Transportation Pooled Fund Program TPF-5(552) Quarterly Progress Report

Quarter 1, January – March 2026

prepared by
M. Sitek

Nuclear Science & Engineering Division, Argonne National Laboratory

April 2026

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)*	**Transportation Pooled Fund Program - Report Period:**
TPF-5(552)	☒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):	**Phone Number:**	**E-Mail**
James Pagenkopf	*(202) 493-7080*	*james.pagenkopf@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. Computational Analysis of Hydraulic Efficiency of Michigan DOT Covers J and K
This study used three-dimensional computational fluid dynamics to evaluate the hydraulic performance of Michigan DOT Covers J and K for both on-grade and sag inlet applications. The analyses examined inlet interception efficiency, the distribution of captured flow between the grate and curb-opening window, the relative importance of front and side grate interception, the effects of debris blockage, and the hydraulic capacity of the inlets under sag conditions. In addition, CFD results were compared with HEC-22-based design methods to assess the adequacy of current design assumptions.
For on-grade conditions, the simulations showed that hydraulic efficiency depends strongly on gutter discharge, longitudinal slope, and inlet geometry. For both covers, interception efficiency decreased as flow rate and longitudinal slope increased, since higher approach velocities and larger spreads increased the proportion of bypass flow. Across the full range of simulated cases, Cover J consistently performed better than Cover K, intercepting a larger fraction of the approaching runoff under comparable hydraulic conditions. At lower flow rates, both covers were capable of nearly complete interception, but Cover J maintained high efficiency over a broader range of conditions. At steeper slopes and higher discharges, the difference between the two covers became more pronounced, with Cover J showing greater robustness and lower bypass.

The on-grade flow partitioning results further showed that the grate is the dominant interception pathway for both cover types, while the curb-opening window contributes a smaller but still measurable portion of the total intercepted discharge. In most cases, the grate captured the large majority of the intercepted flow, and the internal distribution within the grate demonstrated that front interception is the controlling mechanism. The upstream edge of the grate accounted for most of the grate capture, while side interception remained comparatively small. This trend be-came more pronounced as longitudinal slope increased, indicating that higher approach momentum shifts the hydraulic burden increasingly toward the front edge of the inlet. These findings suggest that inlet geometry influencing frontal capture has the greatest effect on on-grade performance.

The debris simulations showed that localized blockage upstream of the grate can severely de-grade inlet effectiveness. A cylindrical obstruction placed immediately upstream of the inlet di-verted flow away from the grate, increased bypass, and caused a substantial reduction in interception efficiency for both covers. Under the tested condition, Cover J efficiency dropped from 96% to 33%, while Cover K decreased from 90% to 25%. These results demonstrate that even partial blockage of the approach flow path can significantly reduce hydraulic performance and increase the risk of surface ponding. They also indicate that Cover J is somewhat more resilient than Cover K under obstructed conditions, although both designs are highly sensitive to debris accumulation.

For sag conditions, the CFD simulations captured the full drainage process as ponded water above the inlet receded over time. The results confirmed that inlet flow transitions through the expected sequence of hydraulic regimes, beginning with orifice flow at high ponding depths, passing through a transitional regime, and ending in weir flow as the water depth decreases. For both Cover J and Cover K, the unclogged configuration provided the greatest hydraulic capacity, while blockage of either the grate or the curb opening reduced discharge, increased ponding depth, and prolonged drainage time. Among the blockage scenarios considered, grate obstruction generally produced the lowest flow rates and the deepest ponding, indicating that the grate opening is the most hydraulically important component under the modeled sag conditions.

Comparison of the two cover types under sag conditions showed that they follow the same over-all trends, but Cover J again performed somewhat better than Cover K. In the stage-discharge relationships, Cover J generally conveyed slightly higher flow rates for the same ponding depth. The time-series results also showed that Cover J drained more quickly, with lower residual ponding and shorter recession periods, while Cover K exhibited a slower hydraulic response and long-er drawdown, particularly under clogged conditions. These differences indicate that Cover J has slightly greater hydraulic capacity and somewhat lower sensitivity to partial obstruction than Cover K.

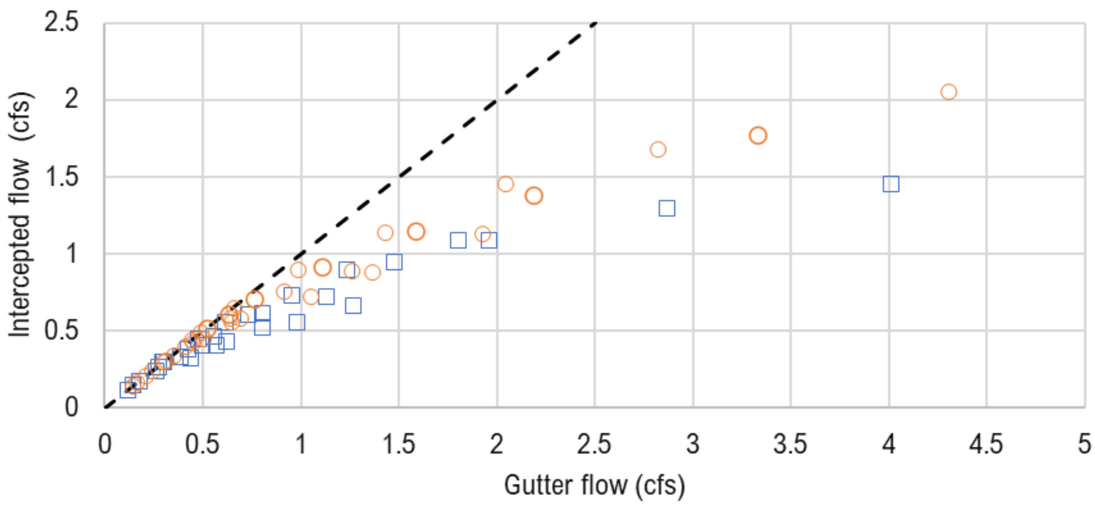

Figure 1. Intercepted flow versus gutter flow for Cover J (orange circles) and Cover K (blue squares). The dashed black line represents the unity line.

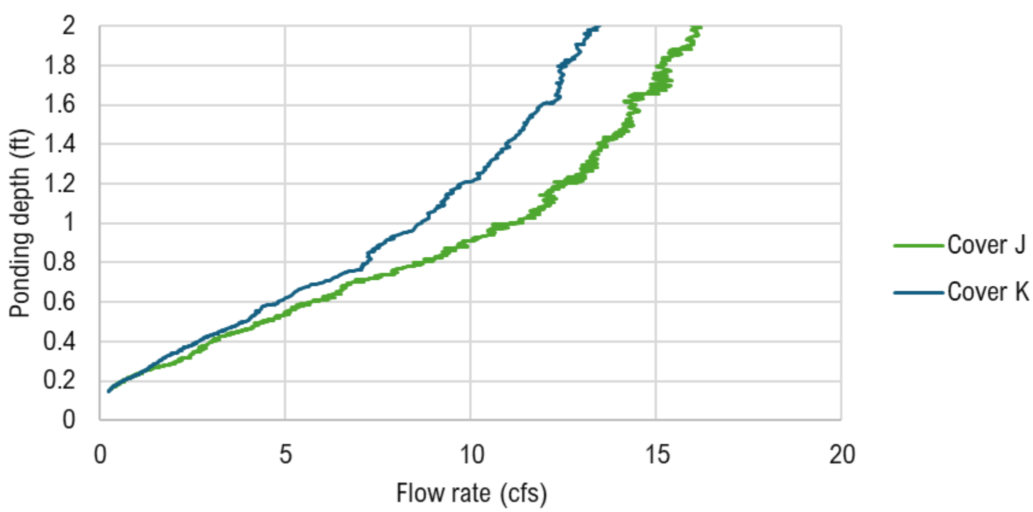

Figure 2. Ponding depth (ft) vs. flow rate (cfs) for Cover J and K.

1.2. Internal Culvert Energy Dissipators

This study evaluates the impact of energy dissipators on flow behavior in culverts using computational fluid dynamics (CFD). The primary objective is to quantify how baffles, wall roughness, inlet conditions, and outlet treatments influence hydraulic performance and to translate these effects into equivalent resistance parameters useful for engineering design. The work is carried out mainly in STAR-CCM+, with OpenFOAM used for code-to-code comparison and for reconstruction of the final model in an open-source framework.

The CFD methodology includes Reynolds-averaged Navier–Stokes (RANS) and large eddy simulation (LES) approaches, with two-phase air–water modeling using the volume of fluid (VOF) method to resolve the free surface. The simulated geometry consists of a sloped circular culvert with configurable wall roughness and multiple baffle arrangements. The model outputs include water depth, velocity, flow rate, friction slope, hydraulic radius, turbulent kinetic energy, turbulence dissipation rate, and equivalent Manning's roughness coefficient.

Baseline simulations of an empty culvert were first used to assess the influence of inlet velocity specification and wall roughness. Comparisons between uniform and fully developed inlet velocity profiles showed that inlet definition affects near-entrance development and local water surface behavior. Wall resistance was investigated using smooth walls, equivalent sand roughness formulations, and explicit corrugated metal pipe representations. These simulations showed that wall roughness affects both velocity and water depth, but in the tested configurations its impact was smaller than the hydraulic effect of baffles.

The introduction of baffles produced a substantial reduction in flow velocity relative to the empty culvert under the same inlet and slope conditions. This deceleration was accompanied by increased turbulence levels, increased flow resistance, and changes in hydraulic radius and water-surface profile. Multiple baffle configurations were investigated, including cases with 5 and 10 baffles, 5 ft and 10 ft spacing, baffles oriented at 90° and ±45°, and baffles with and without cutouts. In general, closer spacing and a greater number of baffles increased the dissipative effect. Baffle orientation also altered the internal flow structure, including the streamline pattern and local water surface shape.

A key finding is that the hydraulic influence of baffles depends strongly on flow regime. Froude number analysis showed that for mildly supercritical conditions, the effect of baffles on the outlet region may be limited, whereas for more strongly supercritical flow the dissipative effect becomes more pronounced. Additional simulations with varying culvert slope confirmed that baffles are more effective under higher-energy flow conditions.

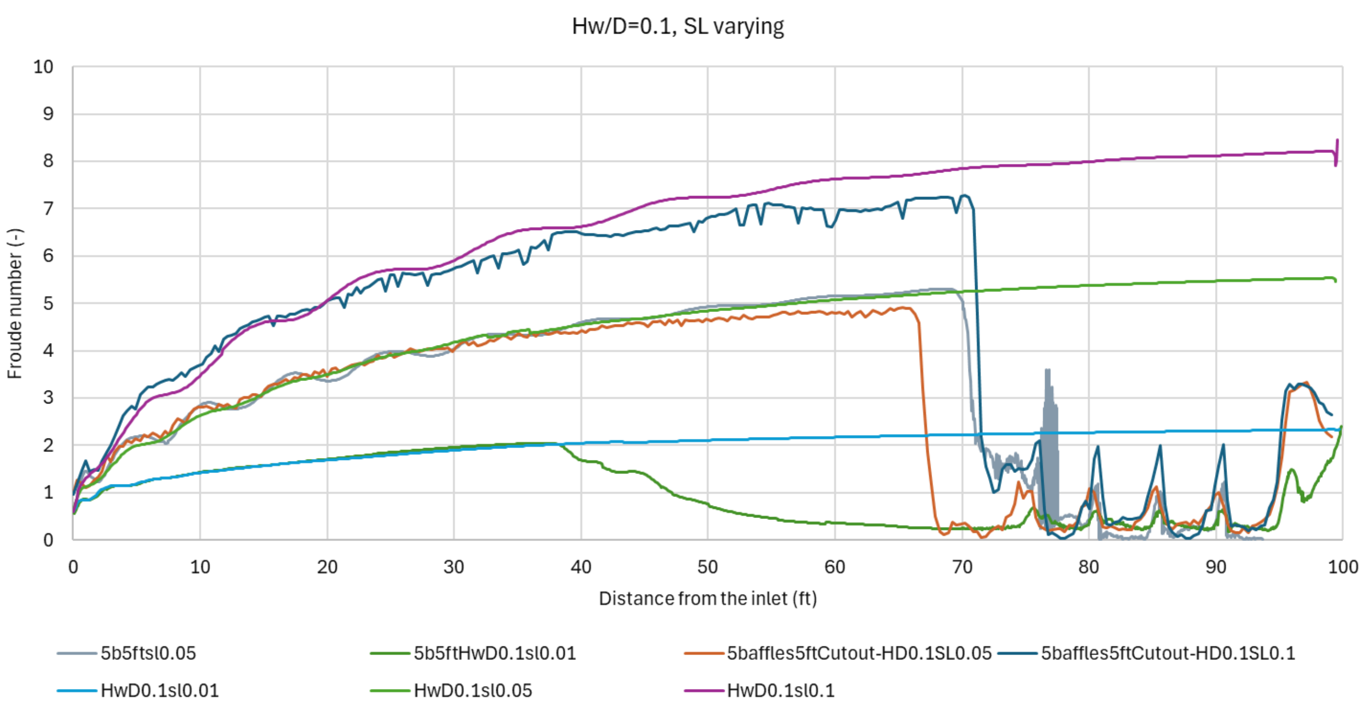

Figure 3. Froude number along the culvert for Hw/D=0.1 and varying slope for an empty culvert and a culvert with 5 baffles spaced 5 ft apart.

Figure 3 shows results for cases with Hw/D=0.1 and several slope values, including SL=0.01, 0.05, and 0.1, for both an empty culvert and a culvert with 5 baffles spaced 5 ft apart. The plotted Froude number distributions along the culvert indicate that the flow remains supercritical over much of the culvert length, but the magnitude of the Froude number changes with slope. The main finding is that the effectiveness of baffles depends on the incoming flow regime. When the inlet condition produces flow with Fr<2 to 3, the baffles have little influence on the outlet flow conditions. In contrast, when the flow is more strongly supercritical, with Fr>2 to 3, the baffles have a more noticeable hydraulic effect

An important component of the study is the derivation of equivalent Manning’s roughness values from the CFD results which is currently under investigation. Using calculated flow depth, velocity, friction slope, and hydraulic radius, the simulations were interpreted in terms of an effective Manning’s n. The results show that baffles can significantly increase the apparent roughness of the culvert. The study investigates a simplified representation of baffle effects using a porous-media-type momentum source term based on an equivalent Manning’s n. In this approach, a culvert with low wall roughness is used as the base case, and the additional resistance associated with dissipators is introduced through a distributed source term in the momentum equations. This method offers a practical way to reproduce the hydraulic effect of baffles without explicitly resolving their geometry, although the implementation requires iterative estimation of the hydraulic radius and associated resistance.

Anticipated work in the next quarter:

1: Computational Mechanics Research on a Variety of Projects

- hydraulic analysis of catch basins on grade and in sump
- culvert hydraulics
- modeling of water film on pavements

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.