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

Quarter 3, July - September 2021

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 current 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: Computational Fluid Dynamics Modelling of Hydraulic Capacity of South Carolina DOT Drainage Structures

Proper design of surface drainage of roadways is essential to minimize flooding and provide traffic safety. Inlets collect the excess storm water from the drainage area and discharge it into storm drains. Knowing the hydraulic efficiency of inlets, defined as the fraction of the total street flow intercepted by the drain, is necessary in drainage design so that the inlet spacing can be determined such that the system can transport all or a majority of the road surface flow during rain events into the drainage system.

Curbs and gutters are concrete structures installed to manage runoff from roadways or parking lots and convey it into the drainage system. When a curb and gutter is used, the gutter cannot be considered a part of the travel lane, instead, it should be included in the paved shoulder [1]. A concrete curb and gutter with 6-in-high curb and a 1.5-ft-wide gutter was considered in the study [2]. Catch basins Type 16 and 17 have the same cross-section [3], [4]. They differ with the length of the opening, which is 4 feet for Type 16, and 8 feet for Type 17. A cross-section through the inlet is shown in Figure 1.

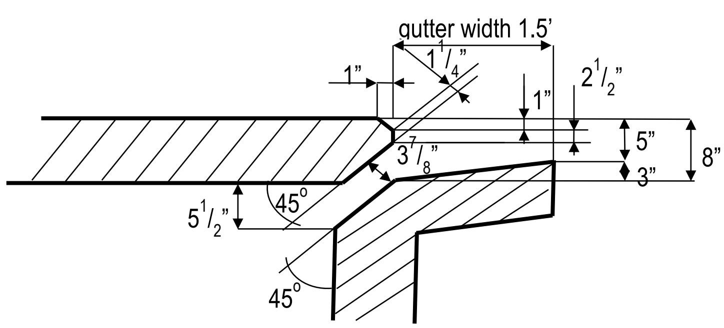


Figure 1. Cross section through the inlets Type 16 and 17

A typical cross-section through an urban road is shown in Figure 2. The purpose of catch basins is to intercept water draining towards the curb on each side of the median. The drainage area width is then equal to one travel lane plus the shoulder (from the road crown to the curb). The design length, which is equal to the spacing between inlets, is such that the spread of water measured from the median is less than the allowable spread for the design rain intensity. The allowable spread differs depending on the type of the road.

The proposed scope of work covered a parametric study with the following road geometry variables. The travel lane is 12 feet wide. The width of the gutter is constant and equal 1.5 feet. The cross-slope is equal to 0.5% and 2%, and the longitudinal slope varies in the range from 0.3% to 16%. The maximum spread was assumed to be 11.5 feet, which covers the cases of the flow on the gutter (1.5 ft), half of the travel lane (6 ft) and, additionally, a bike lane (4 ft wide).

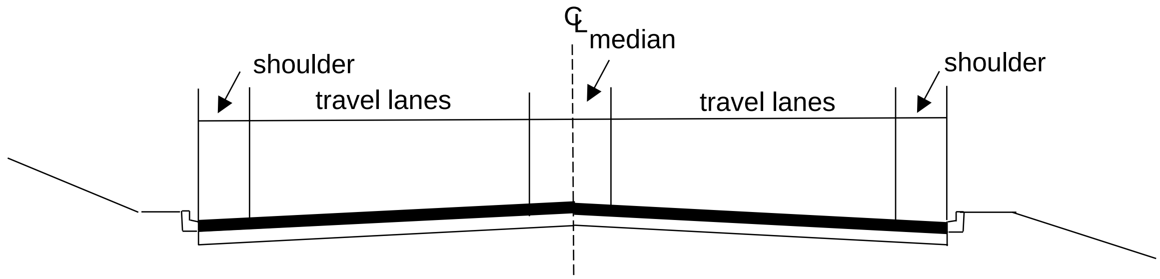


Figure 2. A cross section of a typical urban roadway

A Volume of Fluid (VOF) multiphase fluid model for water on the road with air above was used along with an unsteady Reynolds averaged Navier-Stokes (URANS) solver for the fluid flow governing equations with a k-ε turbulence model and standard wall functions to compute shear stress at the street and barrier wall boundaries. The VOF model makes it possible to model water and air in the same domain and to track the free surface between the two phases. The free surface is shown in Figure 3 with a blue line between wet and dry part of the road. The left-hand side surface is the inlet boundary with specified water velocity, and the right-hand side surface is the outlet boundary. The water can also leave the domain through the curb and gutter inlet. The location of the inlet and outlet boundaries was determined so that they are far enough from the grate not to influence the flow in the area of the grate.

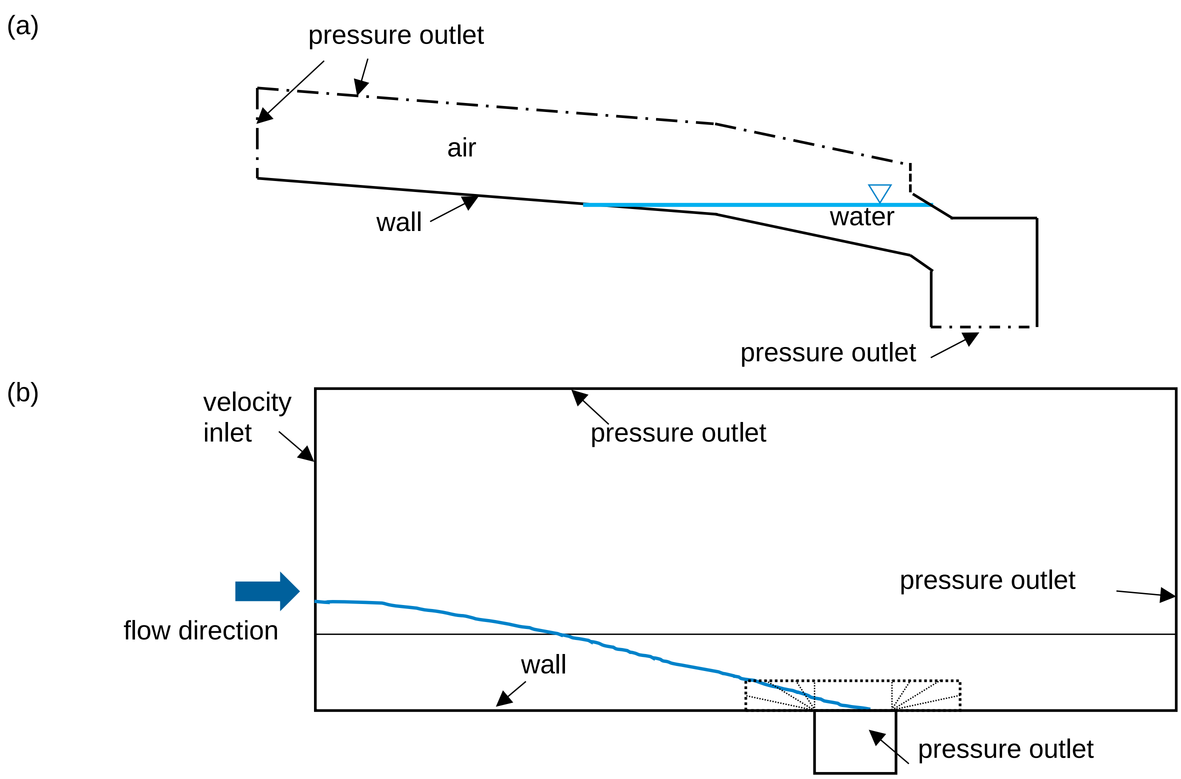
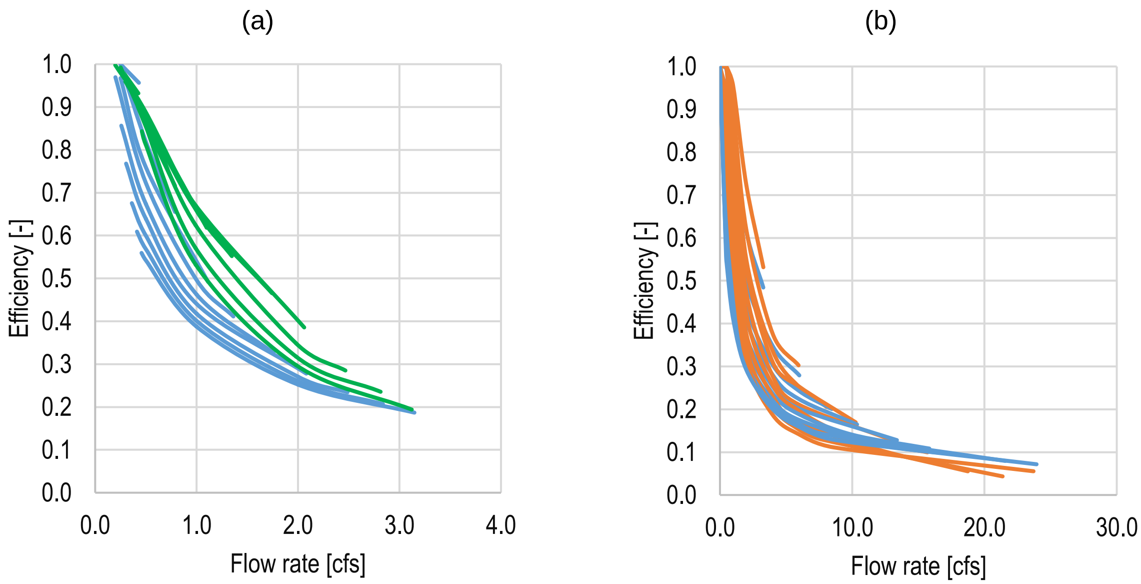


Figure 3. Schematic views of the CFD domain, a) a cross-section through the computational domain, b) a top view of the computational domain with boundary conditions. Note: the drawings are not to scale.

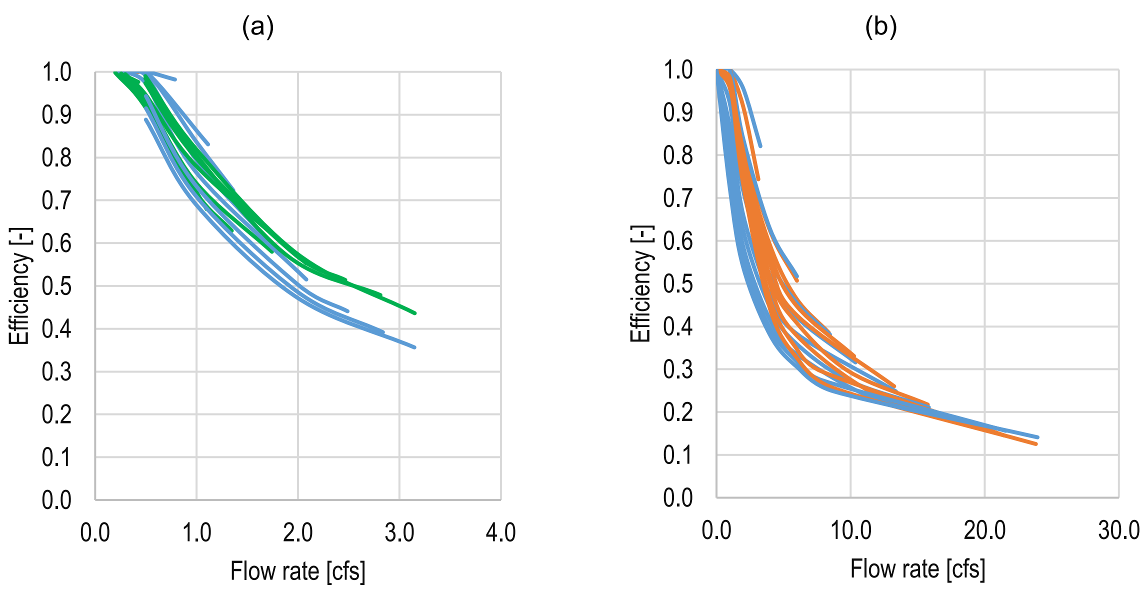
Figure 4 shows the CB-16 and Figure 5 CB-17 catch basin efficiency as a function of the design flow rate at road cross-slopes (a) 0.5 %, and (b) 2 %. Each line represents results for a different longitudinal grade of the road (in the range 0.3%-16%). The plots show a drop in the captured flow with increasing flow rate, which is quite significant for lower flow rates, and slows down for higher flow rates. CFD overestimates HEC-22 results for CB-16 for the entire considered range of flow rates. In the case of CB-17, the CFD efficiency is overestimated for lower flow rates and underestimated for the higher flow rates as compared to the HEC-22 estimates.



blue – HEC-22, green - CFD

blue – HEC-22, orange - CFD

Figure 4. Efficiency as a function of the design flow rate for the CB-16 catch basin at (a) 0.5%, (b) 2% travel lane cross-slope



blue – HEC-22, green - CFD

blue – HEC-22, orange - CFD

Figure 5. Efficiency as a function of the design flow rate for the CB-17 catch basin at (a) 0.5%, (b) 2% travel lane cross-slope

Figure 6 presents the CFD data points with best fits of the data for each of the catch basins and road cross slopes in the form of exponential functions. The equations and R^2 values are provided in the figure.

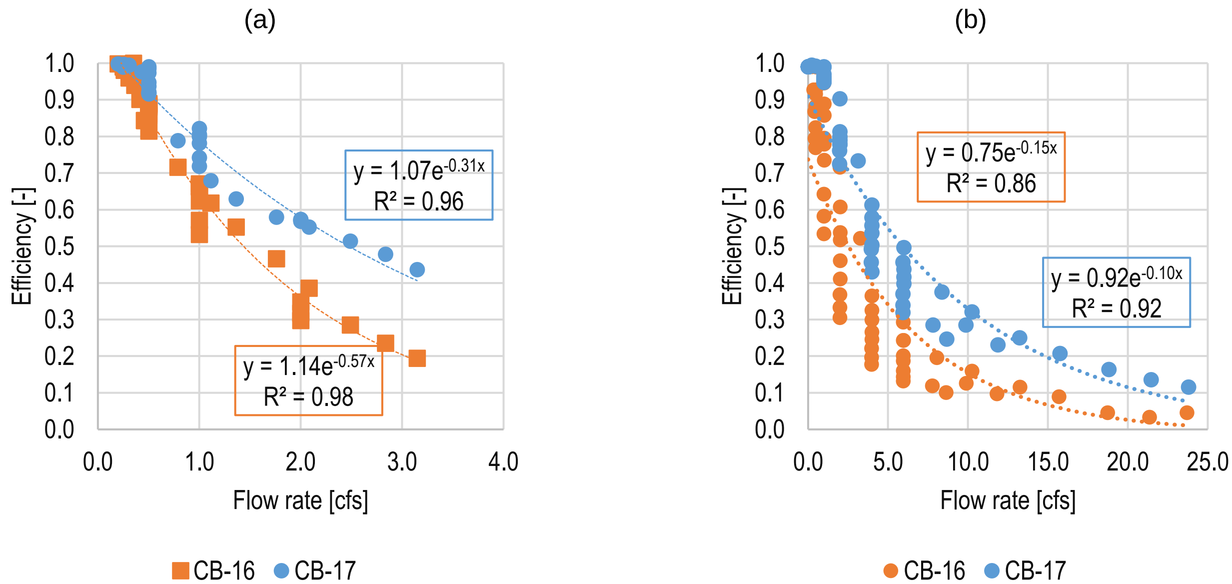


Figure 6. Efficiency as a function of the design flow rate for the CB-16 and CB-17 catch basins at (a) 0.5%, (b) 2% travel lane cross-slope

In the next step, the results of the analysis will be combined in a spreadsheet with programmed calculations that will allow the engineers to design a drainage system on South Carolina roads. Additionally, a manual will be provided to SCDOT, which will include information about the methods of development of the efficiency curves and drainage calculations and also instructions on how to use them in the design process. This will allow SCDOT to modify and create new design information due to changes in roadway and hydraulic design requirements. A description of the analysis case runs will be included, covering all data from the simulations and programing explanations.

References:
[1] South Carolina Department of Transportation Roadway Design Manual, SCDOT, March 2017
[2] Standard Drawing. Curb and Gutter (Concrete), 720-105-01, August 2012
[3] Standard Drawing. Catch Basin Type 16, 719-016-01, March 2009
[4] Standard Drawing. Catch Basin Type 17, 719-017-01, March 2009

2: Computational Mechanics Research Support

Argonne Transportation Research and Analysis Computing Center (TRACC) computational mechanics staff ran nationwide videoconferences every other Thursday that were open to state Department of Transportation staff and university researchers supported by the Federal Highway Administration or state DOTs. The videoconferences provide a venue to discuss approaches and issues related to hydraulics modeling projects. Topics during this reporting period included, but were not limited to:

- new methodologies of scour modeling,
- approaches to modeling and mitigating hydroplaning risk,
- hydraulic analysis of catch basins.

3: Computing Support

TRACC staff provides routine cluster maintenance for FHWA users of the TRACC high-performance computer cluster including software and hardware upgrades, security patching against cyber threats, and development of custom tools to increase user productivity. TRACC staff is currently working on upgrading the TRACC clusters with a new collection of 64-core computer nodes. Work also includes upgrades to the latest scientific and engineering software utilizing industry's best practice guidelines in open-source software and visualization.

Anticipated work next quarter:

1: Computational Mechanics Research on a Variety of Projects

- development of a new methodology for riverbed scour
- hydraulic analysis of a catch basins
- analysis of water film thickness 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, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

None.