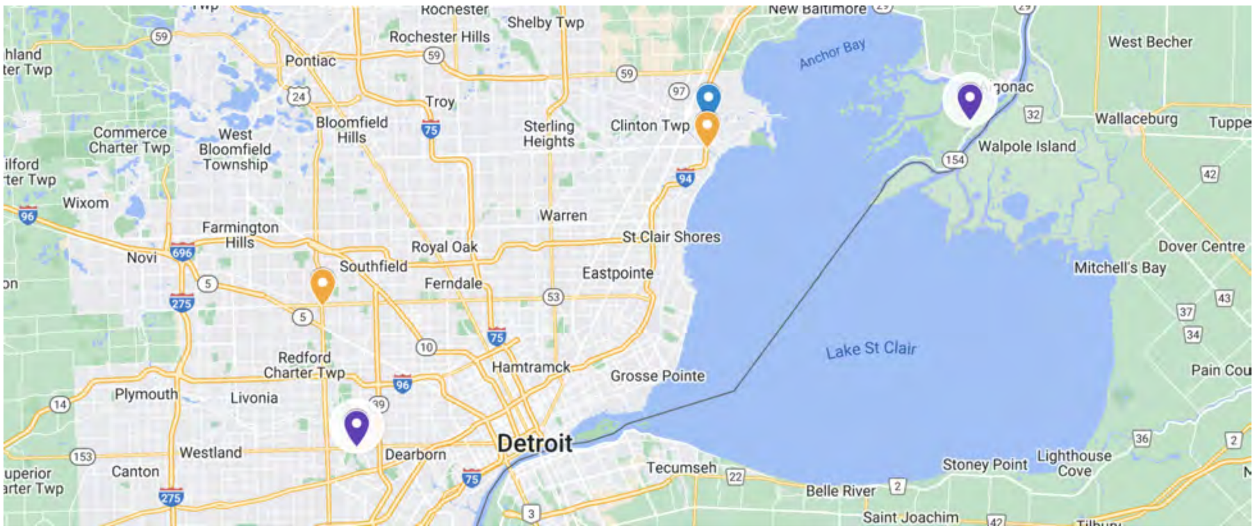
DEPLOYMENT STRATEGY

Drill into the bridge more toward the north end on the upstream side. Mount cantilever straight out from the bridge using tapcons and washers to secure the steel strut channel. (Eastside/Northbound)

Friday, July 8, 2022

Metro: LOCAL
1 New

NEW: MDOT 11328



MDOT 11328 Rouge River (M-153 WB)

[Advance Notice Reference #:89949]

GOOGLE MAP LINK	PARKING ADDRESS
42° 19' 41.894" N 83° 14' 37.2793" W	42° 19' 39.5292" N 83° 14' 33.4165" W

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Henry Ford Hospital	4′ strut channel ½′′ tapcons/washers (2) Winged strut channel connector Telespar receiver

ACCESS CONSIDERATIONS

Railing may hinder drilling.

KEY PHOTOS (additional photos and 360 video in [AirTable]):

	 Video: https://www.youtube.com/watch?v=7lC0oEjLKco

DEPLOYMENT STRATEGY

Mounting the cantilever directly off of the bridge, under the guardrail on the Westbound/North side.

Monday, July 11, 2022

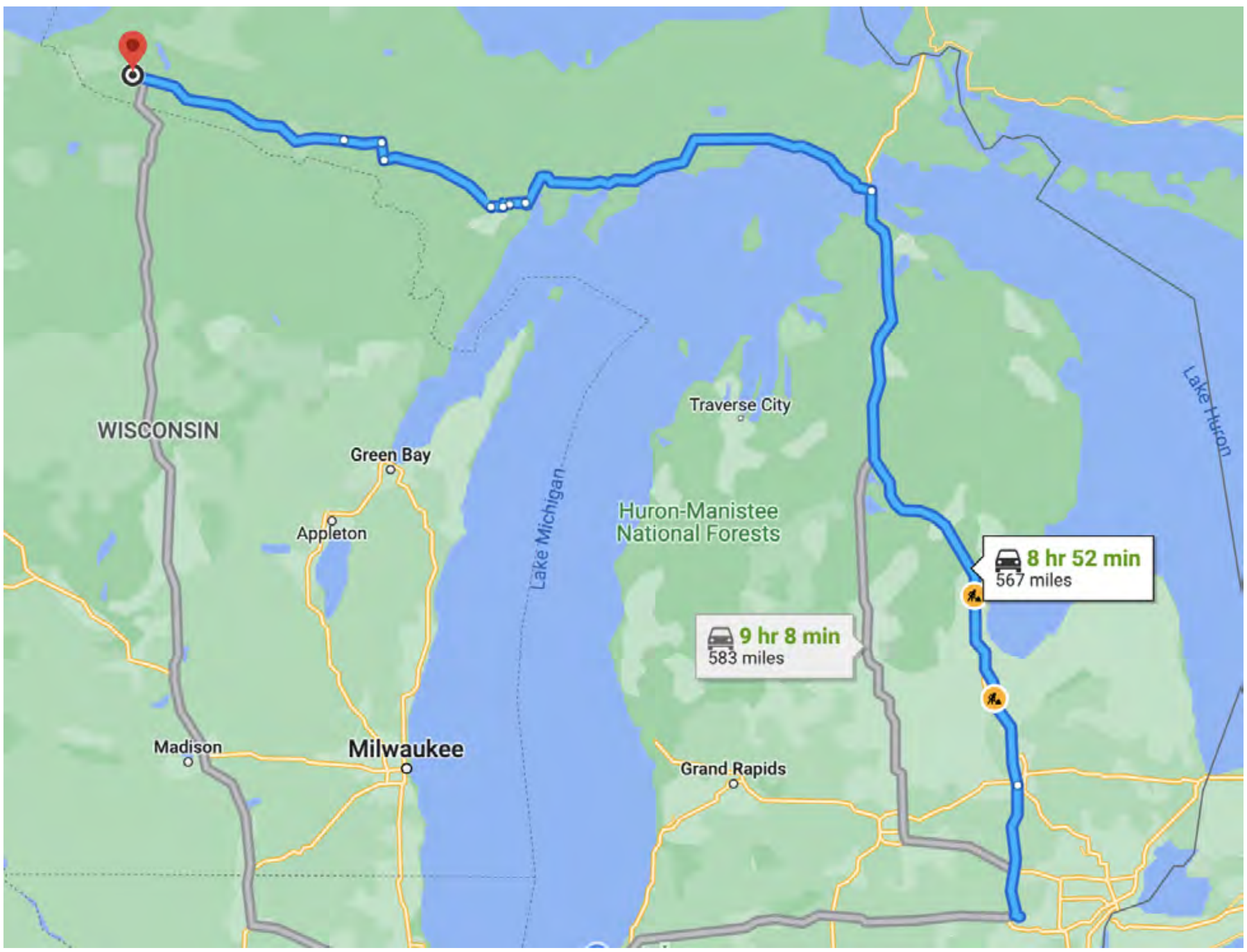
TOTAL LIST OF SUPPLIES

QUANTITY	ITEM
A lot	Gas
10	4 or 5’ strut channels

20	½’ tapcons
20	Washers
10	Winged strut channel connector
10	Telespar receiver
10	Nodes

Superior/North/Bay: OVERNIGHT

Day 1: Travel Day



[DIRECTIONS]

HOTEL INFORMATION:

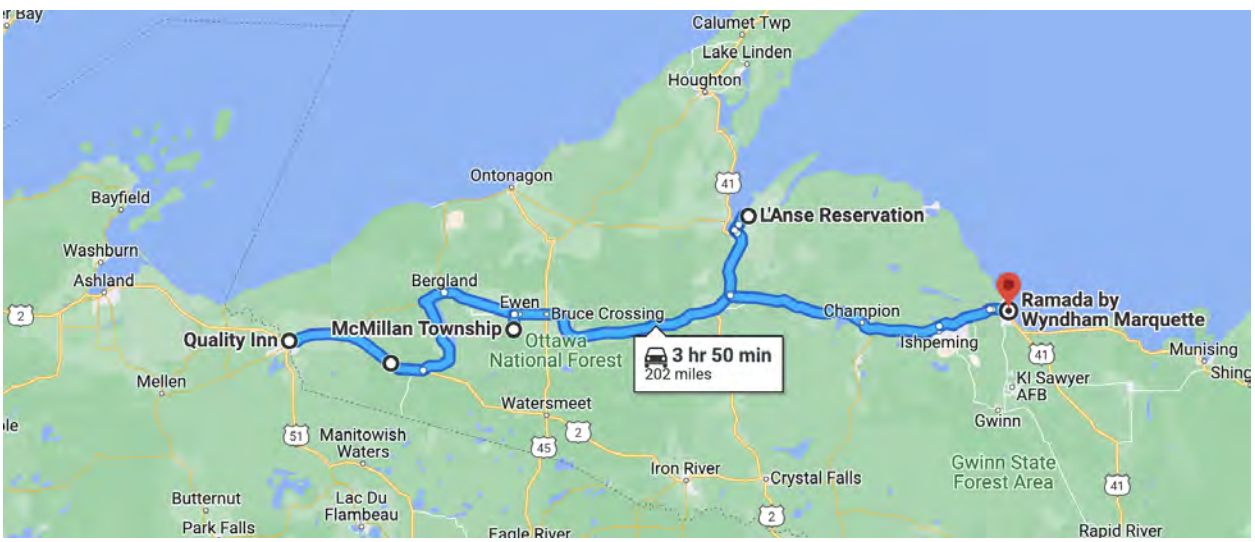
Quality Inn
210 E. Cloverland Dr.
Ironwood, MI 49938
HOTEL WEBSITE
(906) 932-2224

Mitch Confirmation: 11299458
Ken Confirmation: 11299537

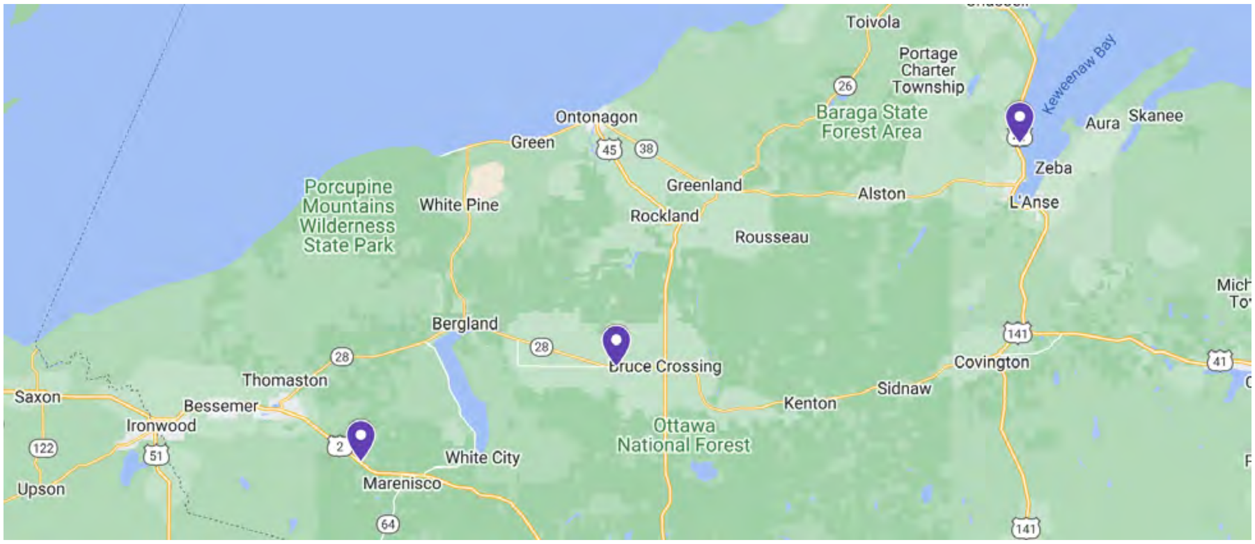
Tuesday, July 12, 2022

Superior/North/Bay: OVERNIGHT
Day 2: Superior: 3 New

NEW: MDOT 2954, MDOT 8488, MDOT 488



DIRECTIONS



MDOT 2954 Little Presque Isle River (US-2 EB)

[Advance Notice Reference #:89885]

GOOGLE MAP LINK

[46° 24' 18" N 89° 46' 45.12" W]

PARKING ADDRESS

Shoulder of the road

CLOSEST EMERGENCY ROOM

[Munising Memorial Hospital]

DEPLOYMENT SUPPLIES REQUIRED

4' steel strut channel
½" tapcons/washers (2)
Winged strut channel connector
Telespar receiver

ACCESS CONSIDERATIONS

Must go over the guard rail, may need waders.

KEY PHOTOS (additional photos and 360 video in [AirTable]):

	 Video: https://youtu.be/8OH5dwvGahY

DEPLOYMENT STRATEGY

Drill into the wingwall on the Eastbound/South side and install cantilever parallel to the overpass/road using tapcons and washers to secure 4’ steel strut channel.

MDOT 8488 S Branch Octonagon River (US-28 WB)

Advance Notice Reference #:90195

GOOGLE MAP LINK	PARKING ADDRESS
46° 32' 4.9333" N 90° 23' 48.8594" W	Ewen Do it Best Building Sup

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Munising Memorial Hospital	4’ steel strut channel ½’’ tapcons/washers (2) Winged strut channel connector Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://youtu.be/jgwNWKE3ZeE

DEPLOYMENT STRATEGY

No water around the wingwalls. Drill into concrete on the outside of the railing. Mount toward the center of the stream using tapcons and washers to secure a 4' steel strut straight out from the road.

North side of road (WB)

MDOT 488 Little Carp River (US-41 SB)

Advance Notice Reference #:89888

GOOGLE MAP LINK

46° 50' 7.813" N 88° 29' 32.1169" W

PARKING ADDRESS

46° 50' 5.4334" N 88° 29' 17.2453" W

CLOSEST EMERGENCY ROOM

Baraga County Memorial Hospital

DEPLOYMENT SUPPLIES REQUIRED

Winged strut channel connector
Telespar receiver
4' steel strut channel

ACCESS CONSIDERATIONS

Having waders may help while deploying on the wingwall.

KEY PHOTOS (additional photos and 360 video in AirTable):

 	 Video: https://youtu.be/cNSskOVetOU

DEPLOYMENT STRATEGY

Clear the vegetation growing over the wingwalls - clear enough room to drill and mount 4' strut channel over water. Aim to deploy on the upstream (west) side. If there's too much obstruction, move to the downstream (east) side.

HOTEL INFORMATION:

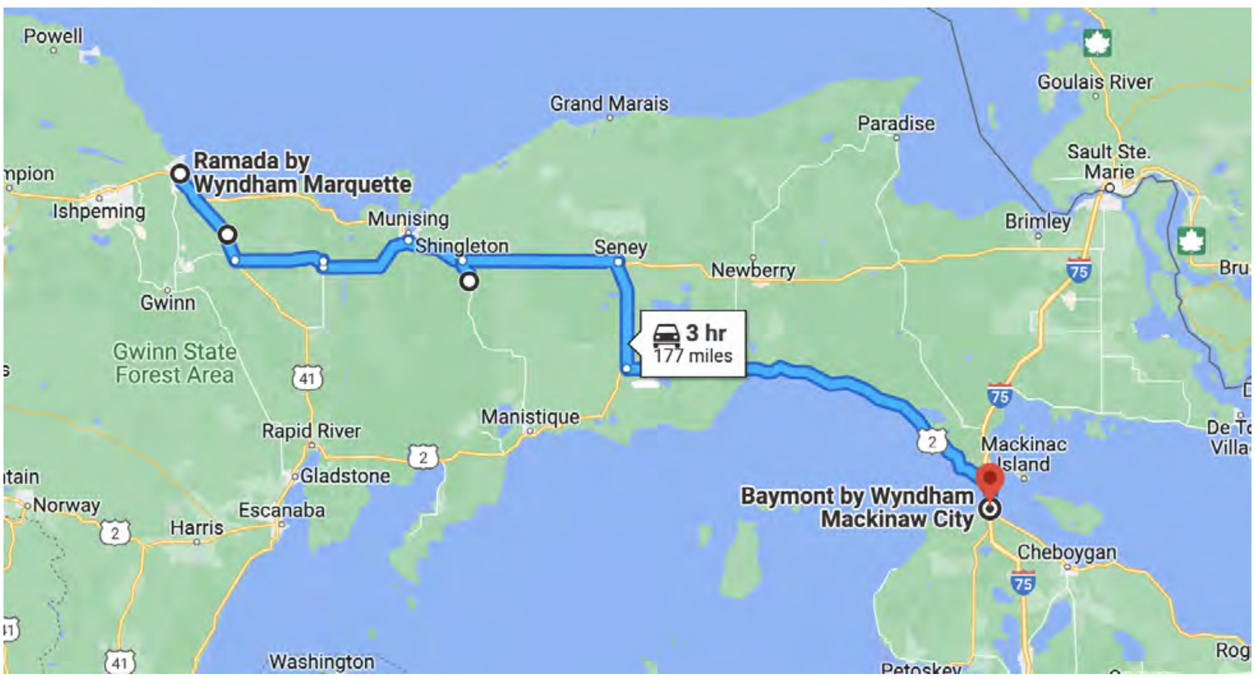
Ramada by Wyndham Marquette
412 W. Washington St.
Marquette, MI 49855
HOTEL WEBSITE
906-228-6000

Mitch Confirmation: 80854ED083733
Ken Confirmation: 80854ED083737

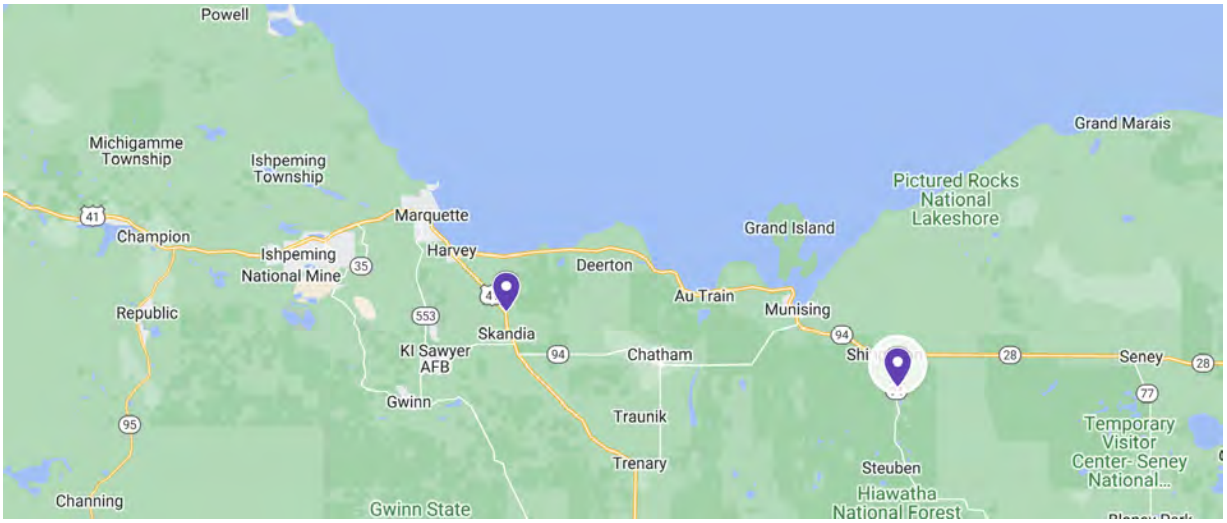
Wednesday, July 13, 2022

Superior/North/Bay: OVERNIGHT
Day 3: Superior: 2 New

NEW: MDOT 6513, MDOT 9682



[DIRECTIONS]



MDOT 6513 Chocolay River (US-41 SB)

Advance Notice Reference #:89890

GOOGLE MAP LINK

46° 24' 27.3733" N 87° 14' 46.6393" W

PARKING ADDRESS

46° 24' 29.3494" N 87° 14' 56.2585" W

CLOSEST EMERGENCY ROOM

Munising Memorial Hospital

DEPLOYMENT SUPPLIES REQUIRED

4′ steel strut channel
½′′ tapcons/washers (2)
Winged strut channel connector
Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://youtu.be/Dx24XgOw5dw

DEPLOYMENT STRATEGY

Drill into concrete on the Southbound/Westside, mount cantilever on wingwall upstream side of structure parallel to road using tapcons and washers to secure 4’ steel strut channel.

MDOT 9682 N Branch Stutts Creek (US-94 SB)

Advance Notice Reference #:89891

GOOGLE MAP LINK	PARKING ADDRESS
46° 18' 2.5333" N 88° 41' 15.3989" W	Shoulder of the road

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Munising Memorial Hospital	4’ steel strut channel ½’’ tapcons/washers (2) Winged strut channel connector Telespar receiver

ACCESS CONSIDERATIONS

May need waders.

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://youtu.be/XD2F3iCRSgg

DEPLOYMENT STRATEGY

Drill into concrete on the Southbound/Westside, mount cantilever on wingwall upstream side of structure parallel to road using tapcons and washers to secure 4' steel strut channel.

HOTEL INFORMATION:

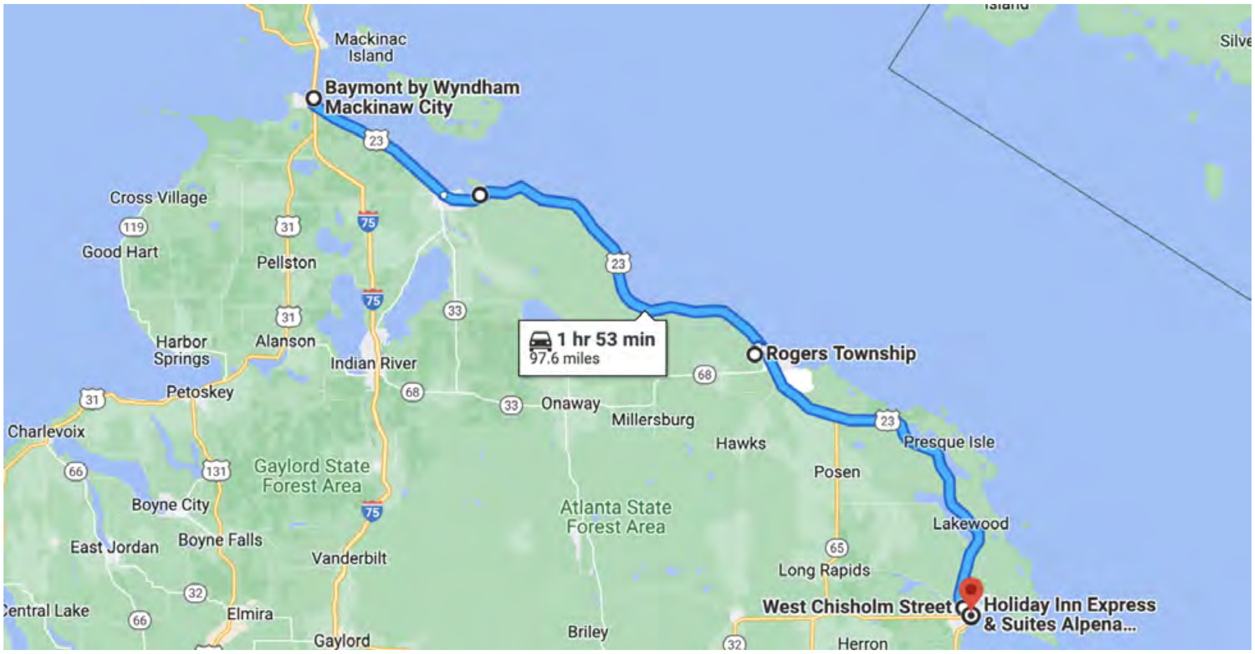
Baymont by Wyndham Mackinaw City
109 S. Nicolet Street
Mackinaw City, MI 49701
HOTEL WEBSITE
231-436-7737

Mitch Confirmation: 81683ED056871
Ken Confirmation: 81683ED056872

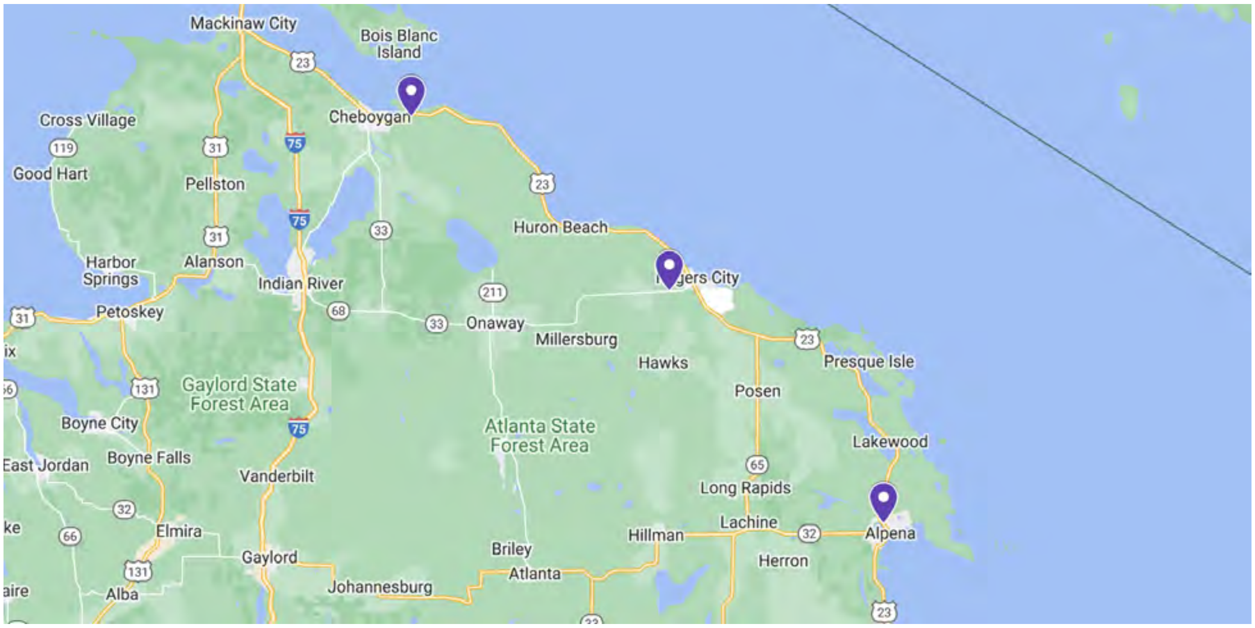
Thursday, July 14, 2022

Superior/North/Bay: OVERNIGHT
Day 4: North: 3 New

NEW: MDOT 1500, MDOT 8955, MDOT 335



[DIRECTIONS]



MDOT 1500 Elliot Creek (US-23 NB)

Advance Notice Reference #:89892

GOOGLE MAP LINK

45° 38' 46.68" N 84° 23' 42.6444" W

PARKING ADDRESS

Shoulder of road. (wide gravel area)

CLOSEST EMERGENCY ROOM

McLaren Northern Michigan - Cheboygan Campus Emergency Department

DEPLOYMENT SUPPLIES REQUIRED

3-4' strut channel
½''tapcons/washers (2)
Winged strut channel connector
Telespar receiver
Waders (maybe)

ACCESS CONSIDERATIONS

May need to enter stream in order to get a proper/working deployment.

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://youtu.be/RortsYFudbE

DEPLOYMENT STRATEGY

Bridge mounted on concrete overpass straight out from road using tapcons and washers to secure 3-4' steel strut channel (Northbound/Eastside)

MDOT 8955 N Trout River (M-69 EB)

Advance Notice Reference #:89893

GOOGLE MAP LINK	PARKING ADDRESS
45° 24' 7.9333" N 83° 52' 42.5244" W	Shoulder of road

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
McLaren Northern Michigan - Cheboygan Campus Emergency Department	4' steel strut channel 1/2 '' tapcons/washers (2) Winged strut channel connector Telespar receiver Waders (maybe)

ACCESS CONSIDERATIONS

Must go over guard rail to access the wingwall.

KEY PHOTOS (additional photos and 360 video in AirTable):

	Video: https://www.youtube.com/watch?v=M_ZGac-8fng

DEPLOYMENT STRATEGY

Drill into concrete, mount on the wingwall going parallel with the road using tapcons and washers to secure 4’ steel strut channel (Eastbound/Southside - East Wingwall).

MDOT 335 Thunder Bay River (U-23 SB)

Advance Notice Reference #:89894

GOOGLE MAP LINK	PARKING ADDRESS
45° 4' 30.0137" N 83° 26' 56.949" W	HPC Credit Union

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Alpena Health And Medical Clinic	5’ strut channel ½’’ tapcons/washers (2) Winged strut channel connector Telespar receiver Waders

ACCESS CONSIDERATIONS

Fence borders both walkways on the bridge. May need to deploy node closer to shore before fencing starts.

KEY PHOTOS (additional photos and 360 video in AirTable):

	Video: https://www.youtube.com/watch?v=UtVIhnZP0wk

DEPLOYMENT STRATEGY

Place cantilever along the length of the bridge (from the shore outward), as opposed to having it straight out from the road. 5' strut channel should allow for enough clearance from the edge of the water in the case that water levels drop (Southbound/Westside).

HOTEL INFORMATION:

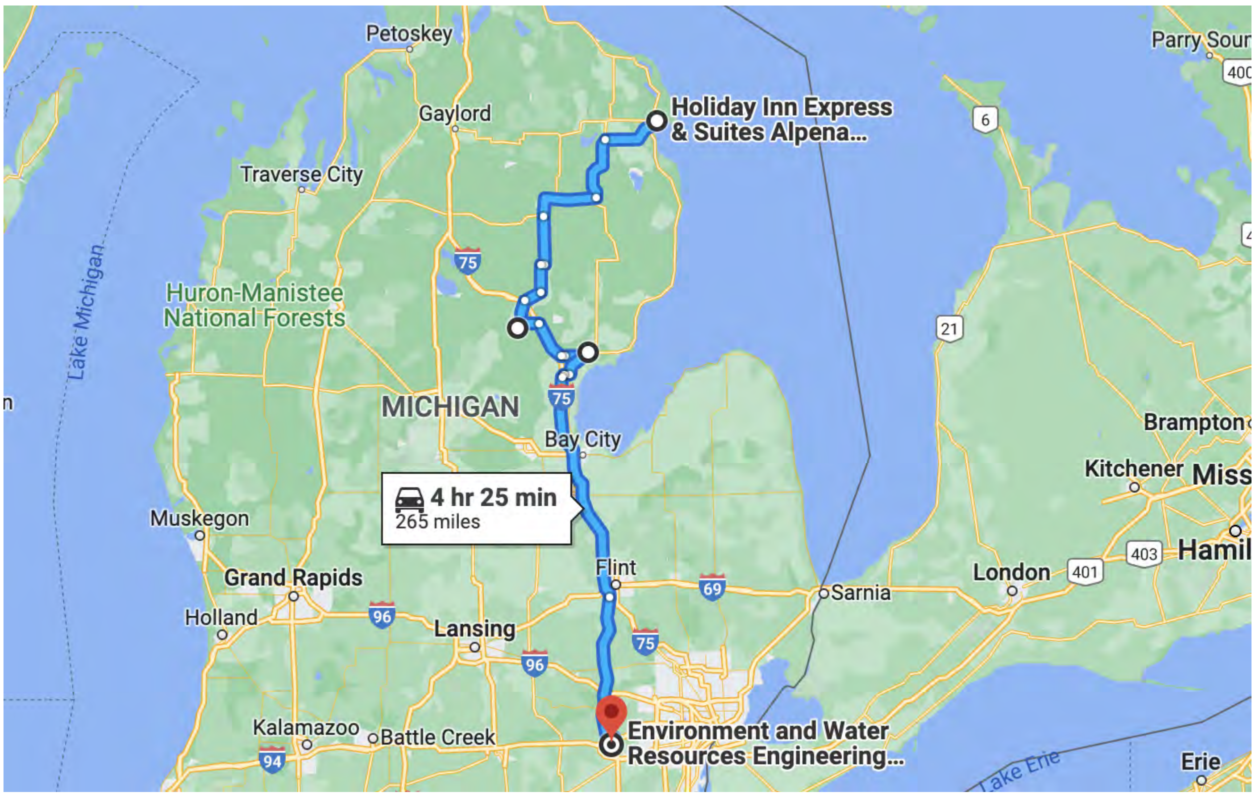
Holiday Inn Express & Suites - Alpena Downtown
225 River Street
Alpena, MI 49707
HOTEL WEBSITE
Hotel Front Desk: 989-340-1800

Mitch Confirmation: 27396161
Ken Confirmation: 45576646

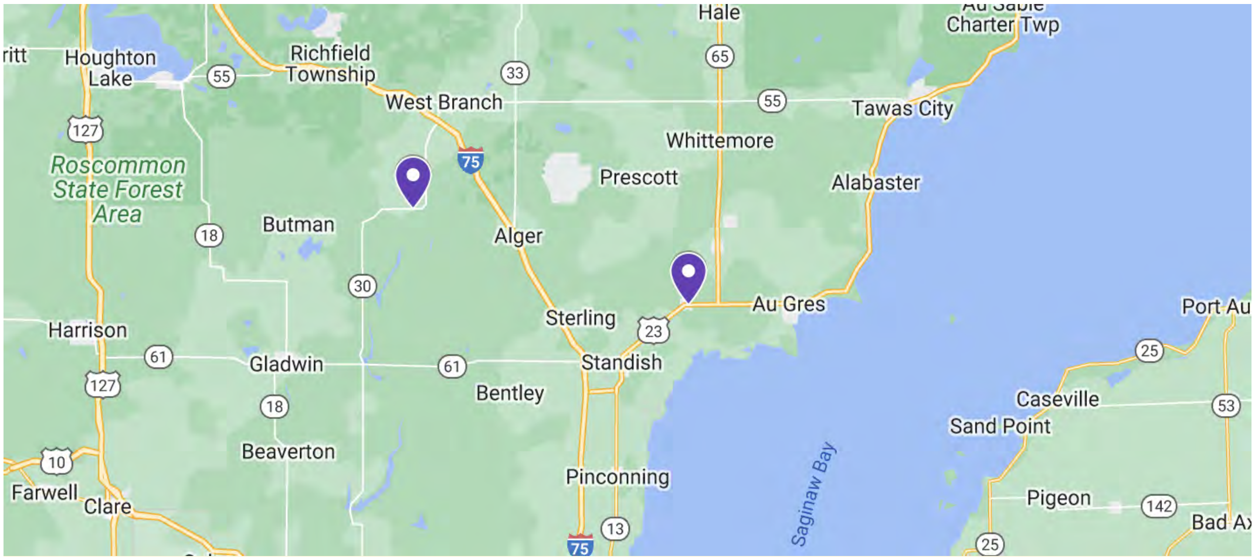
Friday, July 15, 2022

Superior/North/Bay: OVERNIGHT
Day 5: Bay: 2 New

NEW: MDOT 2892, MDOT 390



[DIRECTIONS]()



MDOT 2892 Tittabawassee River (US-30 EB)

[Advance Notice Reference #:89895](#)

GOOGLE MAP LINK	PARKING ADDRESS
44° 9' 22.5698" N 84° 19' 37.362" W	Shoulder of the road

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Emergency Department	4' steel strut channel ½'' tapcons/washers (2) Telespar Receiver Winged strut channel connector

ACCESS CONSIDERATIONS
Waders necessary if node needs to be pole mounted.

KEY PHOTOS (additional photos and 360 video in AirTable):

DEPLOYMENT STRATEGY

Place cantilever along the length of the bridge (from the shore outward), as opposed to having it straight out from the road. 5’ strut channel should allow for enough clearance from the edge of the water in the case that water levels drop (Southbound/Westside).

MDOT 390 Rifle River (US-23 WB)

[Advance Notice Reference #:89896]

GOOGLE MAP LINK	PARKING ADDRESS
44° 2' 51.7337" N 83° 51' 54.5569" W	44° 2' 51.27" N 83° 51' 21.4675" W

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED

Emergency - Ascension Standish Hospital	Winged strut channel connector '4 steel strut channel ½'' tapcons/washers (2) Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

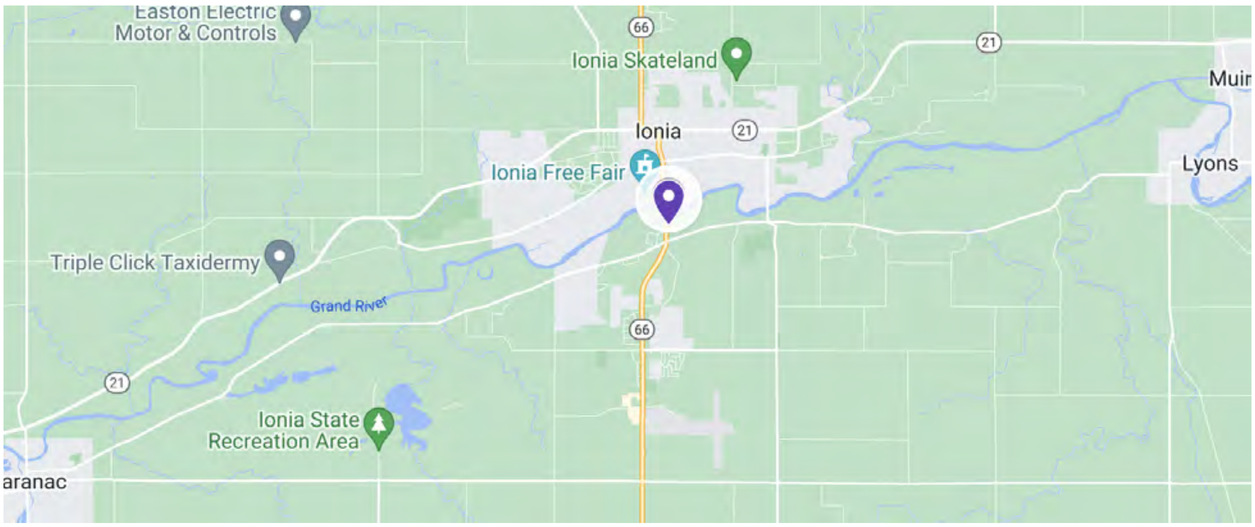
DEPLOYMENT STRATEGY

Drill into overpass (below railing/on sidewalk), mount cantilever straight out from bridge using two tapcons and washers to secure strut channel (Westbound/Northside)

Tuesday, July 19, 2022

Grand: LOCAL
1 New, 1 Swap (Washtenaw)

NEW: MDOT 3970



TOTAL LIST OF SUPPLIES

QUANTITY	ITEM
1	Winged strut channel connector
1	4' strut channel
4	½" Tapcons
4	Washers
2	Nodes
1	Telespar receiver

MDOT 3970 Grand River (M-66 NB)

[Advance Notice Reference #:89897]

GOOGLE MAP LINK

42° 58' 18.494" N 85° 4' 17.3593" W

PARKING ADDRESS

M-66 Car Wash

CLOSEST EMERGENCY ROOM

Sparrow Ionia Hospital Emergency Room

DEPLOYMENT SUPPLIES REQUIRED

Winged strut channel connector
4’ steel strut channel
½’’ tapcons/washers (2)
Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

Video:
https://www.youtube.com/watch?v=lCiRu2GKY3M

DEPLOYMENT STRATEGY

Drill into the bridge (below railing/on sidewalk/upstream). Mount cantilever on the upstream side straight out from the bridge using tapcons and washers to secure a 4’ steel strut channel.(Northbound/Eastside).

ARB046: Kaiser South: Swap

GOOGLE MAP LINK	PARKING ADDRESS
https://www.google.com/maps/place/42%C2%B016'45.0%22N+83%C2%B048'41.4%22W/@42.2791589,-83.8117666,75m/data=!3m1!1e3!4m5!3m4!1s0x0:0xddd3540710bbcd62!8m2!3d42.279155!4d-83.811493	Parking lot next to site

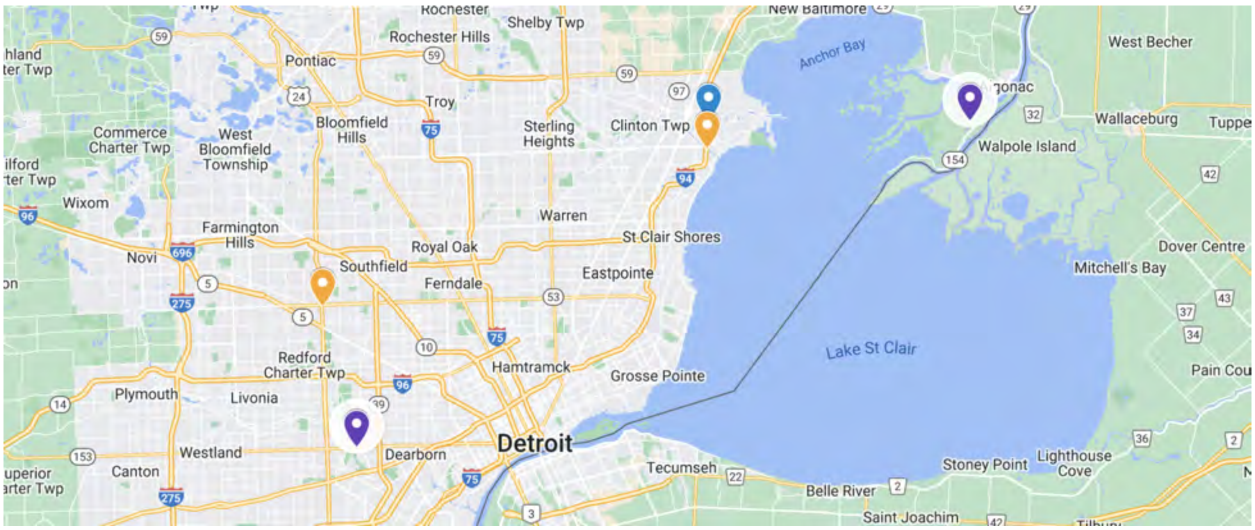
CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
University of Michigan Hospital	

ACCESS CONSIDERATIONS
None

Wednesday, July 20, 2022

Metro: LOCAL
1 New

NEW: MDOT 6142



TOTAL LIST OF SUPPLIES

QUANTITY	ITEM
2	4 or 5’ strut channels
4	½” Tapcons
4	Washers
2	Winged strut channel connector
2	Telespar receiver

MDOT 6142 N&S RDS (I-94 NB)

[Advance Notice Reference #:89948]

GOOGLE MAP LINK

[42° 35' 24.72" N 82° 51' 25.56" W]

PARKING ADDRESS

Shoulder prior to structure/bridge.

CLOSEST EMERGENCY ROOM

My Care Health Center

DEPLOYMENT SUPPLIES REQUIRED

4' steel strut channel
½'' tapcons/washers (2)
Winged strut channel connector
Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

Video:
https://www.youtube.com/watch?v=QpEt3mKfEgk

DEPLOYMENT STRATEGY

Drill into concrete, mount cantilever on bridge straight out from road. Using tapcons and washers, secure 4' steel strut channel. (Northbound/Eastside).

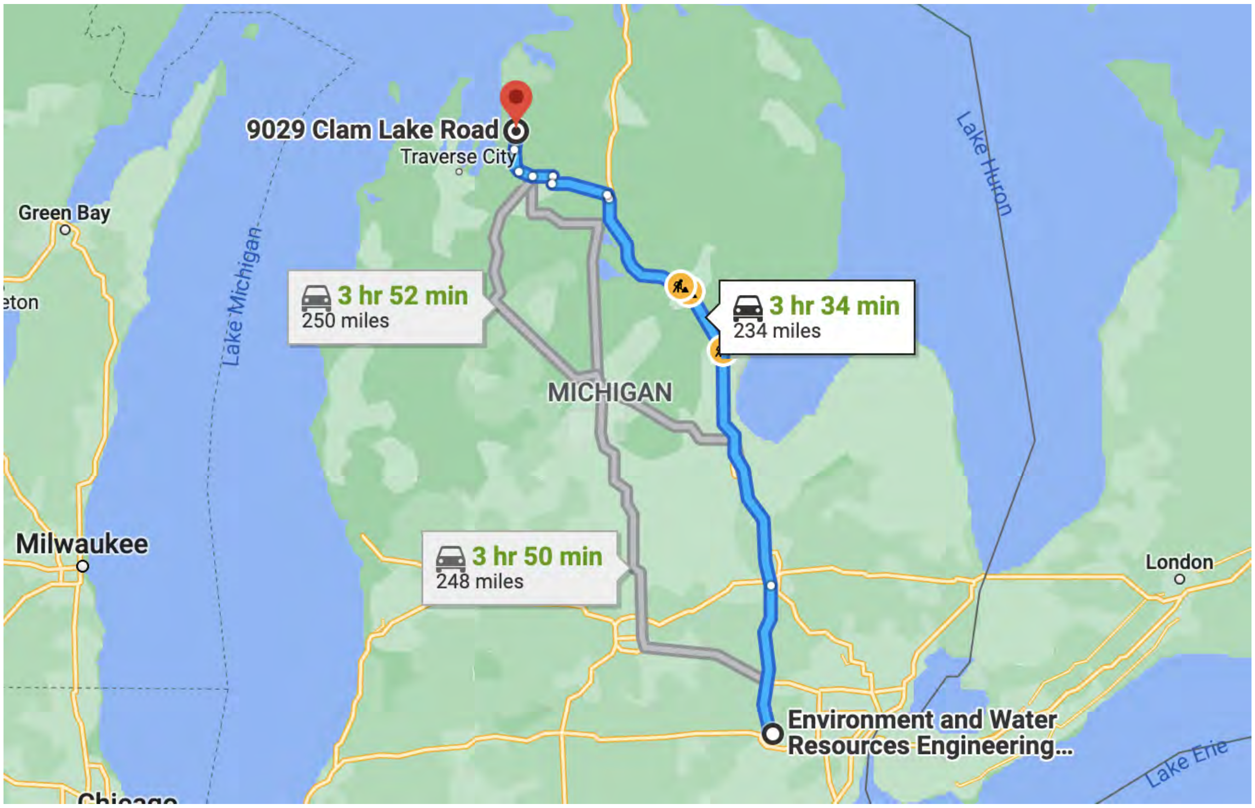
Tuesday July 26, 2022

TOTAL LIST OF SUPPLIES

QUANTITY	ITEM
5	4 or 5' Strut channels
5	Telespar Receiver
5	Winged strut channel connector
4	U Brackets
1	Post Driver
4	5' Steel Strut Channel
4	Strut channel connector
10	½" Tapcons
10	Washers

North/Grand: OVERNIGHT

Day 1: Travel Day



[DIRECTIONS]

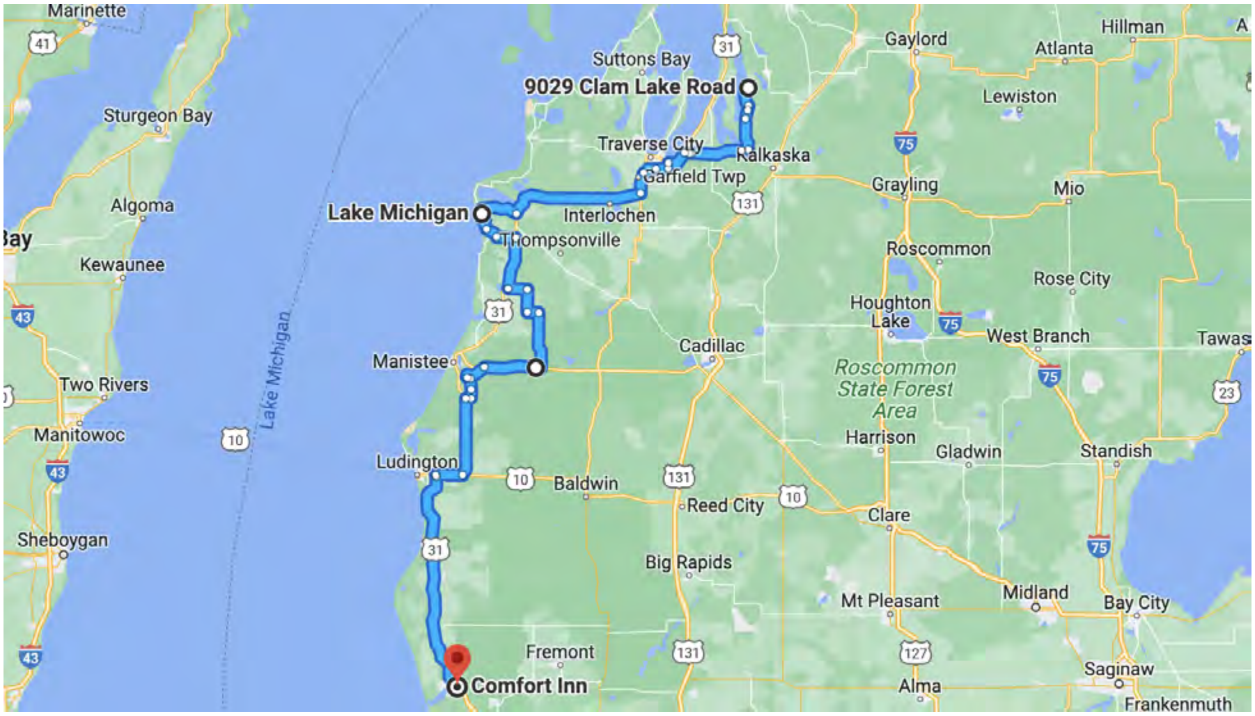
LODGING INFORMATION:

9029 Clam Lake Road
Bellaire, Michigan 49615
(Wojtowicz Cottage)

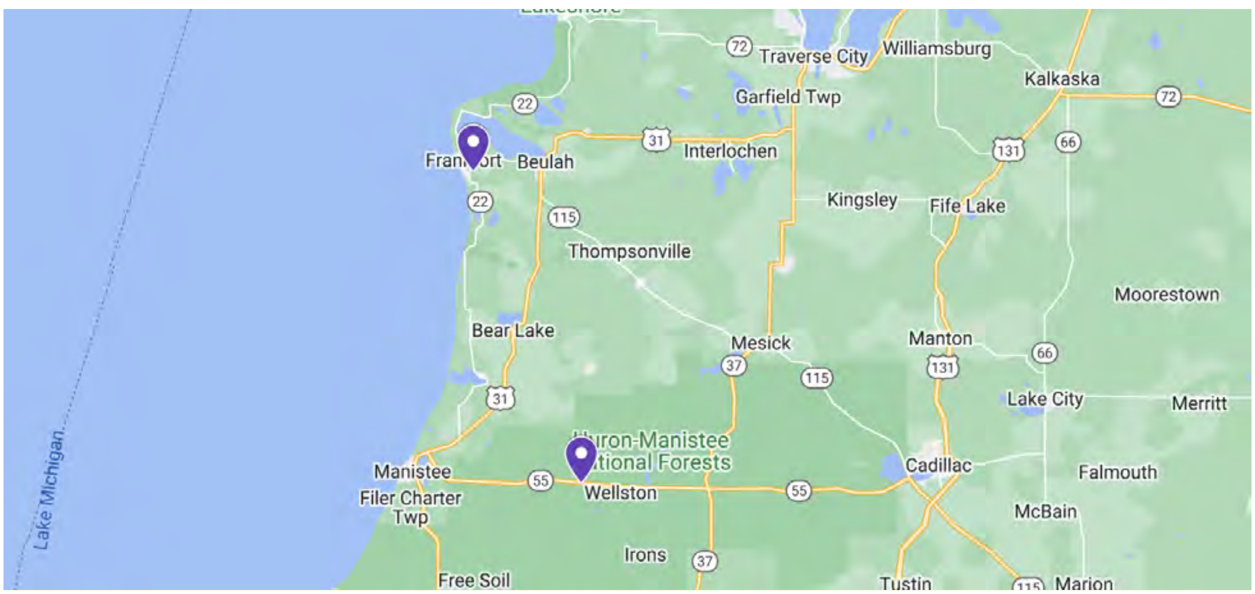
Wednesday, July 27, 2022

North/Grand: OVERNIGHT
Day 2: North: 2 New

NEW: MDOT 752, MDOT 6440



[DIRECTIONS]



MDOT 752 Betsie River (M-22 EB)

Advance Notice Reference #:90018

GOOGLE MAP LINK	PARKING ADDRESS
44° 37' 13.08" N 86° 13' 18.48" W	44° 37' 12.324" N 86° 13' 23.8638" W

CLOSEST EMERGENCY ROOM

Paul Oliver Memorial Hospital

DEPLOYMENT SUPPLIES REQUIRED

3-4’ strut channels
½” tapcons/washers (2)
Winged strut channel connector
Telespar receiver

ACCESS CONSIDERATIONS

Water may be too deep to use waders.

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://www.youtube.com/watch?v=Id_gctCPloM

DEPLOYMENT STRATEGY

Drill into wingwall on upstream (south) side. Mount 4’ steel strut channel running parallel to the road.

MDOT 6440 Pine Creek (M-55 EB)

Advance Notice Reference #:90019

GOOGLE MAP LINK

[44° 13' 48.0137" N 87° 9' 9.3794" W](44° 13' 48.0137" N 87° 9' 9.3794" W)

PARKING ADDRESS

Shoulder of road.

CLOSEST EMERGENCY ROOM

Manistee Hospital

DEPLOYMENT SUPPLIES REQUIRED

3-4' strut channels
½" tapcons/washers (2)
Winged strut channel connector
Telespar receiver
Waders (maybe)

ACCESS CONSIDERATIONS

May need waders to deploy the node.

KEY PHOTOS (additional photos and 360 video in AirTable):

Video:
https://www.youtube.com/watch?v=oumml5-Cw5E

DEPLOYMENT STRATEGY

Drill into wingwall on north side (downstream) of structure, which appears to have more open space to avoid any interference. Maybe go as far to angling the strut channel away from the road to keep node safe during repair on the overpass.

HOTEL INFORMATION:

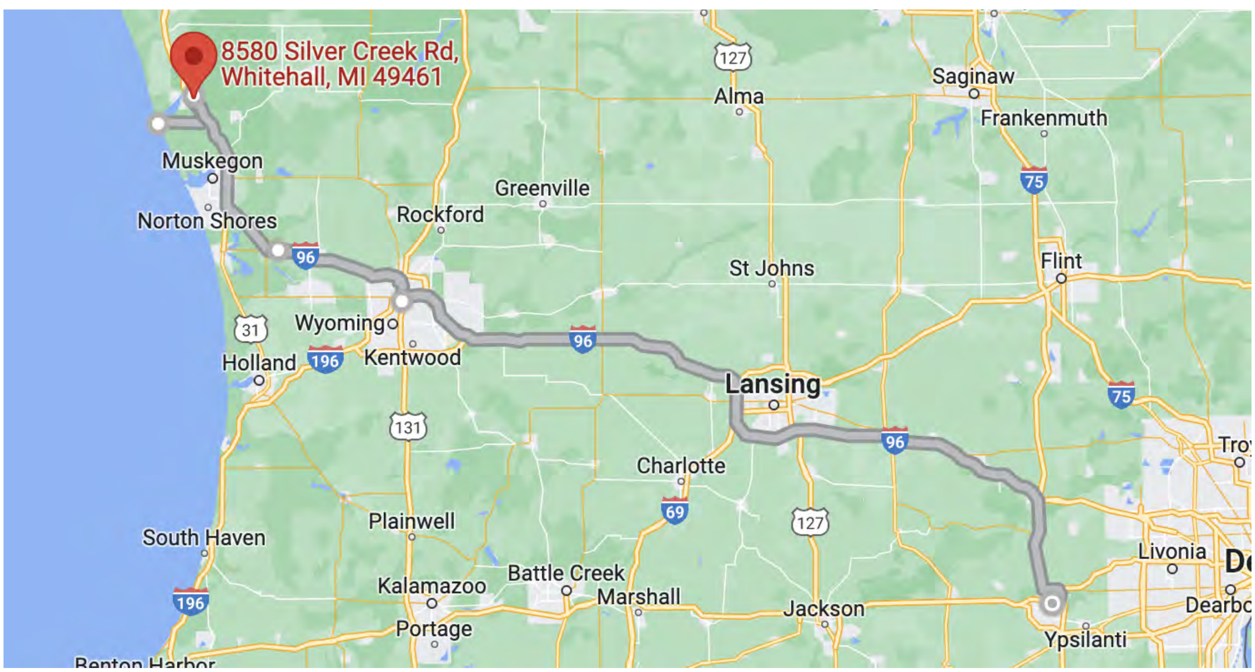
Comfort Inn - Whitehall
2822 Durham Road
Whitehall, MI 49461
HOTEL WEBSITE
Hotel Front Desk: 231-893-4833

Mitch Confirmation: 11864750
Ken Confirmation: 11866510

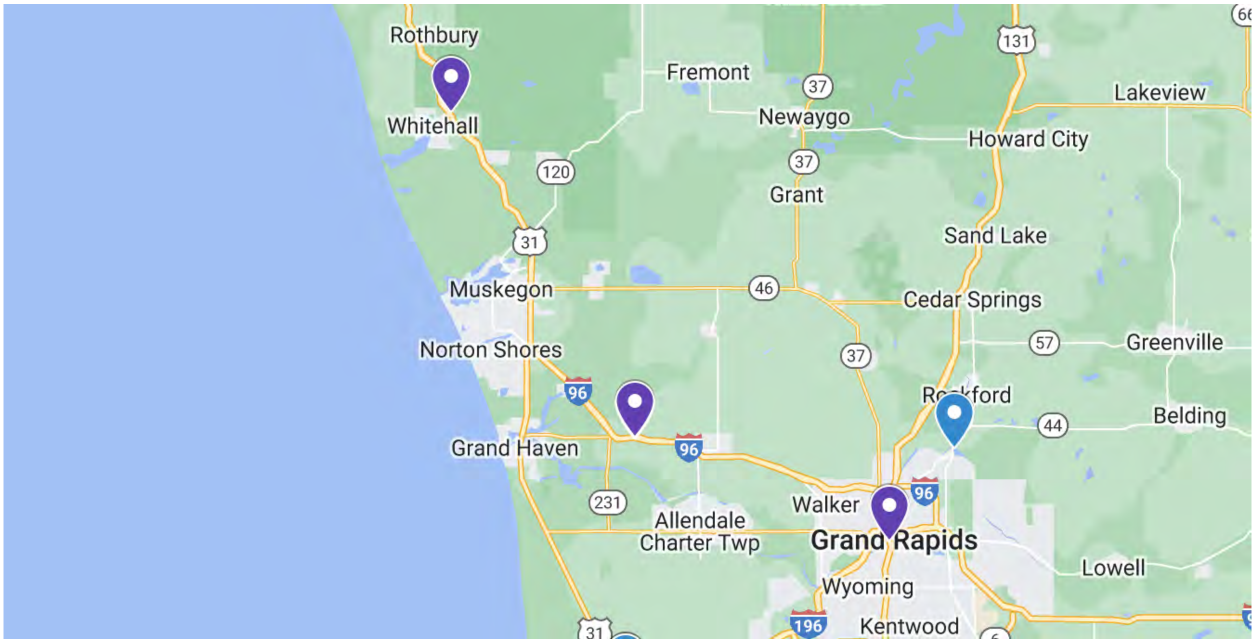
Thursday, July 28, 2022

North/Grand: OVERNIGHT
Day 3: Grand: 3 New

NEW: MDOT 8767, MDOT 4932, MDOT 7587



DIRECTIONS



MDOT 7587 White River (US-31 NB)

Advance Notice Reference #:90020

GOOGLE MAP LINK	PARKING ADDRESS
43° 25' 30.374" N 86° 19' 42.9193" W	On the right shoulder, in the grassy area just past the guardrail.

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Lake Shore Medical	Telespar receiver 4′ strut channel ½″ tapcons/washers (2) U bracket WInged strut channel connector Post driver 5′ steel strut channel (2) Strut channel connector

ACCESS CONSIDERATIONS

Railing may not leave enough space to drill.

KEY PHOTOS (additional photos and 360 video in AirTable):

<table>
<tr>
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Video:
https://www.youtube.com/watch?v=Ub9AhUY7IK8</td>
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DEPLOYMENT STRATEGY

Winged walls have riprap which would be an obstruction, mounting strut channel directly to the bridge would be the best bet. If railing does not have enough space, pole mount in the reeds would then be the next best strategy (Northbound/Eastside).

MDOT 8767 Crockery Creek (I-96 WB)

Advance Notice Reference #:90021

GOOGLE MAP LINK	PARKING ADDRESS
43° 4' 27.854" N 86° 3' 15.4393" W	On the right shoulder

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
North Ottawa Community Health System	Winged strut channel connector ½” tapcons/washers (2) 4’ steel strut channel Telespar receiver

ACCESS CONSIDERATIONS

None

KEY PHOTOS (additional photos and 360 video in AirTable):

DEPLOYMENT STRATEGY

Winged walls have riprap which would be an obstruction, mounting strut channel directly to the bridge would be the best bet. If railing does not have enough space, pole mount in the reeds would then be the next best strategy (Northbound/Eastside).

MDOT 4932 Grand River (M-45 WB)

Advance Notice Reference #:90022

GOOGLE MAP LINK	PARKING ADDRESS
42° 57' 47.894" N 85° 40' 45.7993" W	Pay meter lane adjacent to bridge

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Trinity Health Saint Mary's - Grand Rapids	Telespar receiver 4' strut channel ½" tapcons/washers (2) U bracket WInged strut channel connector Post driver 5' steel strut channel (2) Strut channel connector

ACCESS CONSIDERATIONS

Railing may inhibit drilling

KEY PHOTOS (additional photos and 360 video in AirTable):

	 Video: https://www.youtube.com/watch?v=t8cxWpIvLOo

DEPLOYMENT STRATEGY

Drill into the bridge under railing if possible to secure a cantilever straight out from the road (horizontal). If unable to drill under the railing, try to drill on the outer wall to secure the strut channel vertically (Westbound/Northside).

Monday, August 1, 2022

Metro 3: LOCAL: ROAD CLOSURE REQUIRED

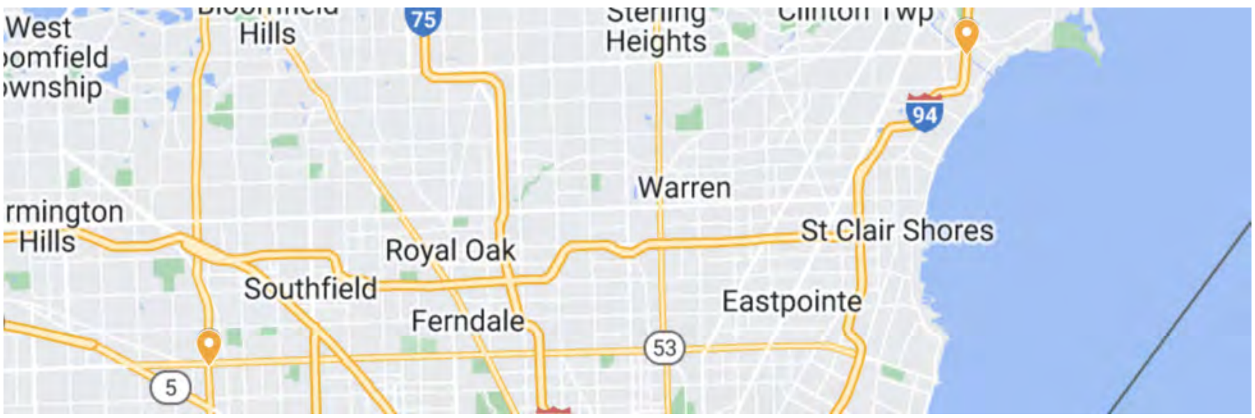
Metro: 1 New

NEW: MDOT 6140

Meet Road Closure Crew at 8:30am on ramp from Metro Parkway to 94 W (appox. location)

Ramp will close at 9:00am

Contact Information: Daniel Godfrey: 248-228-6655



MDOT 6140 Clinton River Spillway (I-94)

Advance Notice Reference #:90262

GOOGLE MAP LINK	PARKING ADDRESS
42° 34' 5.534" N 82° 51' 39.9193" W	Shoulder of road after structure.

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
McLaren Macomb	4’ steel strut channel ½’’ tapcons/washers (2) Winged strut channel connector Telespar receiver

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ACCESS CONSIDERATIONS

Shoulder may be slightly more narrow than others.
ROAD CLOSURE REQUIRED

KEY PHOTOS (additional photos and 360 video in AirTable):

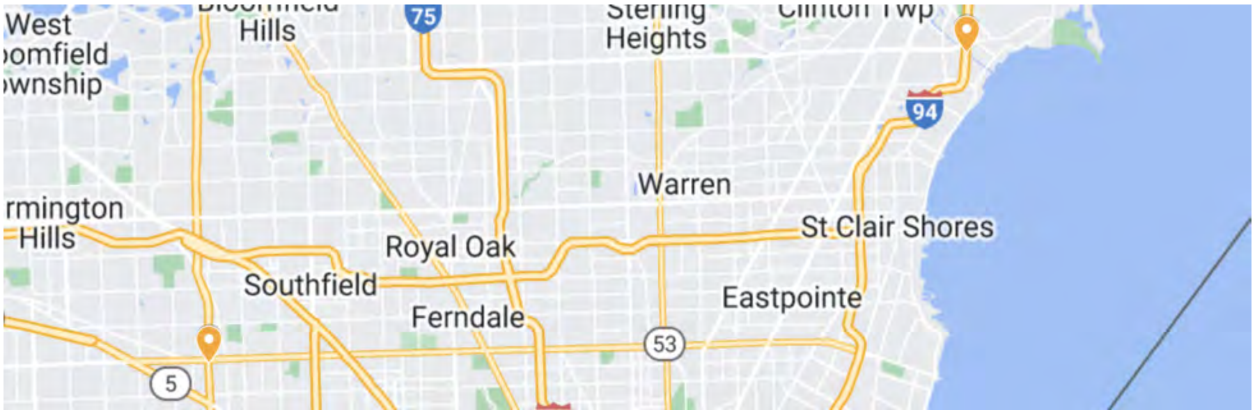
DEPLOYMENT STRATEGY

Drill into the bridge, mount the cantilever perpendicular to the road using tapcons and washers to secure 4’ steel strut channel. (Southbound/Westside)

Wednesday, August 3, 2022

Metro 4: LOCAL: ROAD CLOSURE REQUIRED
Metro: 1 New

NEW: MDOT 11292



MDOT 1192 Rouge River (US-24 SB)

Advance Notice Reference #:90482

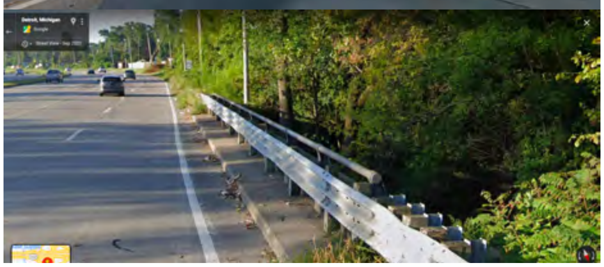
GOOGLE MAP LINK	PARKING ADDRESS
42° 26' 29.4" N 83° 16' 44.04" W	In the lane that would be closed down

CLOSEST EMERGENCY ROOM	DEPLOYMENT SUPPLIES REQUIRED
Beaumont Hospital, Farmington Hills	4’ steel strut channel ½’’ tapcons/washers (2) Winged strut channel connectors Telespar receiver

ACCESS CONSIDERATIONS

Shoulder may be slightly more narrow than others.
ROAD CLOSURE REQUIRED

KEY PHOTOS (additional photos and 360 video in [AirTable]()):

 	No video.

DEPLOYMENT STRATEGY

Drill into concrete below the guard rail, mount the cantilever straight out from the road (westside)

UNIVERSITY OF MICHIGAN

Swapping University of Michigan Open Storm Depth Nodes

Tools/Supplies Needed:

- 9/16" socket (a few sites have different sizes (¾", etc.; bringing a socket set may be best to plan ahead).
- Impact driver
- New depth sensor node

NOTE: All lock combinations (2245)

Procedure:

1) Using a 9/16" socket, start by taking out the tapcon.
   NOTE: If there are two wedge anchors instead of one tapcon and one wedge anchor, remove the nut off of the front anchor and loosen the back one. Have the second person get a good grip on the strut channel, as these may get heavy, and remove the second nut to take out the strut channel.
2) Once the tapcon is removed, loosen the back wedge anchor nut with a 9/16" socket and rotate the strut channel.
3) Use the combination "2245" on the long shackle lock to remove the node from the handle.
4) Remove node from the handle.
5) Put the node back into the handle on the strut channel and insert the long shackle lock back into place. Also, scrambling its combination.
6) Rotate the strut channel back into position.
   NOTE: If there were two wedge anchors, have one person get a good grip of the strut channel and put it back into position over the anchors. Put the washer and nut back onto the rear anchor and tighten down. Then repeat for the front one as well.
7) Line up the strut channel with the existing tapcon hole and tighten back into place.
8) Tighten the wedge anchor down.
9) Give the strut channel a good wiggle to make sure it's securely tightened.
10) Take a couple of photos and submit a form to UM here.