Transportation Pooled Fund Program TPF-5(446) Quarterly Progress Report

Quarter 2, April – June 2023

prepared by
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TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): _FHWA_______________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *(i.e., SPR-2(XXX), SPR-3(XXX) or TPF-5(XXX)* *TPF-5(446)*	**Transportation Pooled Fund Program - Report Period:** ☐Quarter 1 (January 1 – March 31) ☒Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 1 – December 31)

Project Title:
High Performance Computational Fluid Dynamics (CFD) Modeling Services for Highway Hydraulics

Name of Project Manager(s): *Kornel Kerenyi*	**Phone Number:** *(202) 493-3142*	**E-Mail** *kornel.kerenyi@fhwa.dot.gov*
Lead Agency Project ID:	**Other Project ID (i.e., contract #):**	**Project Start Date:**
Original Project End Date:	**Current Project End Date:**	**Number of Extensions:**

Project schedule status:

☒ On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	**Total Cost to Date for Project**	**Percentage of Work Completed to Date**

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	**Total Amount of Funds Expended This Quarter**	**Total Percentage of Time Used to Date**

Project Description:

The Federal Highway Administration established an Inter-Agency Agreement (IAA) with the Department of Energy's (DOE) Argonne National Laboratory (ANL) Transportation Analysis Research Computing Center (TRACC) to get access and support for High Performance Computational Fluid Dynamics (CFD) modeling for highway hydraulics research conducted at the Turner-Fairbank Highway Research Center (TFHRC) Hydraulics Laboratory. TRACC was established in October 2006 to serve as a high-performance computing center for use by U.S. Department of Transportation (USDOT) research teams, including those from Argonne and their university partners. The objective of this cooperative project is to:

- Provide research and analysis for a variety of highway hydraulics projects managed or coordinated by State DOTs.
- Provide and maintain a high-performance Computational Fluid Dynamics (CFD) computing environment for application to highway hydraulics infrastructure and related projects.
- Support and seek to broaden the use of CFD among State Department of Transportation employees.

The work includes:

- Computational Mechanics Research on a Variety of Projects: The TRACC scientific staff in the computational mechanics focus area will perform research, analysis, and parametric computations as required for projects managed or coordinated by State DOTs.
- Computational Mechanics Research Support: The TRACC support team consisting of highly qualified engineers in the CFD focus areas will provide guidance to users of CFD software on an as needed or periodic basis determined by the State DOTs.
- Computing Support: The TRACC team will use the TRACC clusters for work done on projects; The TRACC system administrator will maintain the clusters and work closely with the Argonne system administrator's community; The TRACC system administrator will also install the latest versions of the STAR-CCM+ and OpenFOAM CFD software and other software that may be required for accomplishing projects.

Progress this Quarter:

(Includes meetings, work plan status, contract status, significant progress, etc.)

1: Computational Mechanics Research on a Variety of Projects

1.1: Hydraulic Efficiency of Michigan DOT Cover 'C' in on-Grade and Sag Locations

The hydraulic performance of the catch basin cover 'C' has been analyzed for on-grade and sag locations with the use of computational fluid dynamics software STAR-CCM+ v.17.06. The Michigan DOT engineers use the cover on freeways with 8 to 10-feet-wide shoulders at 4% and traveled lanes usually sloped at 2%, among others. The longitudinal grade varies between 0.3% and 5%. The maximum flow rate used in the analysis is about 2 cfs.

The cover is composed of a grate and a curb box and is for use with a concrete curb and gutter. Figure 1 shows drawings of the cross section of the gutter, cover C assembly, and a plan view of the grate.

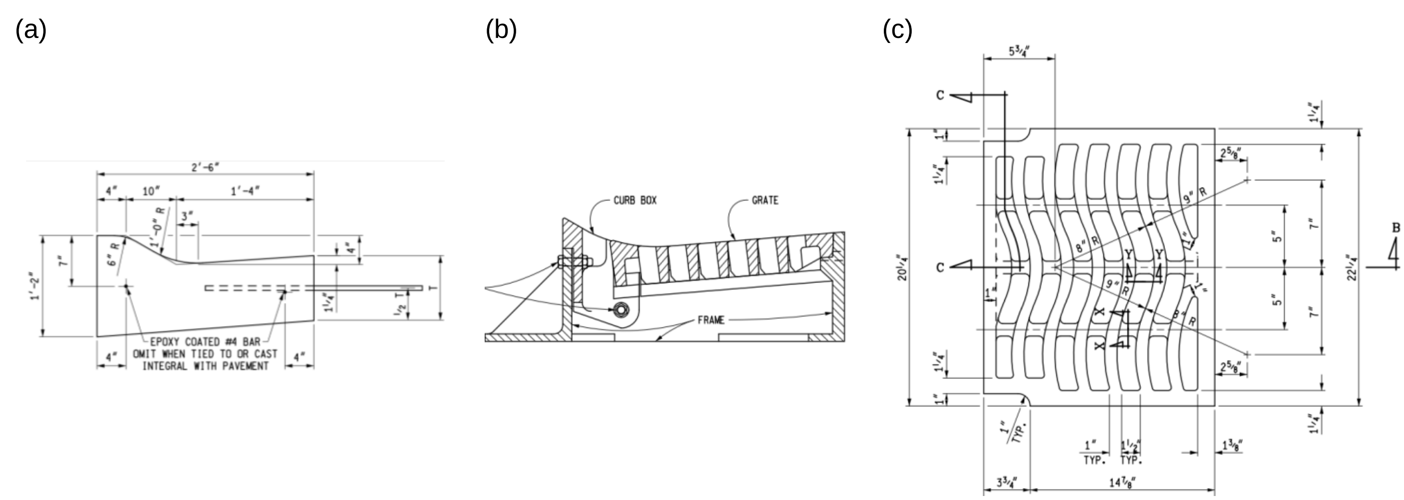


Figure 1. Standard drawings

The computational domain for the on-grade condition is shown in Figure 2. It covers a section of a roadway pavement, curb and gutter and the cover C with a catch basin underneath. The geometry was recreated based on the standard drawings provided by MDOT.

The open-channel flow on pavement is simulated with Eulerian multiphase model to account for phase 1: water and phase 2: air. Volume of fluid model is used to find the interface between the phases i.e., water surface. Surface tension force on the interface between the two phases is also defined. The selected flow solver is unsteady RANS with SST k-ω turbulence model and wall functions with roughness height to model turbulent flow on a rough surface. The cross- slope is represented in the geometry of the pavement, and the longitudinal slope is modeled by modification of the components of the gravitational acceleration vector.

Different boundary conditions on the model surfaces are marked with different colors in Figure 2. The color coding is as follows: orange – pressure outlet with atmospheric pressure, red – inlet velocity, grey – rough wall boundary. Figure 3 shows an example velocity distribution at the inlet to the computational domain. Firstly, the mean velocity and spread are calculated using the Manning formula for the combination of cross – and longitudinal slope, and discharge. Then, the fully-developed velocity distribution is computed using an additional computational model that simulates a small section of a long road by employing the periodic translational boundary conditions with an assumed mass flow rate. Finally, the obtained velocity magnitude and phase (water and air) distribution is used as the inlet conditions in the main model.

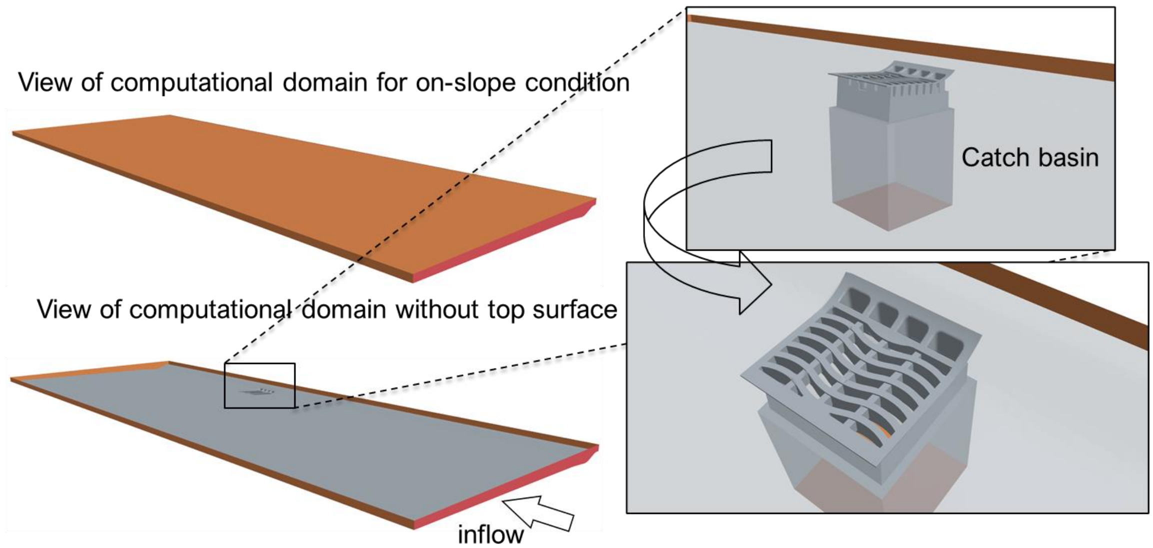


Figure 2. Computational domain for on-slope condition

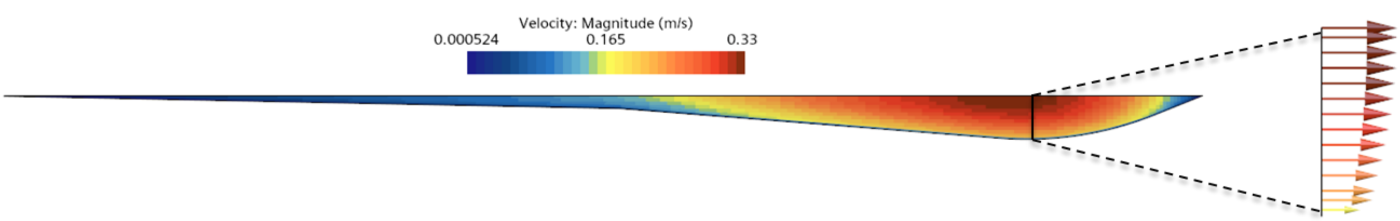


Figure 3. Example of fully developed velocity distribution

The Manning coefficient used by MDOT is typically 0.020 to account for drainage efficiency losses due to pavement roughness, but also debris, such as dry leaves, grass clippings, trash, etc., that accumulate in the vicinity of the drainage. In the computational model, the roughness of the pavement is taken into account with the use of the rough wall functions with a roughness height corresponding to Manning coefficient 0.016 and the clogging of the grate is modeled by closing the orifices of the grate in varying percentage. The conversion from Manning's 'n' and roughness height is done using the Colebrook-White equation as presented in [1, 2].

Project deliverables cover: the hydraulic efficiency as a ratio of intercepted to total flow on a grade, and orifice and weir flow regime, and transition between them in sump condition, among others. The following figures present some of the current findings.

A set of simulations is performed with varying gutter flow over a pavement with a 0.02 and 0.04 cross slope and 0.01 longitudinal slope. Figure 4 shows the water surface at discharge 0.9 cfs, which gives flow spread of about 4 ft; the flow spreads more in the vicinity of the drain for 0.02 grade, but the flow over the grate is very similar for both cases. The percentage of the intercepted flow is also similar; it is 88% for 0.04 grade and 85% for 0.02 grade. The plot of hydraulic efficiency vs. discharge shows that the efficiency difference decreases with increasing flow rate, in the analyzed range of parameter values.

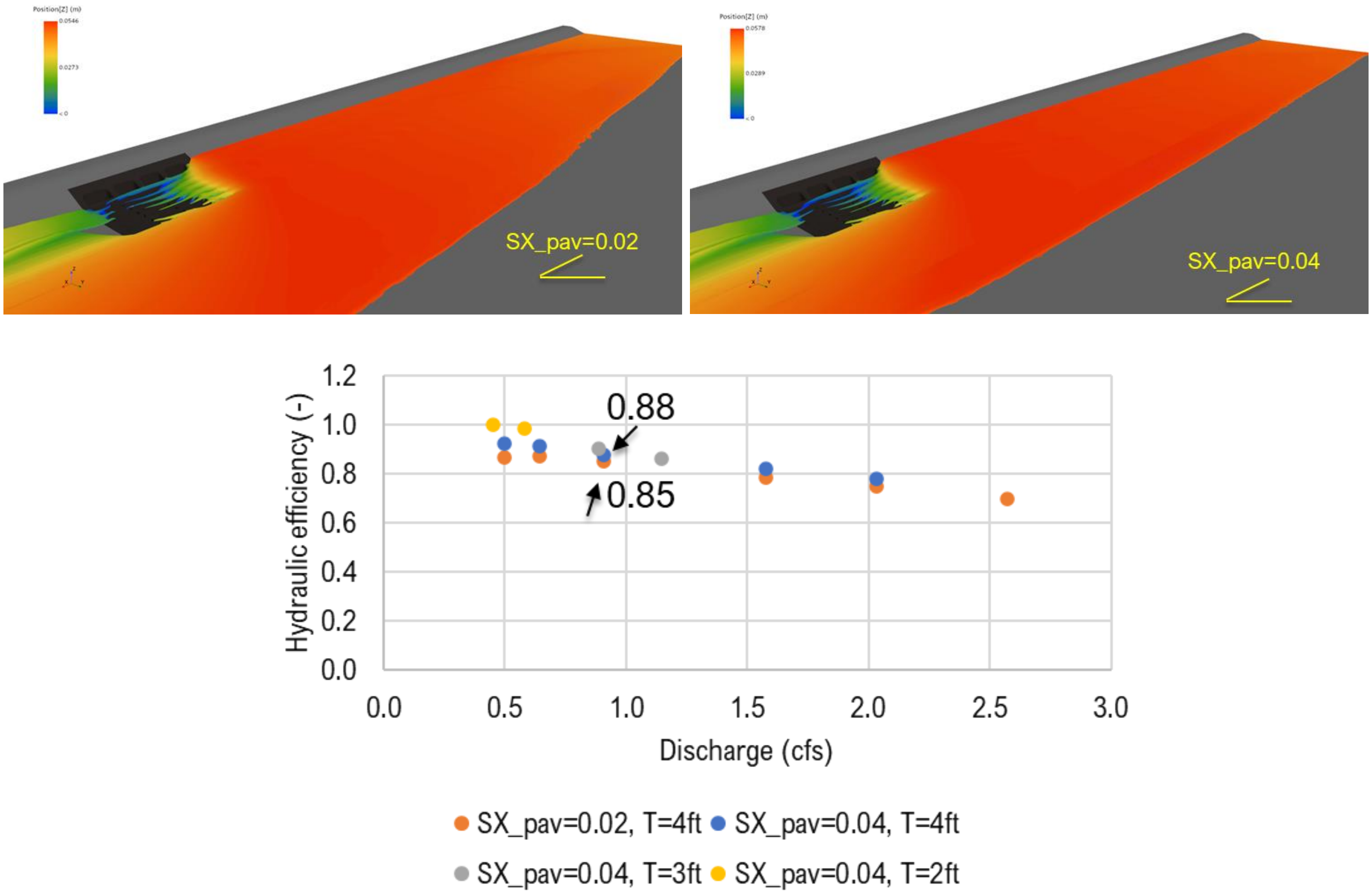
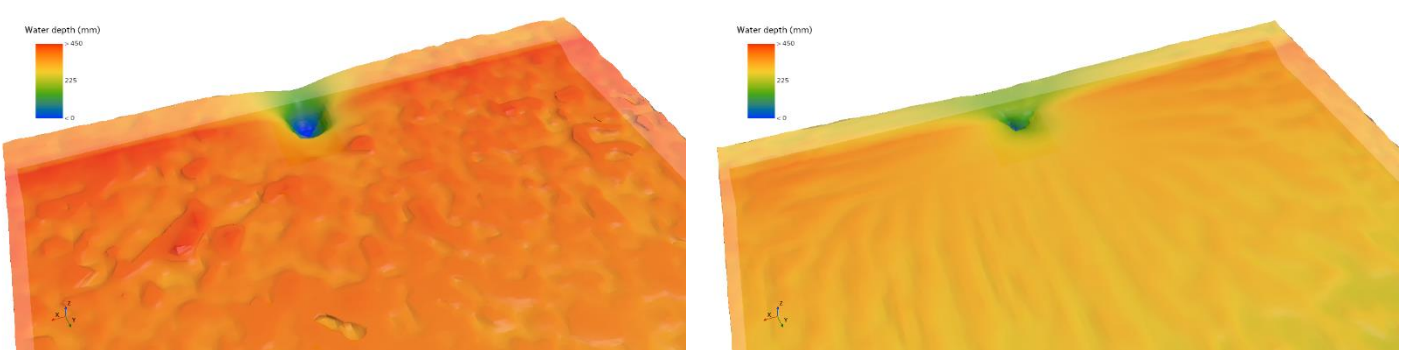


Figure 4. Comparison of hydraulic efficiency change due to the varying shoulder cross slope.

Figure 5 shows snapshots of the water surface changes during a simulation of the sump conditions. In this model, the longitudinal slope is zero. Initially, the model is filled with water up to approx. 3 ft. During the simulation water can leave the domain only through the cover C and the catch basin. The flow transitions from the orifice regime (unbroken water surface) to the weir regime (water surface breaks over the grate). The surface is colored with vertical position in the global Cartesian coordinate system. The plot in Figure 7 shows the relationship between the water depth and the intercepted flow rate.



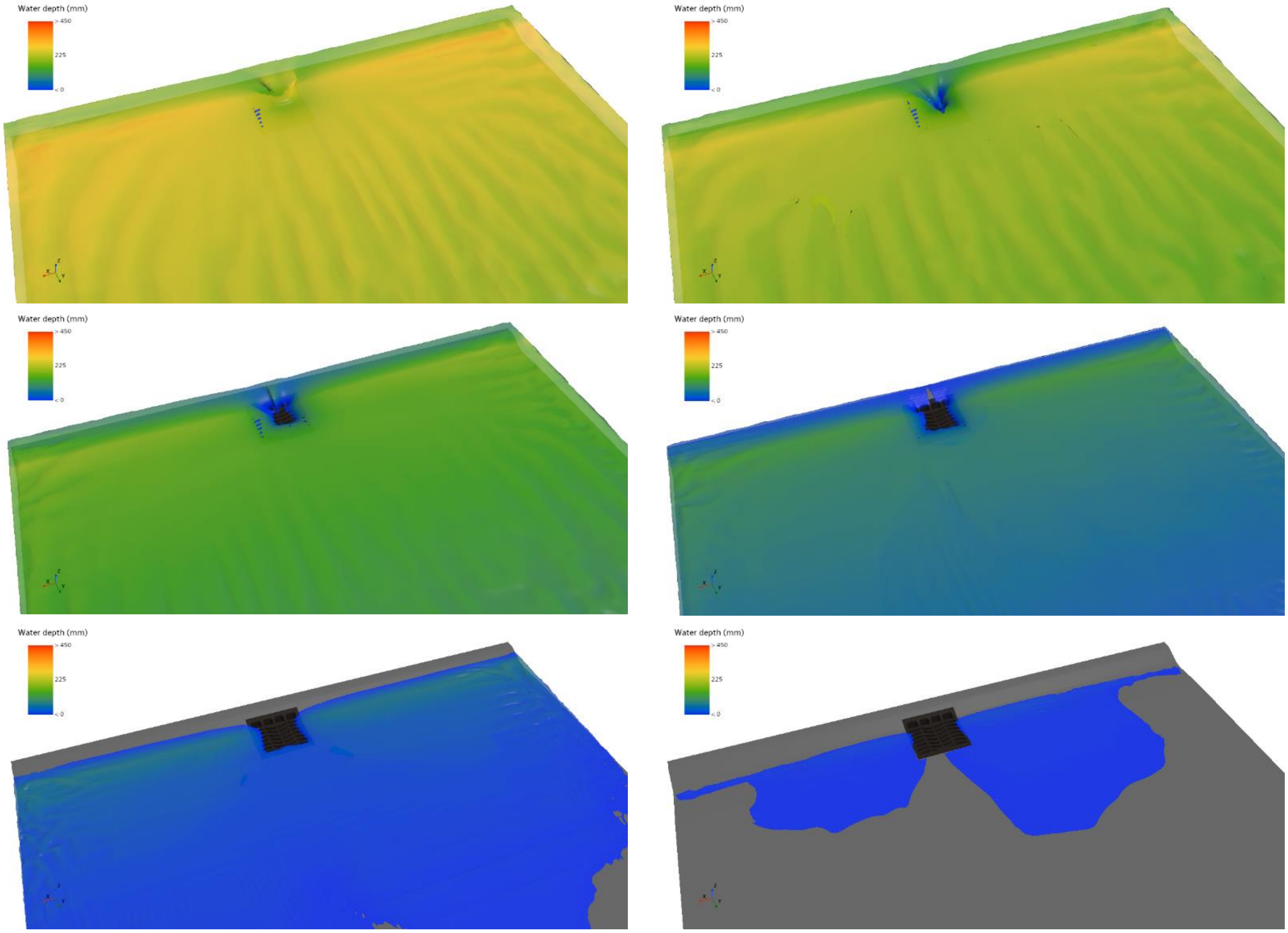


Figure 5. Snapshots of the water surface changes during a simulation of the sump conditions. The flow transitions from the orifice regime (unbroken water surface) to the weir regime (water surface breaks over the grate). The surface is colored with vertical position in a Cartesian coordinate system.

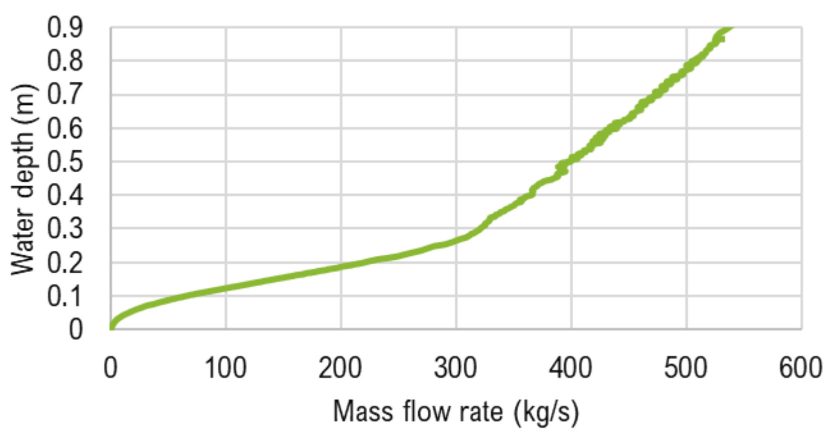


Figure 7. Graph of the water depth vs. intercepted mass flow rate.

References:

[1] Sitek, M.A. and S.A. Lottes. "Computational Analysis of Water Film Thickness During Rain Events for Assessing Hydroplaning Risk Part 2: Rough Road Surfaces.", Argonne National Laboratory, ANL-20/37, July 2020.

[2] M.A. Sitek, S.A. Lottes, J. Syar, Computational Analysis of Hydraulic Capacity of Ohio DOT Catch Basins On-Grade and in Sag Locations, ANL-21/20, April 2021

Anticipated work next quarter:

1: Computational Mechanics Research on a Variety of Projects

- hydraulic analysis of catch basins on grade and in sump
- analysis of water film thickness on pavements (hydroplaning water film thickness and speed)

2: Computational Mechanics Research Support

This work will continue.

Task 3: Computing Support

This work will continue.

Circumstance affecting project or budget.

(Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

None.