RESEARCH PROJECT WORK PLAN

Project Title:	Flooded Pavement Assessment App – Phase II
Total Project Budget:	$200,234
Total Project Duration:	32 months
Public Agency Champion (state, county, city, or township employee):	Raul Velasquez (Raul.Velasquez@state.mn.us) Terry Beaudry (terry.beaudry@state.mn.us) Ben Worel (Ben.Worel@state.mn.us),
Key Words (for cataloging):	Flooded Pavement Road Load Restriction Unsaturated Soil Mechanics
Date Submitted:	8/16/2021

1. PROJECT TEAM

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- Co-Investigator (if applicable):
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2. PROJECT ABSTRACT AND OBJECTIVE(S)

Pavements are dynamic structures and are affected by several parameters such as climate, loading conditions, or material properties. Current pavement analysis and design procedures often rely on empirical or mechanistic-empirical approaches, which renders their ability to incorporate moisture-dependency, especially during periods of excess moisture (such as, post flooding) and to conduct real-time and forecasted pavement capacity and load restriction analyses. While excess moisture in base and subgrade soils during and after inundation of roads has detrimental impacts on longevity and serviceability of pavements, immediate need for transportation agencies is often focused on road closure and opening decisions. The presence of excess water can be due to seasonal ground water level fluctuations, post-storm flooding, and thawing of soil frost and surface snow. An ideal agency decision App for roadway closures and/or load posting is the one that is mechanistic, and holistically evaluates different physical and environmental stressors. Such Application can enhance the resilience of pavement systems in response to extreme events and results in more sustainable, efficient, and cost-effect roads. In an effort supported by the NRRA – Phase I, the research team at the University of New Hampshire (UNH) has studied the mechanistic response of flexible pavement systems during and after flooding events using system dynamics modeling. An initial version of a user-friendly toolkit was developed that would help

agencies to decide on post-flooding roadway opening decisions by mechanistically assessing the pavement capacity on basis of pavement section characteristics, material properties, climatic conditions (past and forecasted), and traffic scenarios. The Phase II project aims to enhance and amplify the recently developed post-flooding roadway assessment. More specifically, the following goals are targeted: (1) improving the user-interface, adaptive functionality such as interacting with pavement analysis software and more diverse material and load options, and computational efficiency of the application; (2) validate this mechanistically programmed application using scaled physical modeling, advance numerical simulation, and in-situ field data. All versions of application would be available for use with corresponding technical and user manual.

3. HOW DOES THIS RESEARCH BENEFIT NRRA STATE DOTS' TAXPAYERS?

At present, a majority of roadway seasonal and post-flooding load restriction (SLR) protocols in NRRA state DOTs depend on either use of subsurface soil information or historic seasonal moisture data. Neither of these methodologies provide robust estimate of actual pavement structural load carrying capacity and both approaches lack in terms of inclusion of climate variables and assessment of roadways in post-storm scenarios. Due to empirically driven nature of the SLR protocols there is potential for imposing either over- or under- restriction on roadways. Both result in substantial loss to general population of National Road Research Alliance (NRRA) member state entities. When over-restriction is used it results in losses to businesses due to limits imposed on trucking and other mean of freight transport. When there is under-restriction scenario, it substantially limits the life-span of roadway infrastructure resulting in excessive pavement repair, rehabilitation and reconstruction costs.

The proposed research will build on Phase-I to develop a mechanistic and verified flooded pavement simulator tool to improve robustness of the load restriction decision process. Due to incorporation of both mechanics and climate data, the tool will enable users to make decisions regarding post-flooding road opening. The toolkit will assist public agencies to make reliable road opening decisions during and after flooding and for various traffic classes. This ability will also have tremendous impact on NRRA state DOTs' taxpayers as it directly impacts access of emergency responders and other post-flooding aid to impacted areas. The first version of the UNH's Flooded Pavement Assessment App was presented to NRRA members and also to at-large transportation community during TRB 2021 annual meeting, which received significant attention and interest.

The proposed project is aligned with the NRRA Phase-II strategic goals of sustainability and resiliency, the proposed project will: (1) result in a more efficient and performance-based load restriction protocol that would reduce the maintenance operation programs (minimizing the impact of operations on the climate and environment); (2) enhance the pavement service life and help agencies to make more informed decisions post flooding (improve the resilience of our transportation systems); (3) provide a robust toolkit to maintain road safety and emergency transportation management (promote public health and healthy communities); (4) enhance resiliency of pavement infrastructure by use of real-time as well as forecasted climatic information to ensure that post extreme event emergency response can be planned and executed.

4. SUMMARY OF RESEARCH METHODOLOGY (SCOPE)

The main outcome of this project will be an updated and validated toolkit for pavement engineers to make decisions regarding load restrictions during and after flood events. Although the current toolkit, developed after Phase-I, encompasses all fundamental aspects of pavement response, it incorporates several material models and constitutive relations from the literature. Some of these relations are approximate and some were developed for limited material options or boundary conditions. Thus, it is expected that the toolkit requires several versions of validation and modification. These modifications are needed to ensure the most accurate and reliable pavement response assessment. Further, this calibration and validation campaign should be done at different scales to provide a balanced approach between the practicality and technical soundness. The proposed research is divided into 10 tasks. At the beginning of the project and in Task 1, the team will seek feedback from NRRA states members to finalize and fine tune the application's modification/validation campaign. In Task 2, the survey data will be evaluated where, in consultation with the TAP, the team will layout a detailed plan for validation and verification of the toolkit. Originally, a fourfold calibration and validation campaign was envisioned to be done in a phased approach: (1) using the currently available network-level data – this was done during Phase-I; (2) using the results of scaled physical models – these will be accomplished in Task 3; (4) using advance numerical models – these will be completed in Task 4; and (4) using field data from instrumented road sections – this will be done in Task 5. In addition, the application will be enhanced with more diverse functionality and also in terms of computational efficiency, accessibility, and graphical user interface, in Task 6. Task 7 is out of state travel for researchers to present findings of this project at the annual meeting of the Transportation Research Board and Task 9 and 10 will develop and revise the final report for the study. The final product will provide immediate access to a decision toolkit that can be easily implemented by state DOTs for post-flooding roadway assessment. Specific details of task activities, schedule and deliverables are described in task description section.

5. TASK DESCRIPTIONS, DURATIONS, SCHEDULED DATES, AND KEY MILESTONES

Task 1: NRRA State Member Survey -Agency Specific Inputs for App

- **Description**: State feedback on the PaveSafe app both in terms of functionality and performance are critical to the success of the project. A detailed user survey will be launched where application users' feedback, agency specific typical input for assessment of flooded pavements (e.g., traffic loading and configuration, material inputs, etc.), and recommendation for modifications and/or additions will be collected and summarized.
- **Anticipated Start Date:** 1/1/2022
- **Scheduled Date to Submit Draft Deliverable:** 2/28/2022
- **Scheduled Date for Task Final Approval:** 4/30/2022
- **Duration:** 4 months
- **Deliverable:** A survey summary and synthesis will be generated and reported to TAP, which will form the basis of Task 2.

Task 2: Development of Verification and Validation Plans

- **Description**: Based on the information gathered in the phase-I of this research as well as through agency specific inputs from Task-1, a detailed plan will be developed in this task for conducting verification and validation of the PaveSafe app. The verification efforts will focus on ensuring that app has accurate analysis and calculation steps to reflect pavement responses that are of same quality as those obtained with current state of the art pavement mechanical analysis systems. Validation efforts will be focused on comparing PaveSafe predictions to actual physically measured pavement responses and performances. A three pronged approach for verification and validation will be developed, these will include: (1) small and large scale laboratory physical model testing (task-3), (2) advanced numerical simulation models (task-4), (3) field data from instrumented pavement sections (task-5). The plans developed in this task will detail experimental methodologies, ranges of tested material types, initial and boundary conditions of small and large scale physical models (including moisture states) and numerical simulation details that include constitutive model types, loading types, analysis methods and associated initial and boundary conditions. The experimental plans for scaled physical testing will be developed using fractional factorial experimental design using techniques such as, Plackett-Barman method. Comparative basis used for validation purposes, especially for data from instrumented pavement sections will be defined and discussed in the plans developed during this task.
- **Anticipated Start Date:** 3/1/2022
- **Scheduled Date to Submit Draft Deliverable:** 4/31/2022
- **Scheduled Date for Task Final Approval:** 6/31/2022
- **Duration:** 4 months
- **Deliverable:** A task memo describing verification and validation plans for implementations in tasks 3, 4 and 5 will serve as primary deliverable for this task. Research team will also present the verification and validation plans to the project TAP during this task.

Task 3: Small-scale and Large-scale Physical Modeling

- **Description**: In this task, the testing plan for small and large scaled physical modelling that is developed in Task-2 will be executed. Small scale modelling effort will use bench-scale models (element level testing) primarily composed of geomaterials to verify and enhance PaveSafe app in terms of large number of materials with controlled moisture states and load magnitudes. Main objective of small-scale element level physical models will be to enhance mechanistic response of materials within PaveSafe. Up to twelve different small-scale models will be constructed and tested. Data generated from small-scale testing will also provide improvements to the default material inputs and model parameters used in PaveSafe. In addition to deformations, pore water pressure generation will be measured and effective stress-based limits for soil load bearing capacities will be explored. Large scale models will be constructed with multiple layers and will use various moisture saturation profiles. Main objective of large-scale models will be to provide verification datasets for PaveSafe in a multilayered system with non-uniform moisture

distributions. Up to four different large-scale models will be constructed, each will be tested with up to three different moisture saturation profiles. Dynamic loading will be utilized, both surface deflection and pore water pressure in soil will determined. Measured quantities will be used to verify and enhance PaveSafe predictions.

- **Anticipated Start Date:** 5/1/2022
- **Scheduled Date to Submit Draft Deliverable:** 1/31/2023
- **Scheduled Date for Task Final Approval:** 3/31/2023
- **Duration:** 11 months
- **Deliverable:** A task report will be prepared that will present the details on laboratory experimentation, results of testing and discussion of results. Improvements and modifications to PaveSafe app will be documented and discussed. Research team will present the task efforts and results to the project TAP during this task.

Task 4: Advanced Numerical Modeling

- **Description**: This task will undertake advanced numerical modeling effort to expand the verification and enhancement efforts for PaveSafe beyond those conducted using small and large scale physical models. Analysis plans developed in task 2 will be executed in this task. The analysis effort is expected to utilize computational systems such as GeoStudio software package (the most recent version) where soil moisture movement and pavement mechanical response can be coupled. Models will be first evaluated using lab measured data from task 3 to ensure their veracity, thereafter pavement systems will be evaluated, and results will be used to validate and enhance PaveSafe app. The team will coordinate with TAP to select pavement systems / MnROAD cells with available moisture sensors to simulate transient seepage and pavement response.
- **Anticipated Start Date:** 10/1/2022
- **Scheduled Date to Submit Draft Deliverable:** 5/31/2023
- **Scheduled Date for Task Final Approval:** 7/31/2023
- **Duration:** 10 months
- **Deliverable:** A task memo will be prepared to document advanced modelling results and comparisons between model predictions and PaveSafe. Improvements and modifications to PaveSafe app based on advanced modelling results will be documented and discussed. Modeling and output files will be also provided in the deliverable report. Research team will present the task efforts and results to the project TAP during this task.

Task 5: Validation of App with Instrumented Road Sections

- **Description**: In this task research team will conduct validation and if necessary, calibration of PaveSafe app using weather and instrumentation data from selected MnROAD cells and other NRRA agency road sections. MnROAD cells from 2022 construction as well as those with useful data from previous construction cycles will be used as primary data sources. Research team will work with MnROAD staff in providing feedback with respect to instrumentation and data

requirements to support this task. Research team will use a survey of NRRA agency members to gather information with respect to acquisition of field data from roadways that have been subjected to excessive moisture states. Validation efforts will employ statistical testing to demonstrate accuracy of PaveSafe app in prediction of pavement responses and to ensure that reliable load restriction and closure recommendations are predicted. This task will require considerable support from MnROAD staff. Details on support and effort of MnROAD staff is provided in section 13 (Agency Assistance) of this work-plan.

- **Anticipated Start Date:** 5/1/2023
- **Scheduled Date to Submit Draft Deliverable:** 10/31/2023
- **Scheduled Date for Task Final Approval:** 12/31/2024
- **Duration:** 8 months
- **Deliverable:** A task report will be prepared to that provide details of the full-scale pavement section results, comparisons between full scale pavement response and those predicted by PaveSafe and discussions on validation and calibration of PaveSafe. Research team will present the task efforts and results to the project TAP during this task.

Task 6: Miscellaneous Improvements to App

- **Description**: This task will focus on making various improvements to the PaveSafe application in terms of its usability and efficiency. Specifically, the graphical user interface (GUI) will be improved to enable user to define vehicle types (tire and axle configuration and loads), print detailed outputs and have general user experience enhancements (such as, remembering user password, saving input files etc.). This task will also undertake efforts to improve computational efficiency of the software to lower the required analysis times and adopt faster analysis programs (such as, layered elastic analysis programs).
- **Anticipated Start Date:** 8/1/2023
- **Scheduled Date to Submit Draft Deliverable:** 12/31/2023
- **Scheduled Date for Task Final Approval:** 2/28/2024
- **Duration:** 7 months
- **Deliverable:** A task memo will be prepared to that provide details of enhancements that are made to PaveSafe app. An updated version of the PaveSafe app will also be provided to project TAP for testing and providing feedback to research team. Research team will present the task efforts and results to the project TAP during this task.

Task 7: Out-of-State Conference Travel

- **Description:** Preapproval of the **"**Travel Authorization Form" required from NRRA before travel occurs. Travel to Washington DC to present research results at TRB in January 2024.
- **Potential Attendees:** Partial support for PI, Co-PI, or the graduate student.
- **Scheduled Start Date:** 1/1/2024
- **Scheduled End Date:** 1/31/2024

- **Duration:** 1 month
- **Deliverables:**
  - Submit the Travel Authorization Form for each trip, which must be approved by NRRA before travel occurs (allow one month for approval).
  - After completing the trip, provide a brief summary to the TL and PC to initiate payment for the Out-of-State Conference Travel task.

Task 8: Draft final Report, Technical Advisory Panel Review, and Revisions

- **Description:** The PI will prepare a draft final report, following NRRA publication guidelines, to document project activities, findings and recommendations. This report will be reviewed by the Technical Advisory Panel (TAP), updated by the PI to incorporate technical comments, and then approved by the Technical Liaison before this task is considered complete. If possible, a TAP meeting will be scheduled to facilitate the discussion of the draft report.
- **Anticipated Start Date:** 2/1/2024
- **Scheduled Date to Submit Draft Final Report for TAP review:** 4/30/24
- **Scheduled Date for Final Report Approval**: 6/31/2024
- **Duration**: 5 months including TAP review, discussion, and PI revisions
- **Deliverables**: A draft final report for TAP review, and a revised report that is technically complete and approved by the TL for publication.

Task 10: Editorial Review and Publication of Final Report

- **Description:** During this task, the PI will work directly with NRRA's contract editors to address editorial comments and finalize the document in a timely manner. The contract editors will publish the report and ensure it meets publication standards.
- **Scheduled Start Date**: 7/1/2024
- **Scheduled End Date:** 8/31/2024
- **Duration:** two months (required)
- **Deliverables:** Final Publishable Report that meets NRRA's editorial guidelines and standards as well as final version of the PaveSafe app.

KEY MILESTONES

Key Milestone	Target Date	Description
1. Project kick-off web-meeting	1/20/2022	Kick-off meeting to present finalized work plan to TAP and obtain feedback for making any adjustments to the research activities.
2. Project update at NRRA Annual Meeting	5/31/2022	Researchers to present Task 1 and 2 summaries, especially the app demo, NRRA agency survey, and verification plan.

3. Project update web-meeting (Year-1)	3/15/2023	Researchers will present results of scaled physical modeling (Task 3) and the advancements on numerical simulation (Task 4).
4. Project update at NRRA Annual Meeting	5/31/2023	Findings from Tasks 3 and 4 and how they will support the app verification campaign and the overall project findings and deliverables.
5. Project update on state of instrumented road section	9/15/2023	This task specifically targets Task 5. In this meeting the team will discuss the progress on acquiring the field data and also the verification results. In addition, any shortcomings or lack of data will be resolved.
6. Project update at NRRA Annual Meeting and implementation training	5/31/2024	The team will work with NRRA states to organize an implementation training during the annual meeting event.
7. Project close-out meeting	6/15/2024	At this meeting researchers will present the key project findings as well as to demonstrate research products.

Quarterly update reports: In addition to above milestones and task deliverables, researchers will submit quarterly project update with details of activities of each tasks, including progress in terms of percentage of completed task activities and details on any challenges facing the project as well as actions taken to overcome the challenges.

6. BUDGET DETAILS

BUDGET BY LINE ITEM	Description	Budget (Round to nearest dollar)
Salaries		$ 91,432
Majid Ghayoomi, PI (Associate Professor)	Principal investigator for the study. 0.25 months effort in Year 2 and 3.	$ 6,602
Eshan Dave, Co-PI (Associate Professor)	Co-Principal investigator for the study. 0.17 months effort in Year 1-3.	$ 6,364
Graduate Research Assistant	A graduate student will be responsible for conducting experiments, modeling, analysis, data collection, and preparing the reports under the supervision of project PI and Co-PI. Time and effort for 5 semesters and 2 summer periods over the length of project.	$ 75,466
Undergraduate Research Assistant	125 hours of undergraduate student helper in Year 1 and 2 are budgeted providing assistance in experiments and modeling.	$ 3,000
Fringe Benefits		$ 2,451
Majid Ghayoomi, PI	Fringe rate: 7.9%	$ 522
Eshan Dave, Co-PI	Fringe rate: 7.9%	$ 503
Graduate Assistant	Fringe rate: 7.9% (only during summer periods)	$ 1,426
Non-Salary		
Out of State Travel:	Travel to TRB Annual Meeting	$ 1,000
Supplies	The cost to cover: license for software, materials and supplies for experiments, sensor replacements, and machine shop costs.	$14,000
Other: Graduate student tuition and fees	Tuition and fees for graduate student for 5 semesters (3 semesters with regular tuition and 2 semesters with dissertation credit only).	$ 33, 976
Subcontractors*		
Total Direct Costs		$ 142,859
Indirect Costs	Indirect Cost Rate: 52, 53, 53.5%	$ 57,375
TOTAL		**$ 200,234**

** Cost for non-academic sub-consultants cannot exceed 50% of the total proposal budget*

7. BUDGET JUSTIFICATION

Out of state travel funds are requested for researchers to travel to Washington D.C. to attend and present research results to transportation community during TRB meeting in January 2023.

8. OVERVIEW OF PROJECT SCHEDULE AND BUDGET

FY22(7/1/21 – 6/30/22)													
Month of Contract													**Budget**
Calendar Month	J	A	S	O	N	D	J	F	M	A	M	J	
Task 1: NRRA State Member Survey - Agency Specific Inputs for App							X	X	R	R			$10,769
Task 2: Development of Validation/Verification Plan									X	X	R	R	$10,769
Task 3: Small-scale and Large-scale Physical Modeling											X	X	
Task 4													
Task 5													
Task 6													
Task 7													
Task 8													
Task 9													
												FY22 Total:	$21,538

FY23(7/1/22 – 6/30/23)													
Month of Contract													**Budget**
Calendar Month	J	A	S	O	N	D	J	F	M	A	M	J	
Task 1													
Task 2													
Task 3: Small-scale and Large-scale Physical Modeling	X	X	X	X	X	X	X	R	R				$48,463
Task 4: Advanced Numerical Modeling				X	X	X	X	X	X	X	X	R	$43,078
Task 5: Verification of App with Instrumented Road Sections											X	X	
Task 6													
Task 7													
Task 8													
Task 9													
												FY23 Total:	$92,037

FY24(7/1/23 – 6/30/24)													
Month of Contract													**Budget**
Calendar Month	J	A	S	O	N	D	J	F	M	A	M	J	
Task 1													
Task 2													
Task 3													
Task 4	R												
Task 5: Verification of App with Instrumented Road Sections	X	X	X	X	R	R							$33,308
Task 6: Miscellaneous Improvements to App		X	X	X	X	X	R	R					$26,924
Task 7: Out-of-State Conference Travel							X						$1,000
Task 8: Draft Final Report								X	X	X	R	R	$16,154
Task 9													
												FY24 Total:	$77,386

FY25(7/1/24 – 6/30/25)													
Month of Contract													**Budget**
Calendar Month	J	A	S	O	N	D	J	F	M	A	M	J	
Task 1													
Task 2													
Task 3													
Task 4													
Task 5													
Task 6													
Task 7													
Task 8													
Task 9: Final Publishable Report	X	X											$10,769
												FY25 Total:	$10,769

The cost of the draft final report task and the final report publication task must each be at least 5% of the total project cost without the benefit quantification cost.

"R" in the schedule indicates the review/revision period

9. SUBCONTRACTOR INFORMATION

N/A

10. ADMINISTRATIVE REQUIREMENTS

A work order will be issued under the terms and conditions of the Master Contract between the NRRA and the University. The proposal submitted to NRRA must comply with the terms and conditions of the Master Contract. It

is understood that PIs, through the University Authorized Representative for the Master Contract, are aware of the Master Contract requirements, including those related to budgeting, quarterly progress reporting, final deliverables, invoicing, reimbursement of travel expenses and payments. A copy of the Master Contract can be obtained from the Office of Sponsored Projects Administration.

In addition, it is expected that the PIs will make themselves available to meet with NRRA Research Services staff, if necessary, to formally review the project progress on semi-annual basis. In most cases this will occur if the project falls behind schedule. PIs shall prepare necessary documentation and information to facilitate meaningful project reviews.

11. MATCHING FUNDS, IN-KIND, OR OTHER CONTRIBUTIONS

N/A

12. INTELLECTUAL PROPERTY/TRADE SECRET INFORMATION

N/A

13. AGENCY ASSISTANCE (NRRA OR OTHER)

This project relies on access to data and test results made available to researchers from MnROAD pavement cells as well as from other roadways of NRRA agencies. Specifically, data from MnROAD test sections on soil-moisture conditions as well as the falling weight deflectometer testing will be necessary to calibrate and validate the PaveSafe app. The timing for delivery of data to researchers is critical and any delay in it will adversely affect the project schedule.

14. INFORMATION TECHNOLOGY NEEDS

To allow MnDOT to assess potential IT needs, impacts and costs, please select all that apply.

☐Storing new data at MnDOT (mark the types of data below).

☐ Videos	☐ Design Files	☐ Text Data
☐ Photos	☐ Spatial Data	☐ Other_____

☐ Giving people outside of MnDOT access to an application or data stored within MnDOT

☐ Giving external applications access to an application or data stored within MnDOT

☐ Hosting or supporting a new application

☐ Integrating a new application or dataset with an existing MnDOT application or dataset