Outcomes of NCHRP 15-55 Hydroplaning

Gerardo Flintsch, Virginia Tech

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The 101 Sessions

Contents

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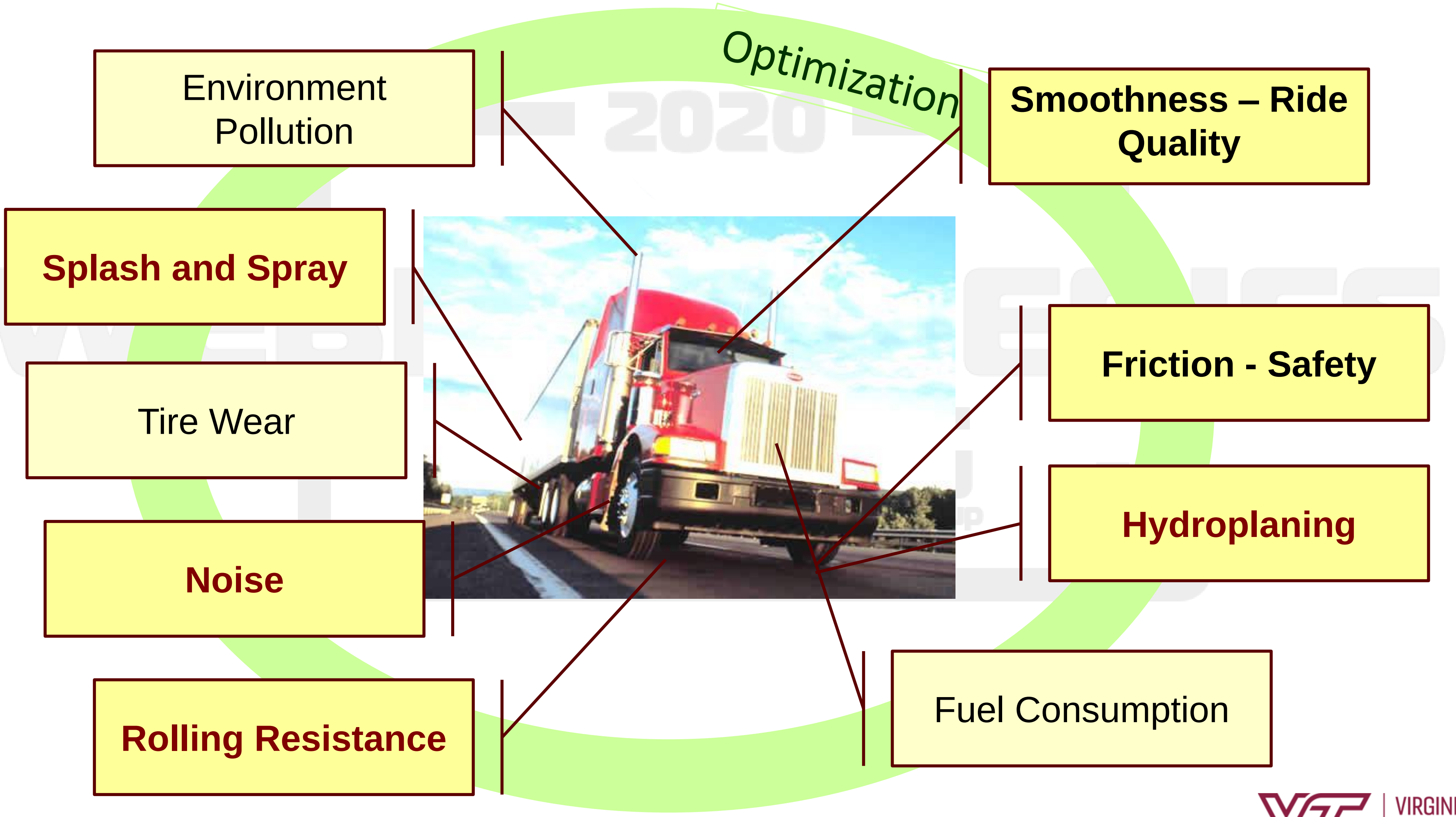
1. Introduction

Vehicle (Tire) / Road (Pavement) Interaction



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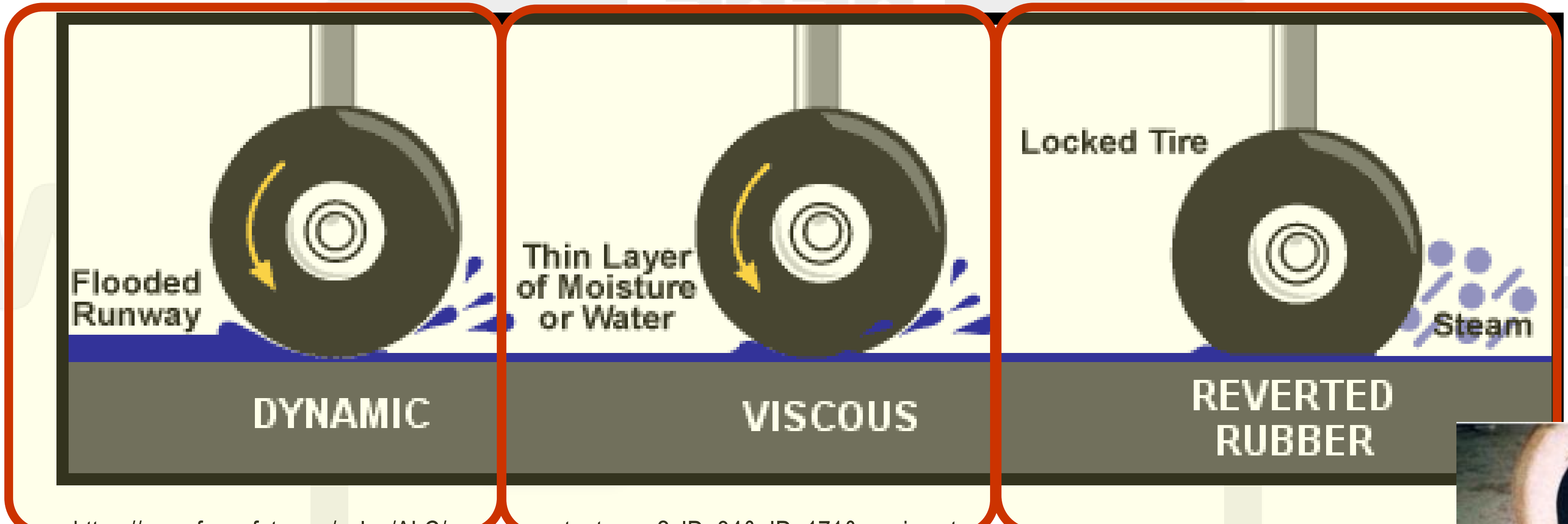
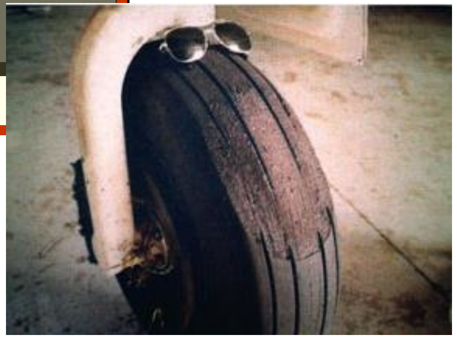
Hydroplaning



https://www.faasafety.gov/gslac/ALC/course_content.aspx?cID=34&sID=171&preview=true



Background

- ✓ AASHTO: hydroplaning is "a condition where one or more tires of a moving vehicle are separated from the pavement by a film of water; usually due to a combination of depth of water, pavement surface texture, vehicle speed, tread pattern, tire condition, and other factors."
- ✓ Hydroplaning is an important safety-related issue
- ✓ Previous studies (e.g., NCHRP 1-29 *Improved Surface Drainage of Pavements* (Anderson et al., 1998)) focused on the accumulation of water on the pavement
- ✓ Other aspects are also critical in assessing the potential for hydroplaning:
  - Vehicle
  - Tire
  - Fluid dynamics at the tire-pavement interface, as well as driver behavior.

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2. Objective

Objective

✓ To develop a comprehensive hydroplaning risk assessment tool that can be used by transportation agencies to help reduce the potential of hydroplaning.

- Treating hydroplaning as a multidisciplinary and multi-scale problem
- Solutions for areas with a high potential of hydroplaning based on a fundamental and meaningful understanding of the problem.

Objective

- ✓ Final Product: Guidance to predict and mitigate hydroplaning on roadways
- ✓ Two supporting products:
  - A ***Hydroplaning Risk Assessment Tool***
    - Practical and simple means for assessing the impact of roadway geometric features on the accumulation of water on the pavement and determining the hydroplaning potential for existing or new roads
  - An ***Integrated Hydroplaning Model***
    - Intermediate product, generated mainly for the development of the simpler, more practical assessment tool

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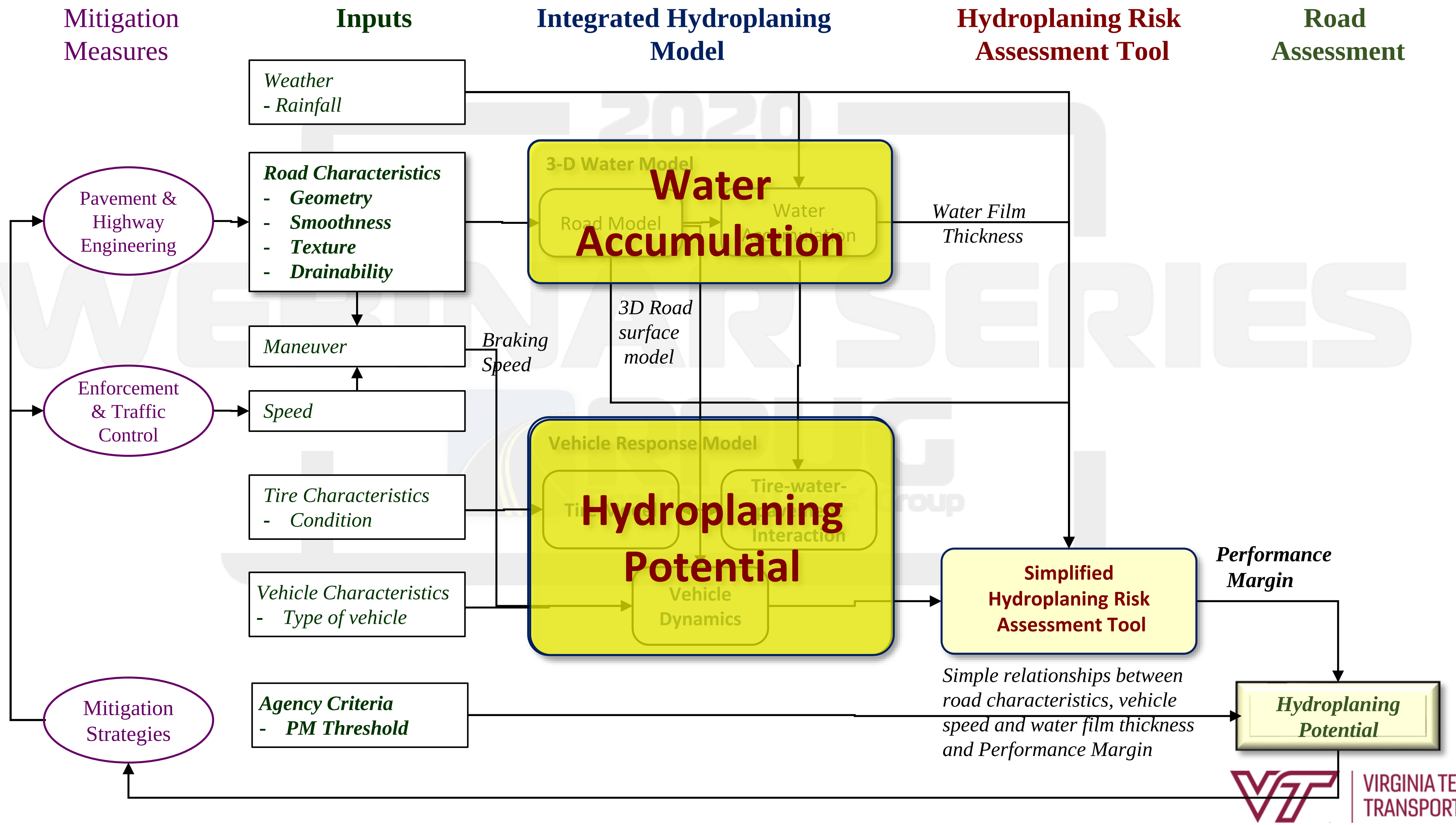
NCHRP 15-55 Research Approach Overview



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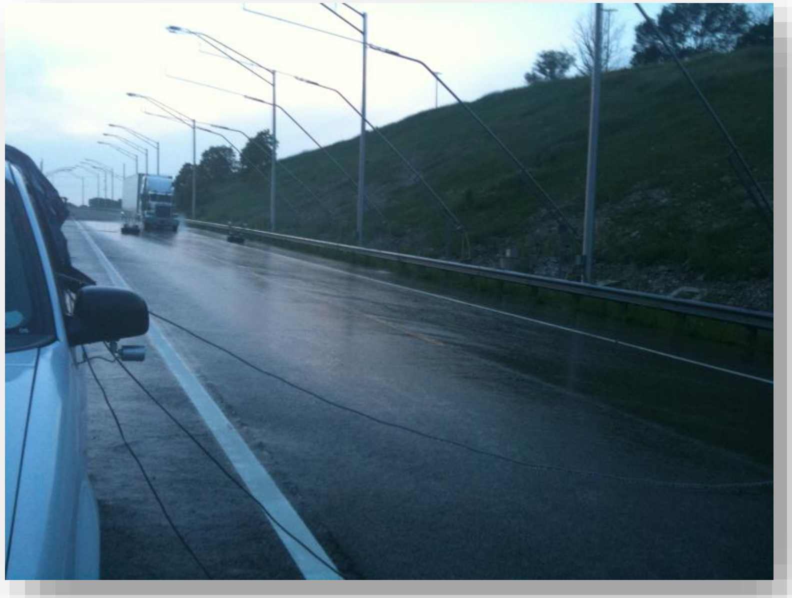
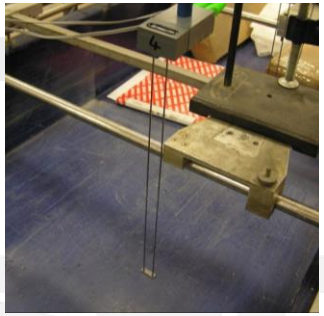
3. Water Accumulation

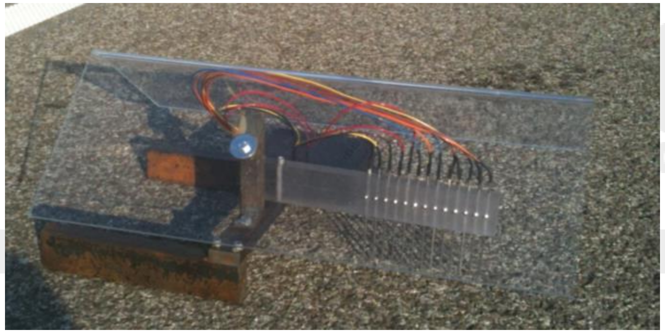


Measuring/Predicting Water Film Thickness

- ✓ Lab Measurements



- ✓ Field Measurements



https://www.lufft.com/products/road-runway-sensors-292/marwis-umb-mobile-advanced-road-weather-information-sensor-2308/

- ✓ Modeling

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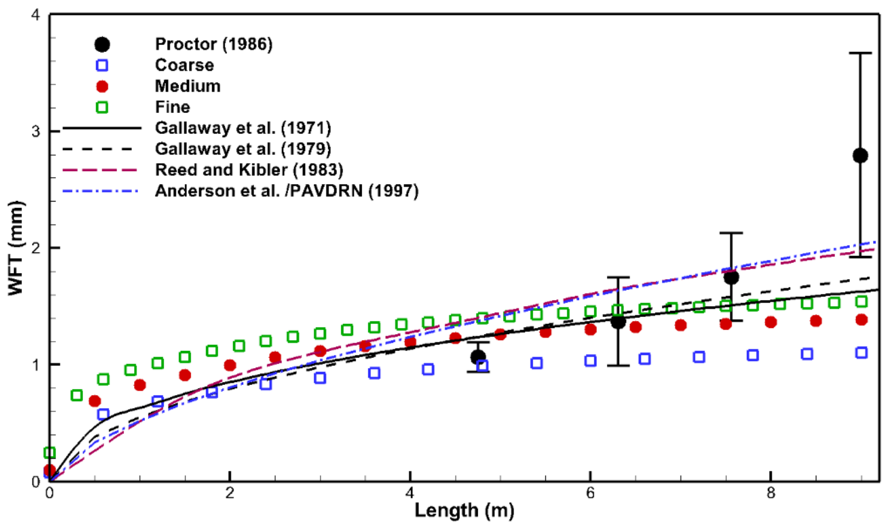
Examples of Water Accumulation Models

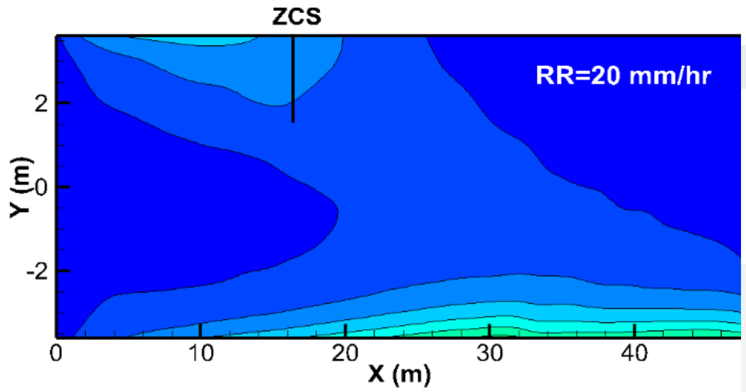
Table 1. Overview of previous and current models.

Models	Input	Description	Functions
TXDOT (1971)	Cross slope Macrotexture Rain intensity	1D empirical equations	$d = 3.38\times10^{-3}(\frac{1}{T})^{-0.11}L^{0.43}I^{0.59}(\frac{1}{S})^{0.42} - T$
PAVDRN (1997)	Cross slope Draining length Pavement Permeability Rain intensity	1D wave equations based on kinematic approximation conservation of mass and momentum	$WFT = (\frac{n\times L\times I}{36.1\times S_x^{0.5}}) - MTD$
TXDOT (2008)	Cross slope Draining length Longitudinal slope Rain intensity	2D wave equations based on Navier-Stokes equation	$\frac{\partial H}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} - r = 0$ $\frac{\partial q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_x^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right) + gh\left(\frac{\partial h}{\partial x} + S_{fx} - S_{ex}\right) = 0$ $\frac{\partial q_y}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q_y^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right) + gh\left(\frac{\partial h}{\partial y} + S_{fy} - S_{ey}\right) = 0$
NCHRP 15-55	Cross slope Draining length Longitudinal slope Macrotexture Pavement characteristics Rain intensity	3D full Navier-Stokes equations	$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_x)}{\partial x} + \frac{\partial(\rho u_y)}{\partial y} + \frac{\partial(\rho u_z)}{\partial z} = 0$ $\frac{\partial(\rho u_x)}{\partial t} + \frac{\partial(\rho u_x^2)}{\partial x} + \frac{\partial(\rho u_x u_y)}{\partial y} + \frac{\partial(\rho u_x u_z)}{\partial z} + \frac{\partial P}{\partial x} + \rho g_x = \frac{\partial \overline{\overline{\tau_{xx}}}}{\partial x} + \frac{\partial \overline{\overline{\tau_{xy}}}}{\partial y} + \frac{\partial \overline{\overline{\tau_{xz}}}}{\partial z}$ $\frac{\partial(\rho u_y)}{\partial t} + \frac{\partial(\rho u_x u_y)}{\partial x} + \frac{\partial(\rho u_y^2)}{\partial y} + \frac{\partial(\rho u_y u_z)}{\partial z} + \frac{\partial P}{\partial y} + \rho g_y = \frac{\partial \overline{\overline{\tau_{xy}}}}{\partial x} + \frac{\partial \overline{\overline{\tau_{yy}}}}{\partial y} + \frac{\partial \overline{\overline{\tau_{yz}}}}{\partial z}$ $\frac{\partial(\rho u_z)}{\partial t} + \frac{\partial(\rho u_x u_z)}{\partial x} + \frac{\partial(\rho u_y u_z)}{\partial y} + \frac{\partial(\rho u_z^2)}{\partial z} + \frac{\partial P}{\partial z} + \rho g_z = \frac{\partial \overline{\tau_{xz}}}{\partial x} + \frac{\partial \overline{\overline{\tau_{yz}}}}{\partial y} + \frac{\partial \overline{\tau_{zz}}}{\partial z}$

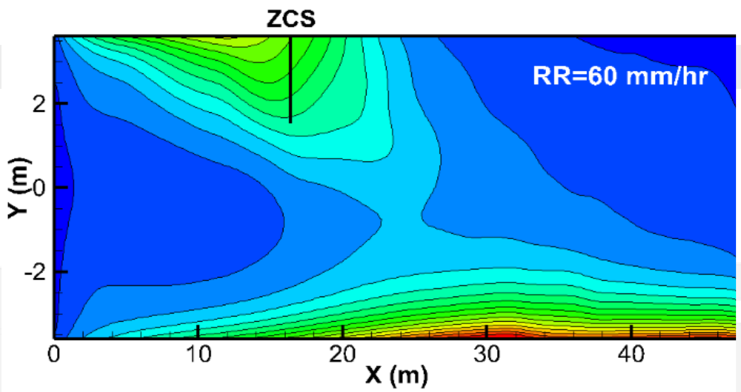
NCHRP 15-55 3D Water Accumulation Model

Validation work with Reed at al. (1989) and 1-D correlations.

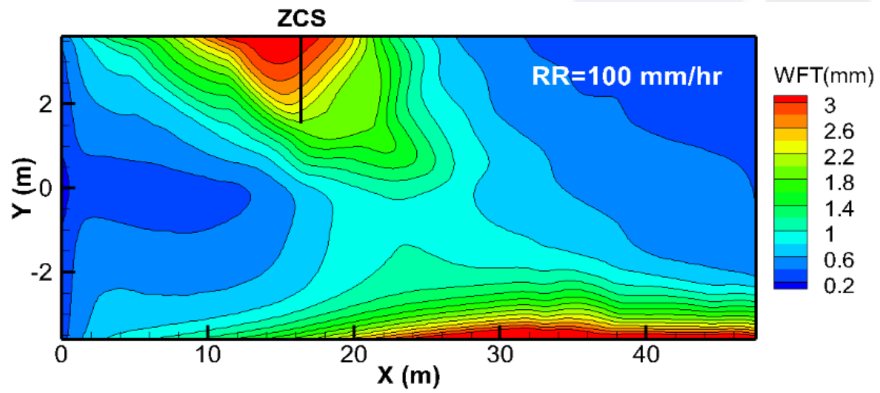




(a) Base case with 20 mm/h

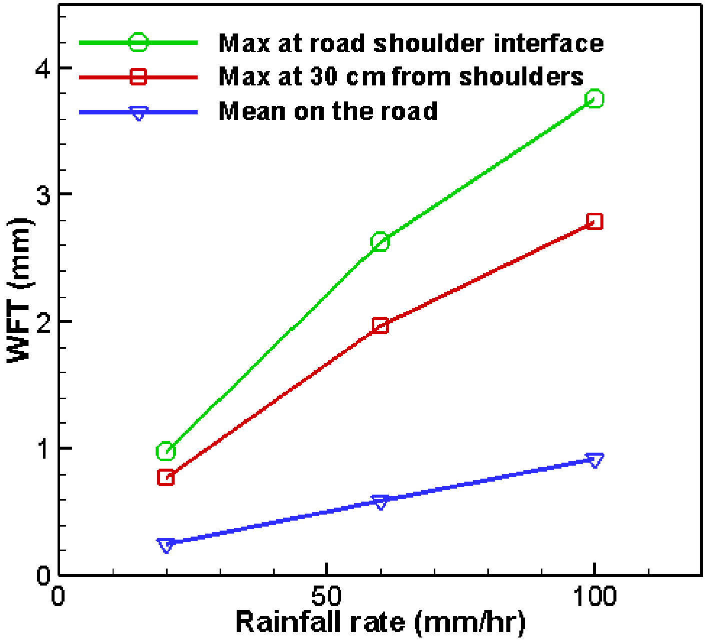


(b) Case 2 with 60 mm/h



(c) Case 3 with 100 mm/h

WFT distribution on pavement with different rainfall rate



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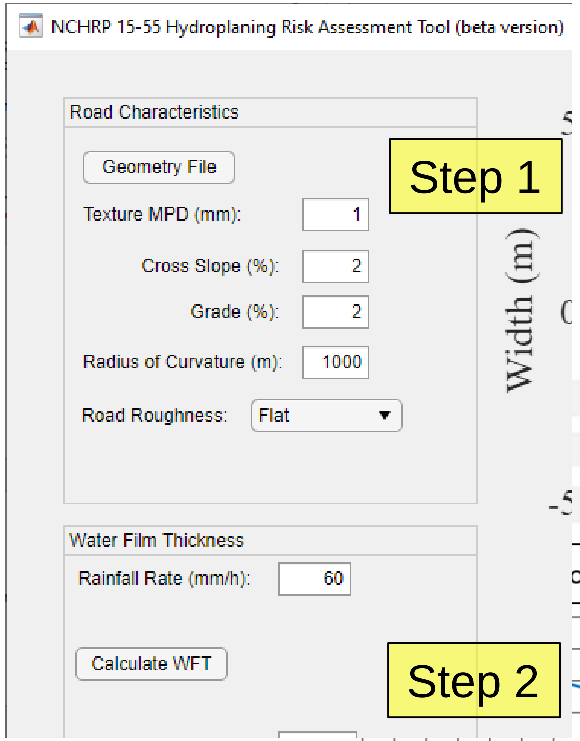
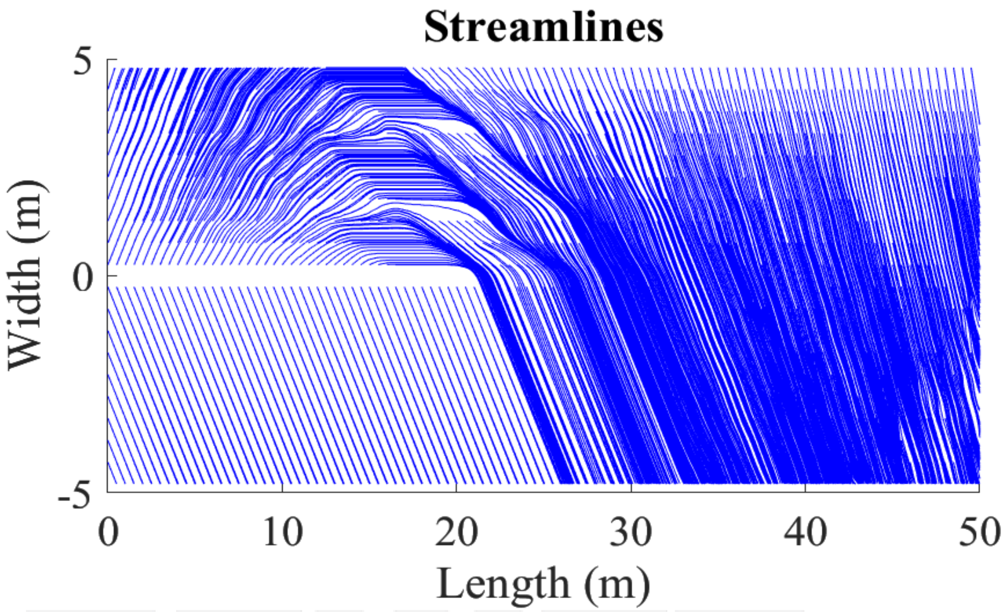
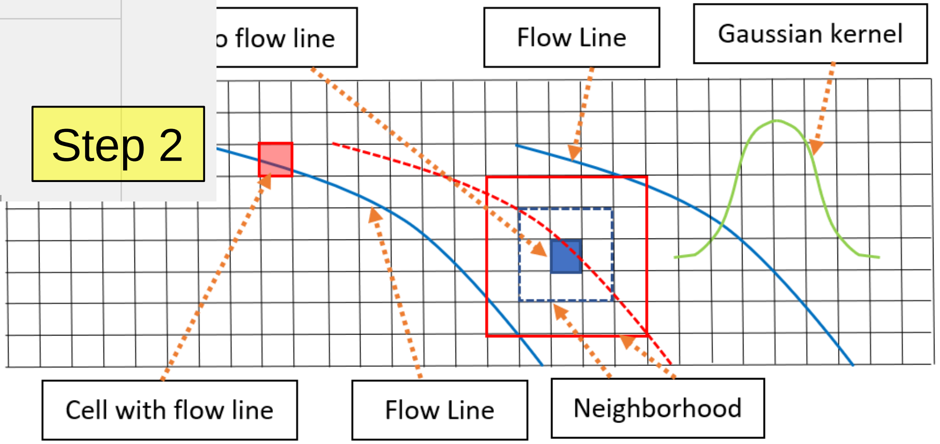
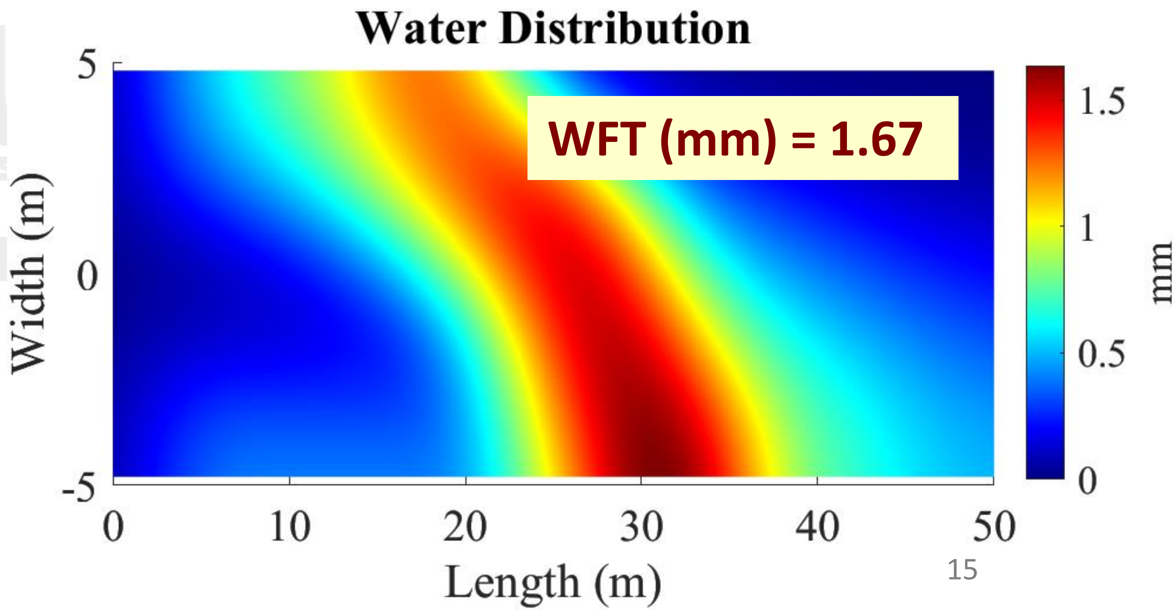
NCHRP 15-55 Hydroplaning Risk Assessment Tool Simplified Water Model



- ✓ Modified Gallaway Equation
- ✓ Gaussian Kernel Smoothing







Comparing the results with Recent FHWA / US Doe / Argonne Reports

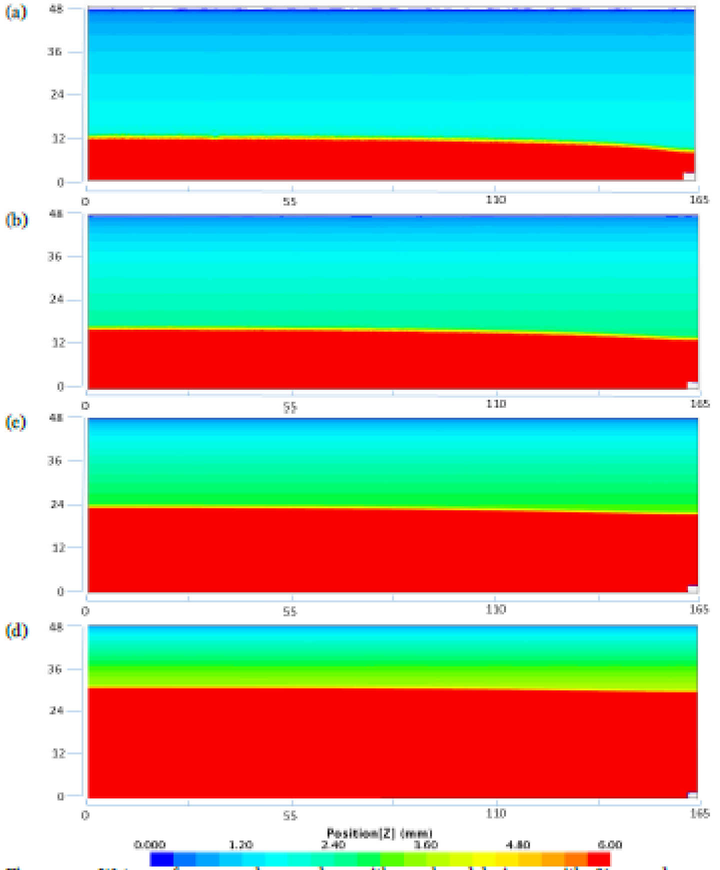
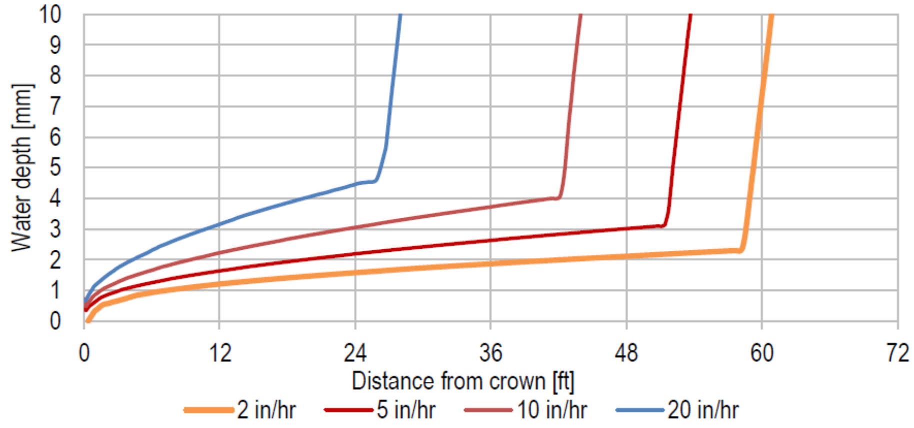


Figure 5-13: Water surface on a 4 lane roadway with a curb and drainage, with 1% cross slope, no longitudinal slope, and at rain intensity (a) 2 in/hr, (b) 5 in/hr, (c) 10 in/hr, and (d) 20 in/hr (curb overflow). The length scale of the computational domain is in feet.



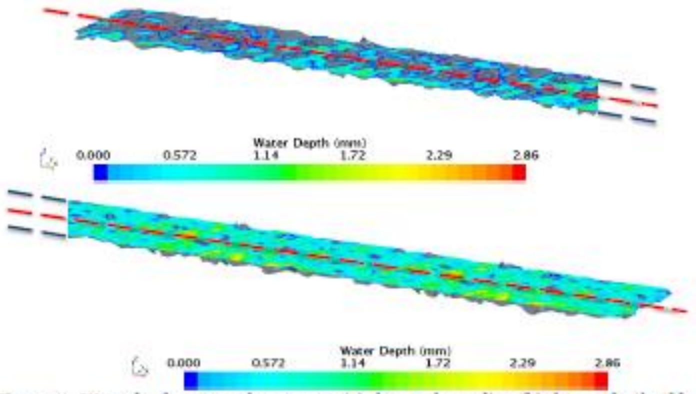
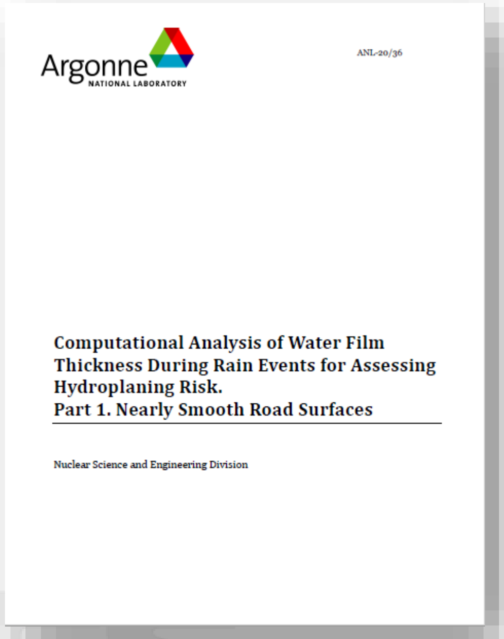


Figure 5-3: Water depth on a rough pavement, (a) close to the median, (b) close to the shoulder. Rainfall intensity 2 in/hr, slope 2%.



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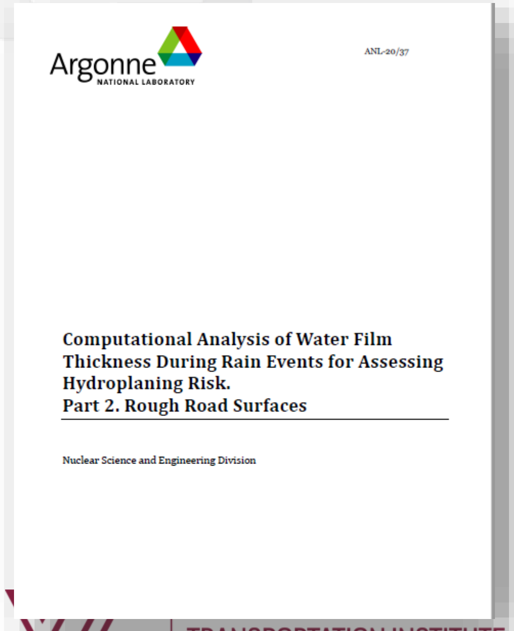
ANL-20/36

Computational Analysis of Water Film Thickness During Rain Events for Assessing Hydroplaning Risk.
Part 1. Nearly Smooth Road Surfaces

Nuclear Science and Engineering Division



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ANL-20/37

Computational Analysis of Water Film Thickness During Rain Events for Assessing Hydroplaning Risk.
Part 2. Rough Road Surfaces

Nuclear Science and Engineering Division

4. Hydroplaning

http://auto.howstuffworks.com/car-driving-safety/accidents-hazardous-conditions/hydroplaning.htm

Traditional Hydroplaning Models: Hydroplaning Speed Prediction

- ✓ NASA:

$$v_p = 51.80 - 17.15(FAR) + 0.72p$$

$$v_p = 7.95\sqrt{p(FAR)^{-1}}$$

- ✓ TXDOT:

$$v_p = SD^{0.04} p^{0.3} (TD+1)^{0.06} A$$

$$A = \max\left(3.507 + \frac{10.409}{WFT^{0.06}}, \left[\frac{28.952}{WFT^{0.06}} - 7.817\right] T^{0.14}\right)$$

- ✓ PAVDRN:

$$v_p = 26.04 WFT^{-0.259}$$

- ✓ USF:

$$v_p = WL^{0.2} p^{0.5} \left(\frac{0.82}{WFT^{0.06}} + 0.49\right)$$

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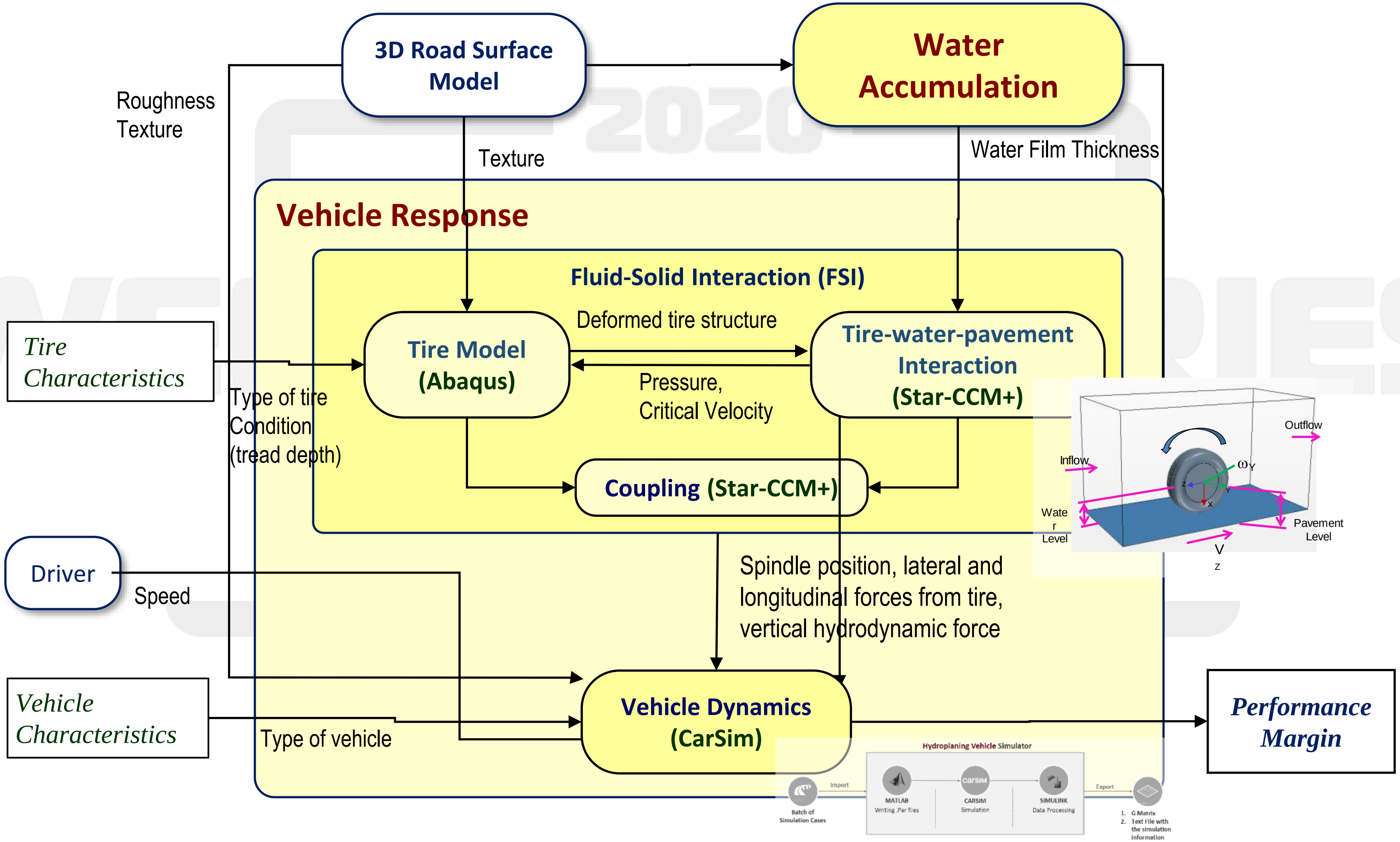
Integrated Hydroplaning Model



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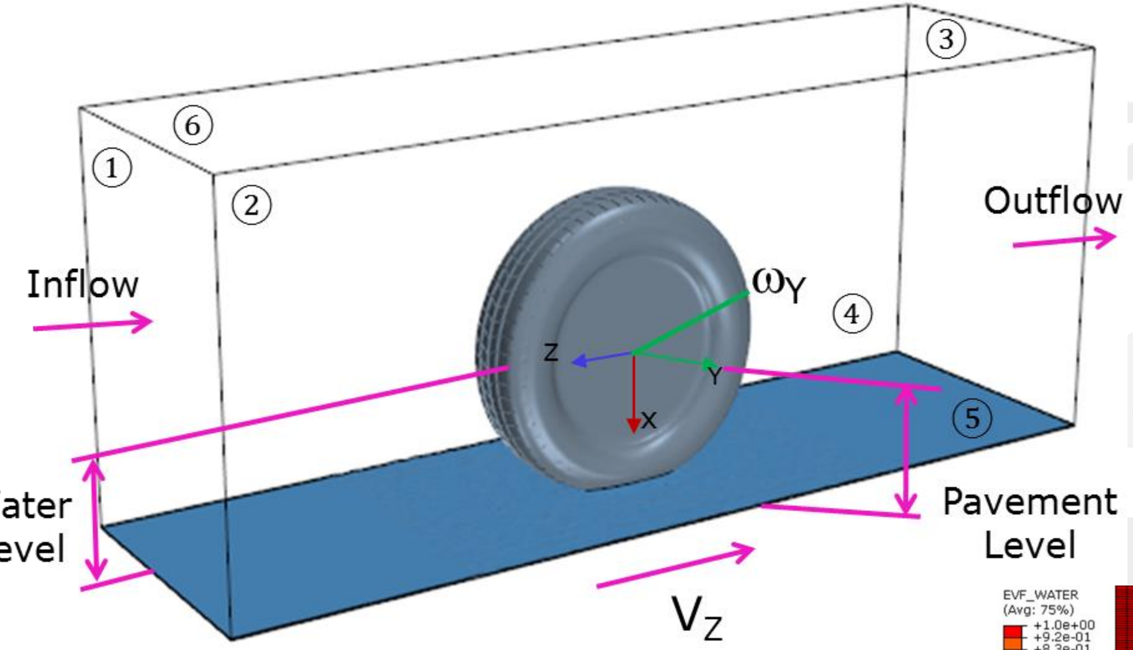
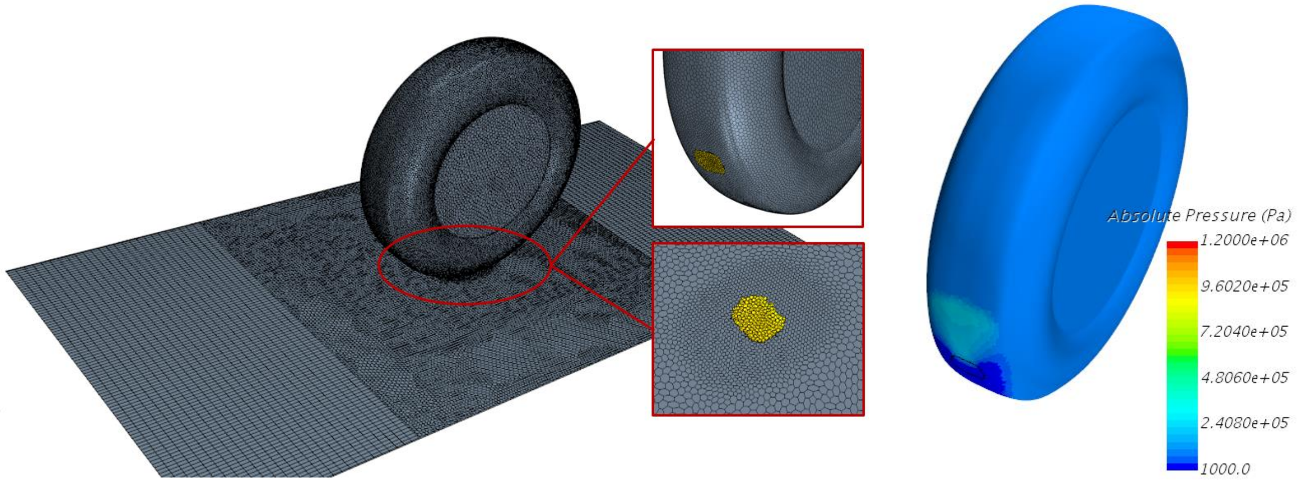
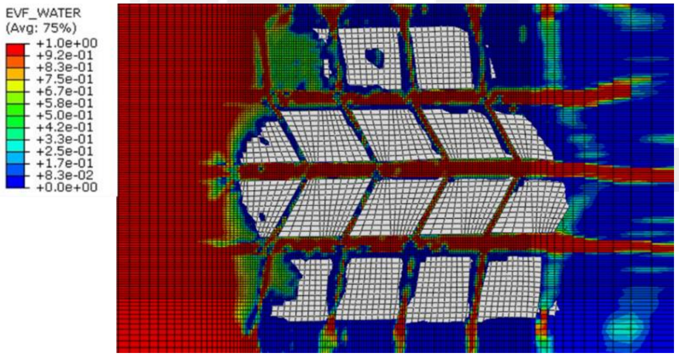
Tire-pavement-water Interaction Model



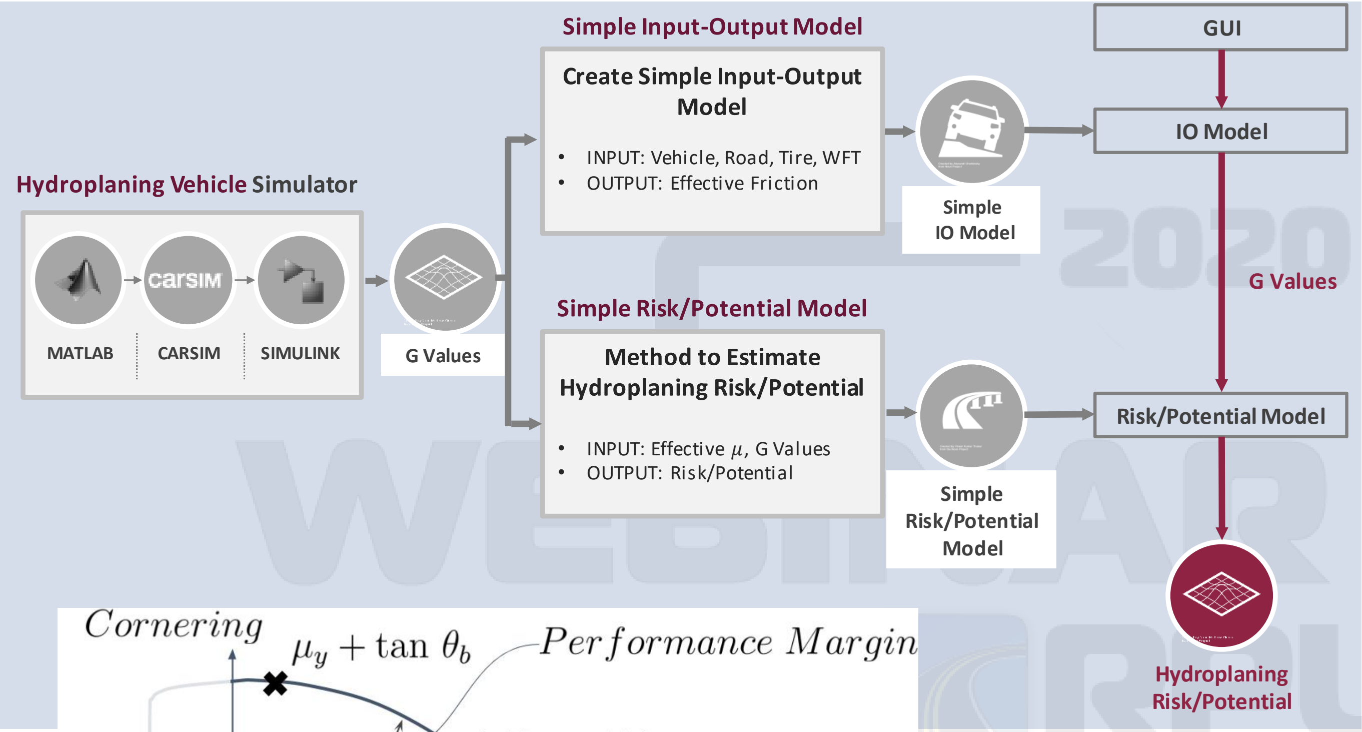
Bald tire mesh profile and pressure distribution on bald tire surface



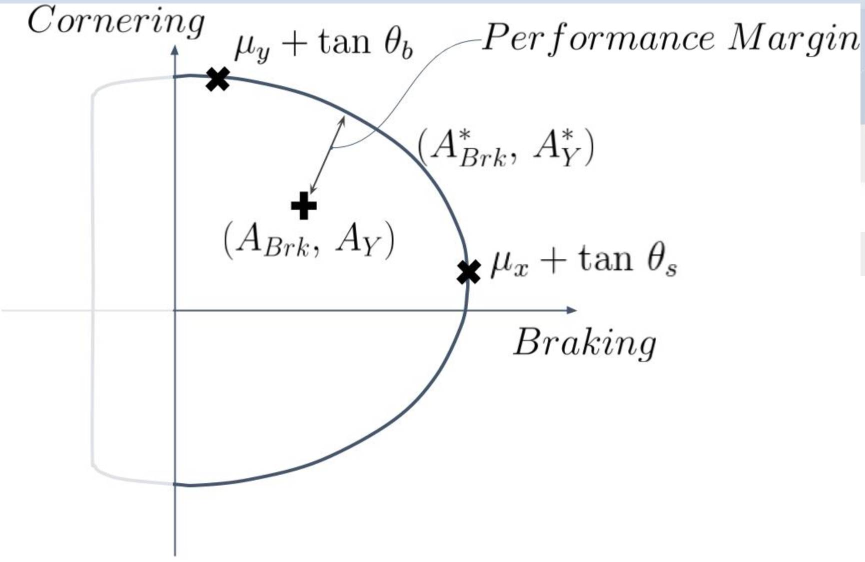


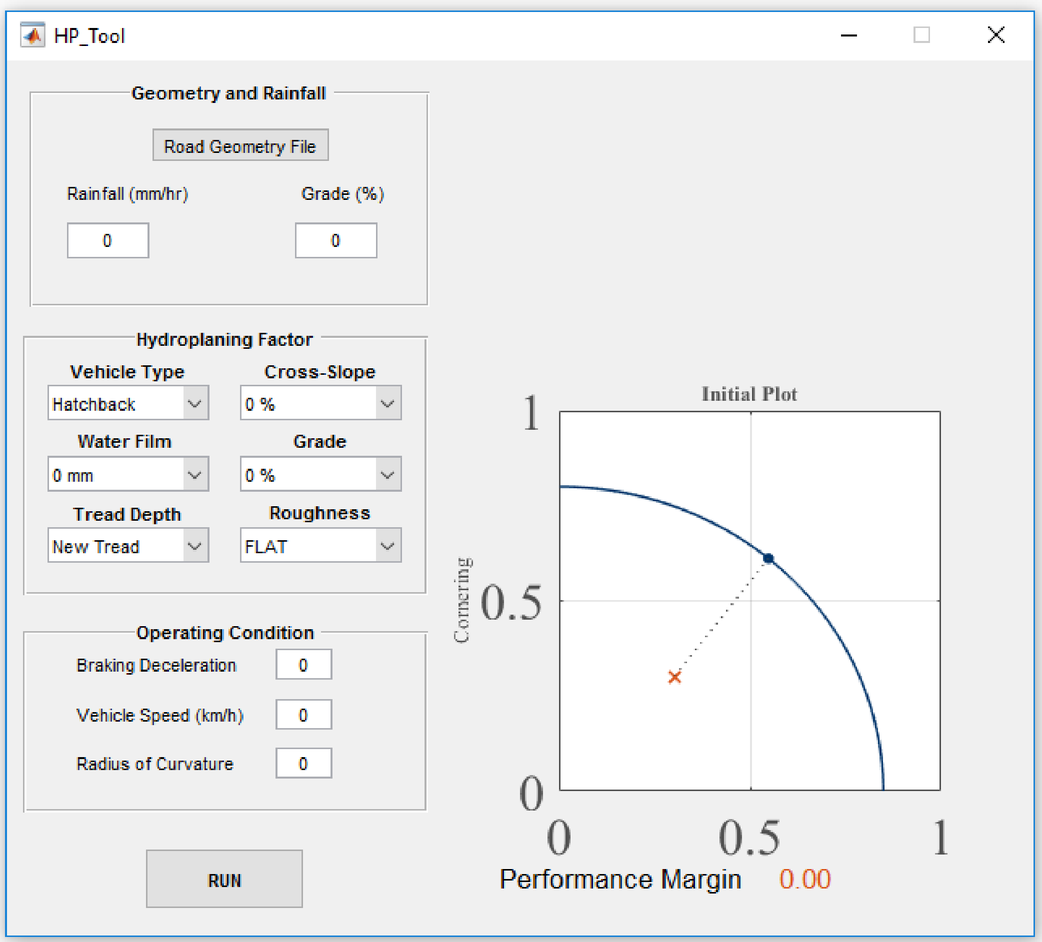
Volume fraction of the water flowing in the tire pattern groove with 5-mm WFT at 40 mph.

Vehicle Dynamics Model - Performance Margin



$$\frac{(A^*_{brk} - tan(\theta_s))^2}{\mu_X^2} + \frac{(A^*_Y - tan(\theta_b))^2}{\mu_Y^2} = 1$$





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4. NCHRP 15-55 Products

NCHRP 15-55 Products

- ✓ NCHRP 15-55 Report: Guidance to Predict and Mitigate Dynamic Hydroplaning on Roadways
- ✓ New definition of Hydroplaning
- ✓ Research-grade “Integrated” Hydroplaning Model
- ✓ Hydroplaning Risk Assessment Tool with Manual
- ✓ RNS for Possible Continuation Efforts

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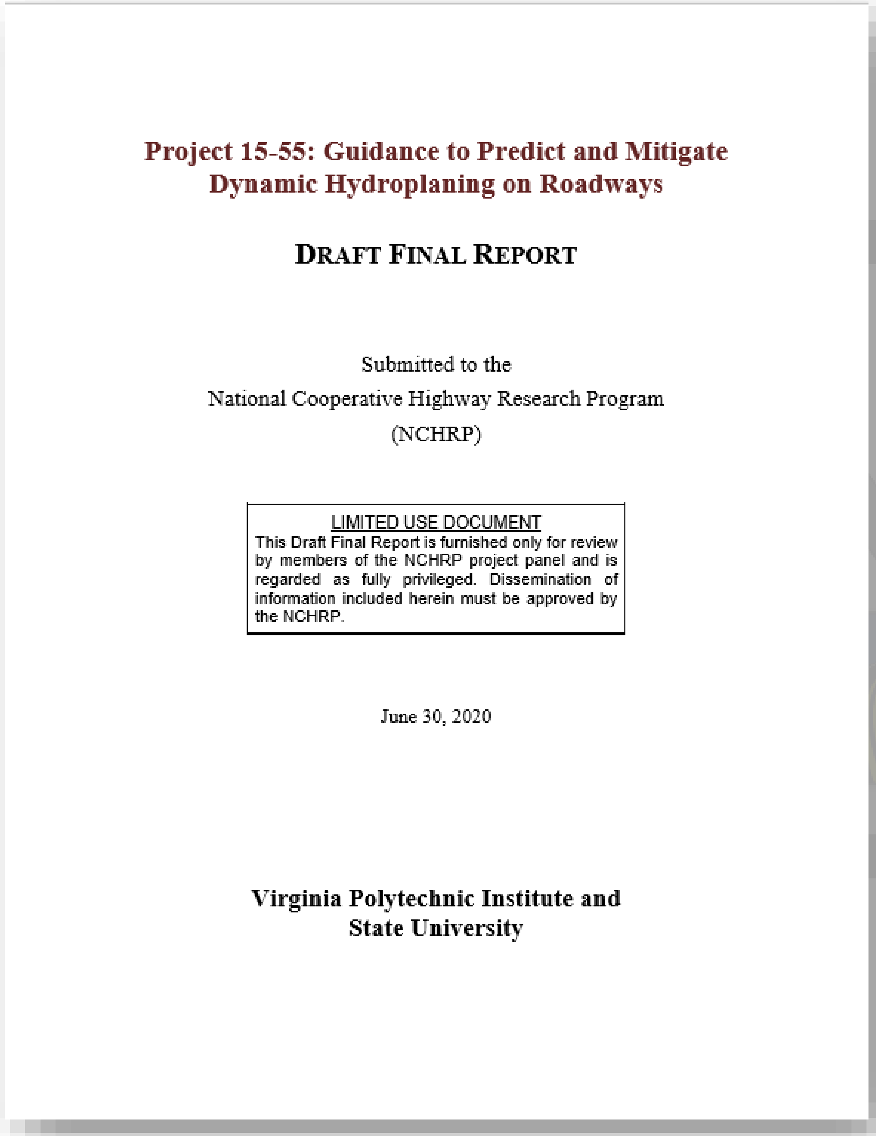
NCHRP 15-55: Guidance to Predict and Mitigate Dynamic Hydroplaning on Roadways


Project 15-55: Guidance to Predict and Mitigate Dynamic Hydroplaning on Roadways

DRAFT FINAL REPORT

Submitted to the
National Cooperative Highway Research Program
(NCHRP)

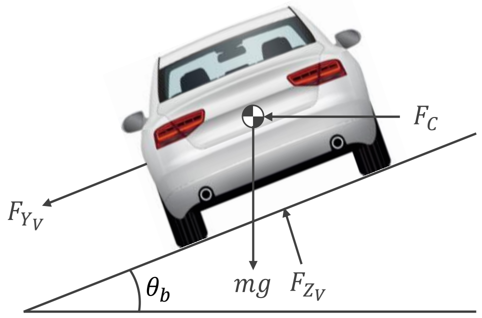
LIMITED USE DOCUMENT
This Draft Final Report is furnished only for review by members of the NCHRP project panel and is regarded as fully privileged. Dissemination of information included herein must be approved by the NCHRP.

June 30, 2020

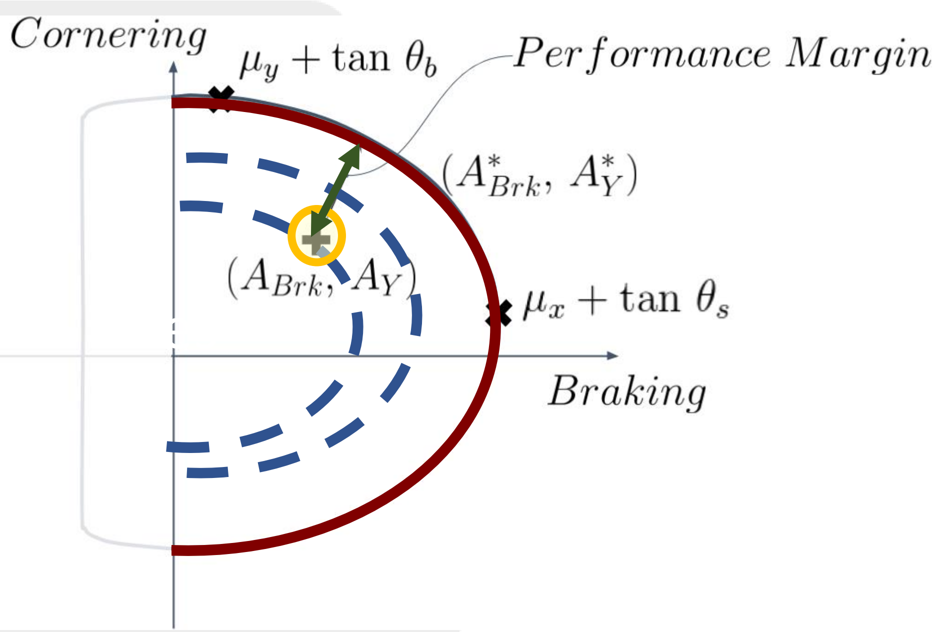
Virginia Polytechnic Institute and State University

Flintsch, G.W., Ferris, J.B., Battaglia, F., Taheri, S., Katicha, S., Chen, L., Kang, Y., Nazari, A., de Leon Izeppi, E., Velez, K., Kibler, D., McGhee, K.K., Project 15-55: Guidance to Predict and Mitigate Dynamic Hydroplaning on Roadways, **Draft Final Report**, June 2020

Hydroplaning Definition



- ✓ Based on vehicle handling capabilities
  - Performance margin (available fiction) dry
  - Required friction
  - Available fiction wet



- ✓ **Performance Margin**

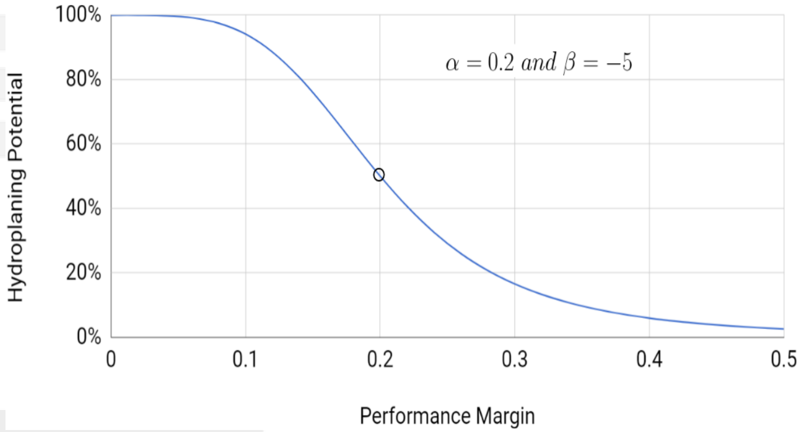
$$\frac{(A^*_{brk} - tan(\theta_s))^2}{\mu_X^2} + \frac{(A^*_Y - tan(\theta_b))^2}{\mu_Y^2} = 1$$

Hydroplaning Potential and Risk

- ✓ Not implemented in the tool

- ✓ Hydroplaning potential

$$H_P = P(\mathrm{H}/\ V\ S\ W) = \left(1 + \left(\frac{PM}{\alpha}\right)^{-4\alpha\beta}\right)^{-1}$$



- ✓ Hydroplaning risk

$$H_R = P(H/\ S) = \sum_V \sum_W P(H\ /\ V\ W\ S))(P\ P(W)\ P\ (W\ /\ S))$$

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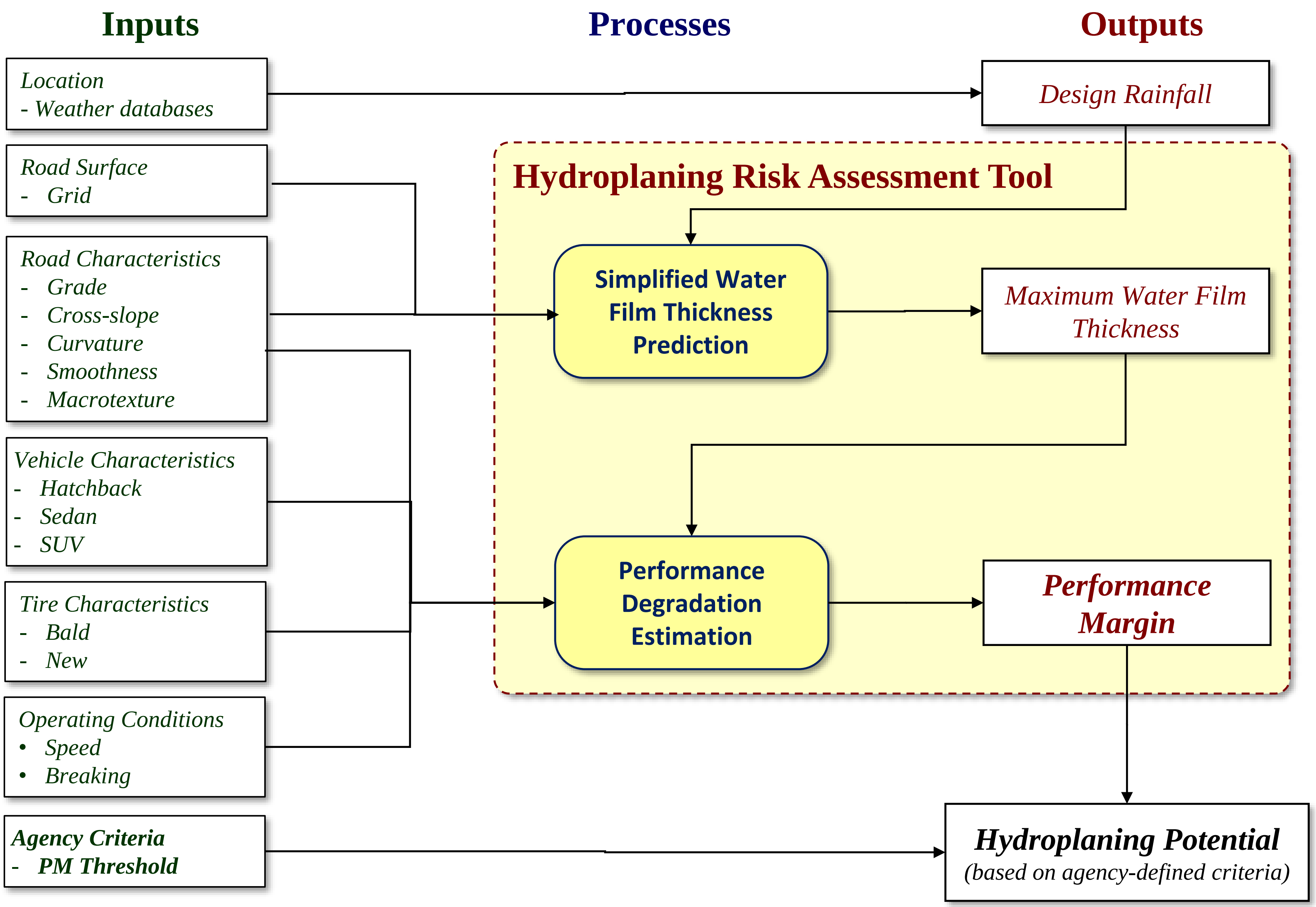
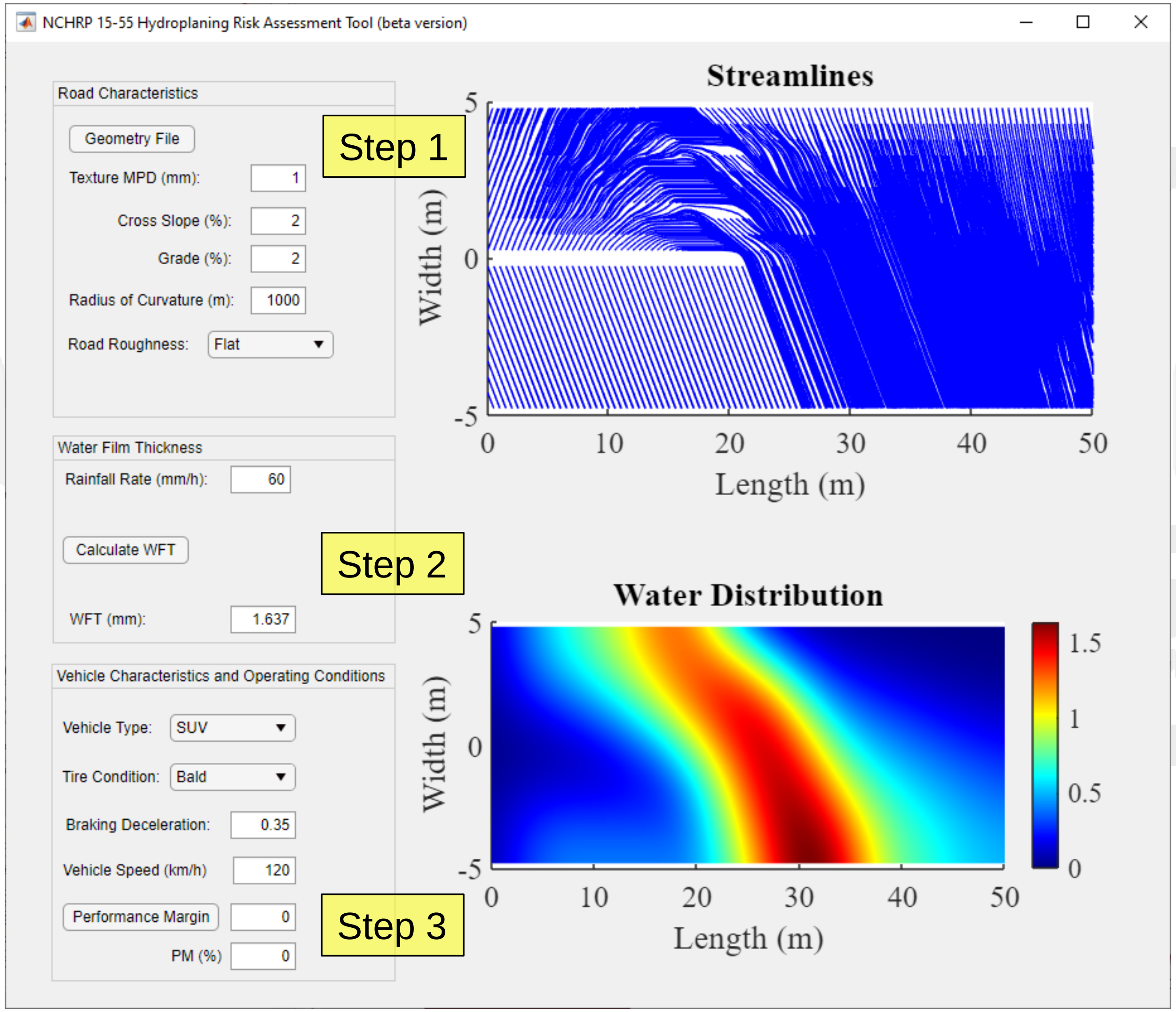
Hydroplaning Risk Assessment Tool

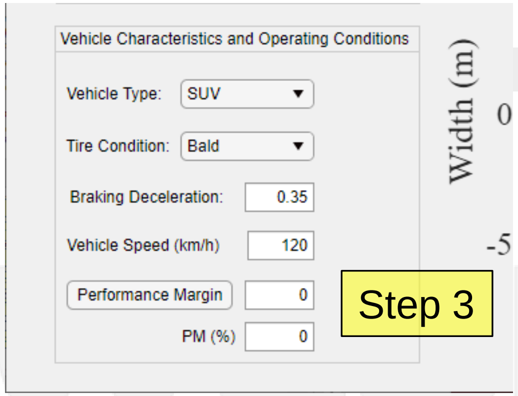


NCHRP 15-55 Tool – beta version

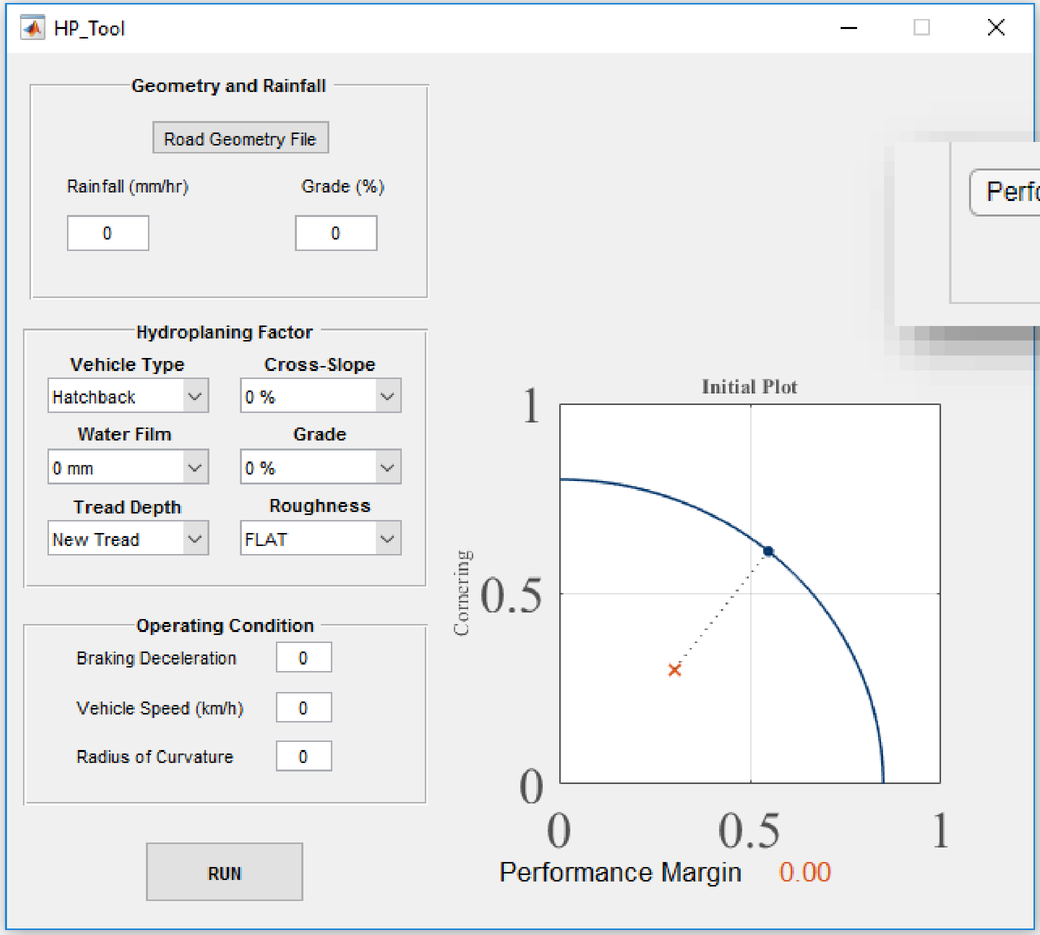


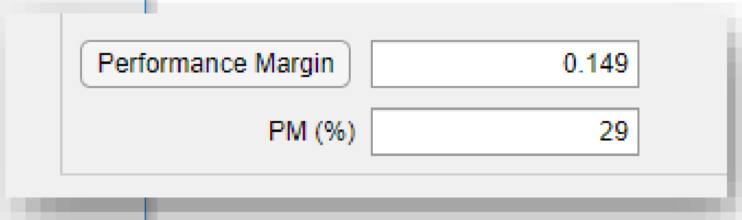
1. Select a file containing a prepared coarse grid for the alignment
2. Add the main surface characteristics and road geometric characteristics
3. Select the design speed and braking deceleration, design vehicle, and tire condition (or approve the default).

Performance Margin Calculation



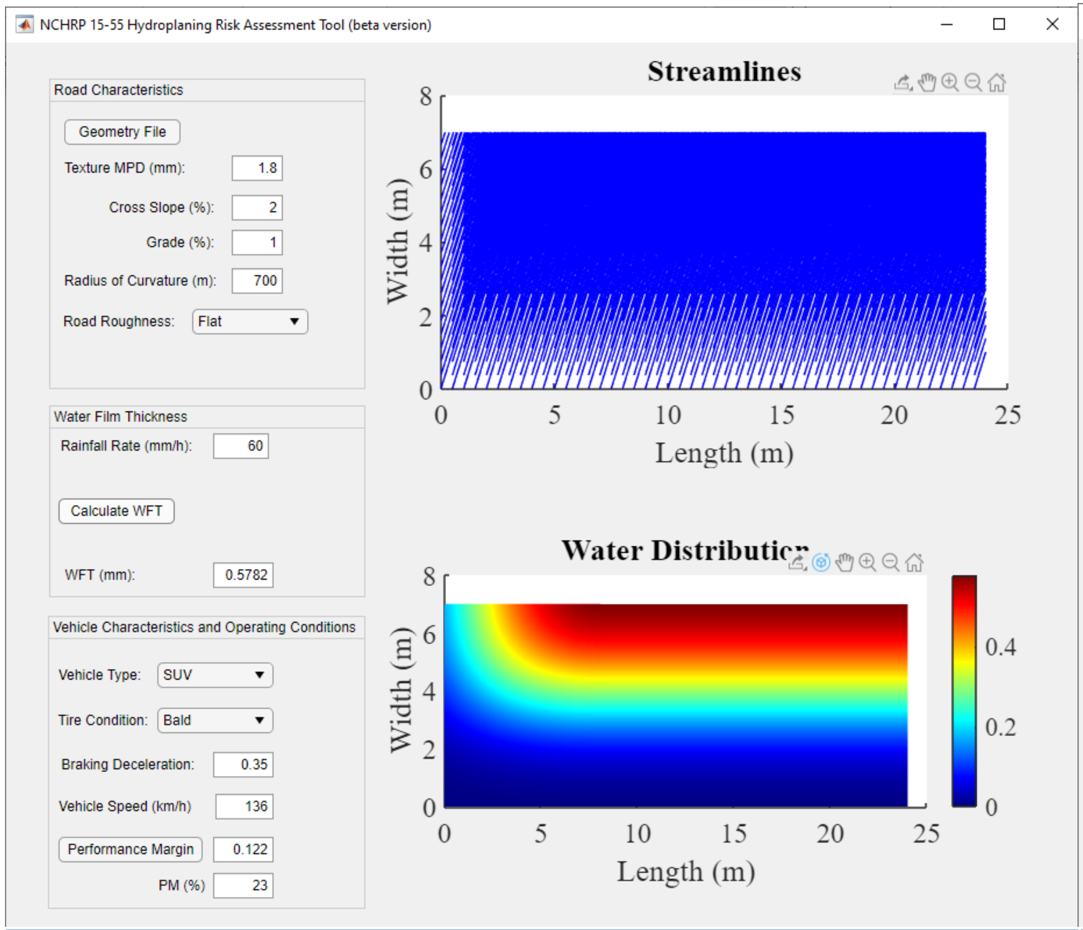
Step 3

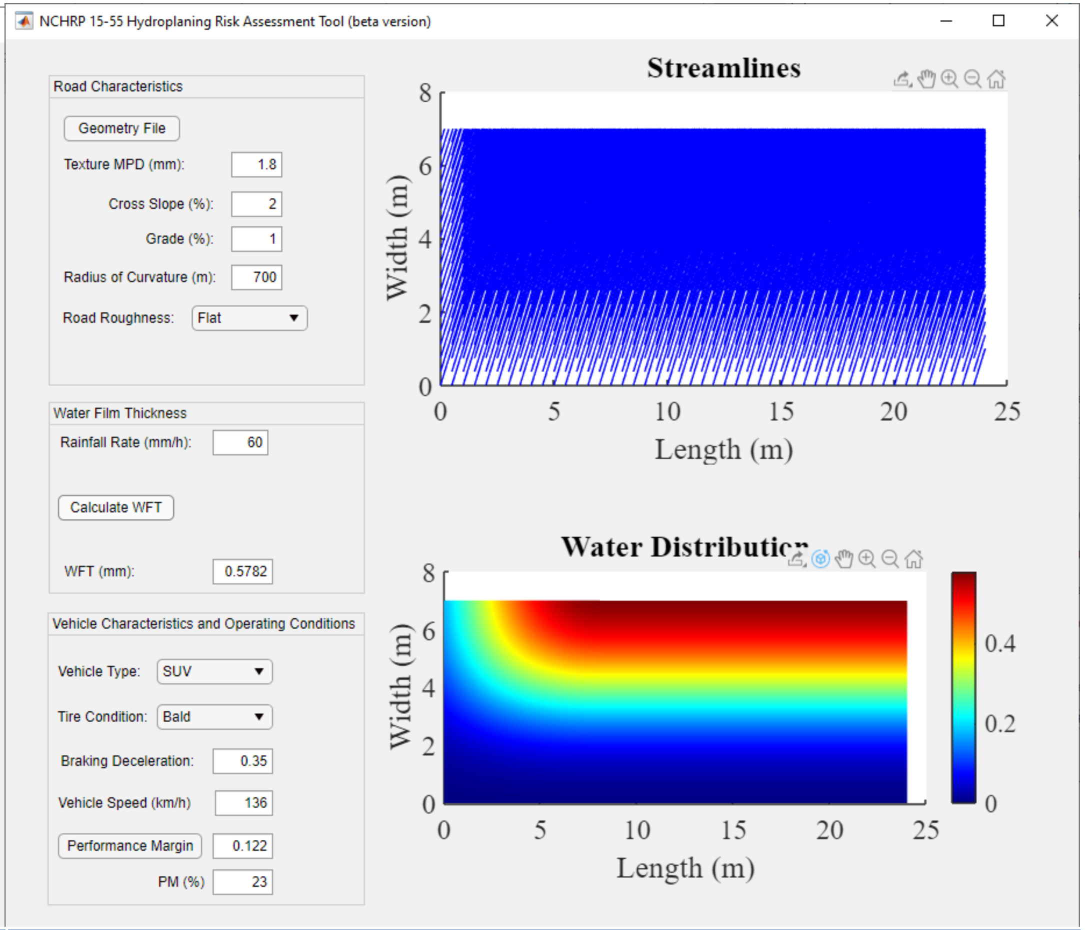




P= 0.15

Example – Effect of Macrotexture

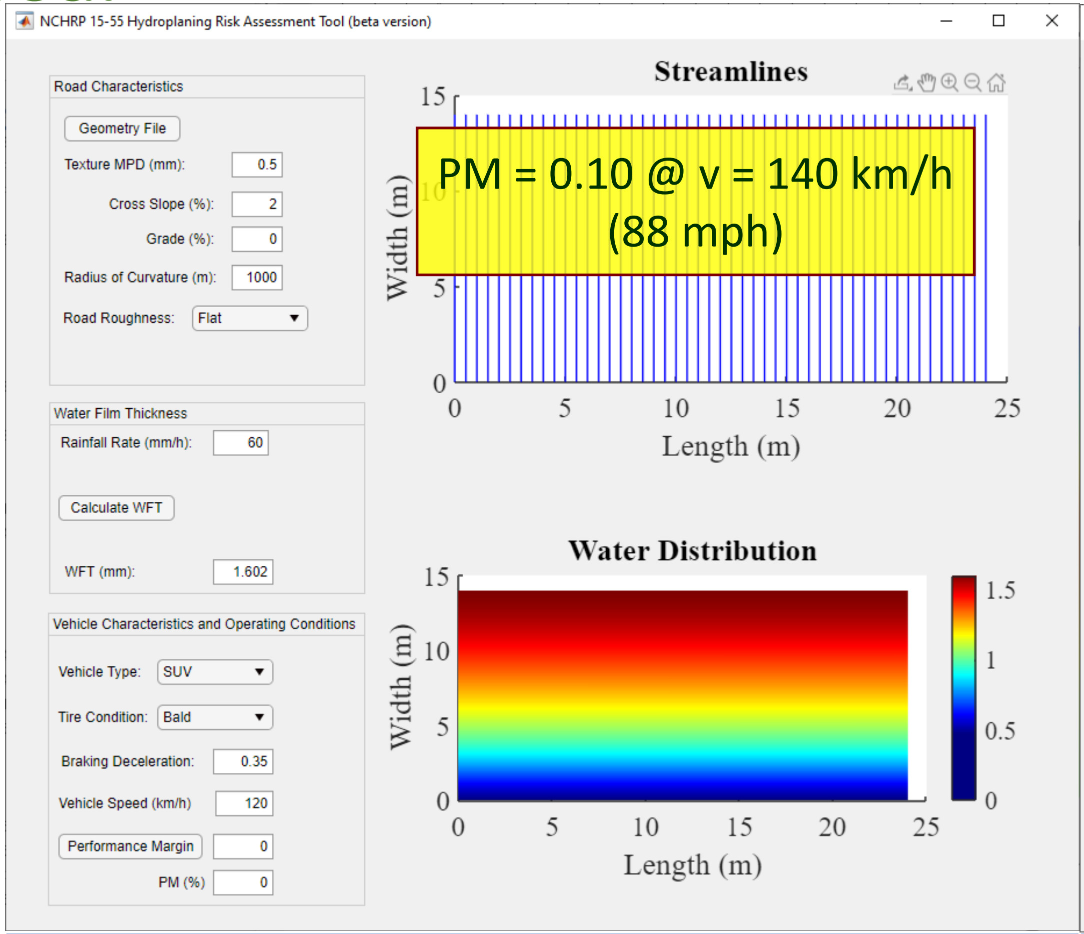


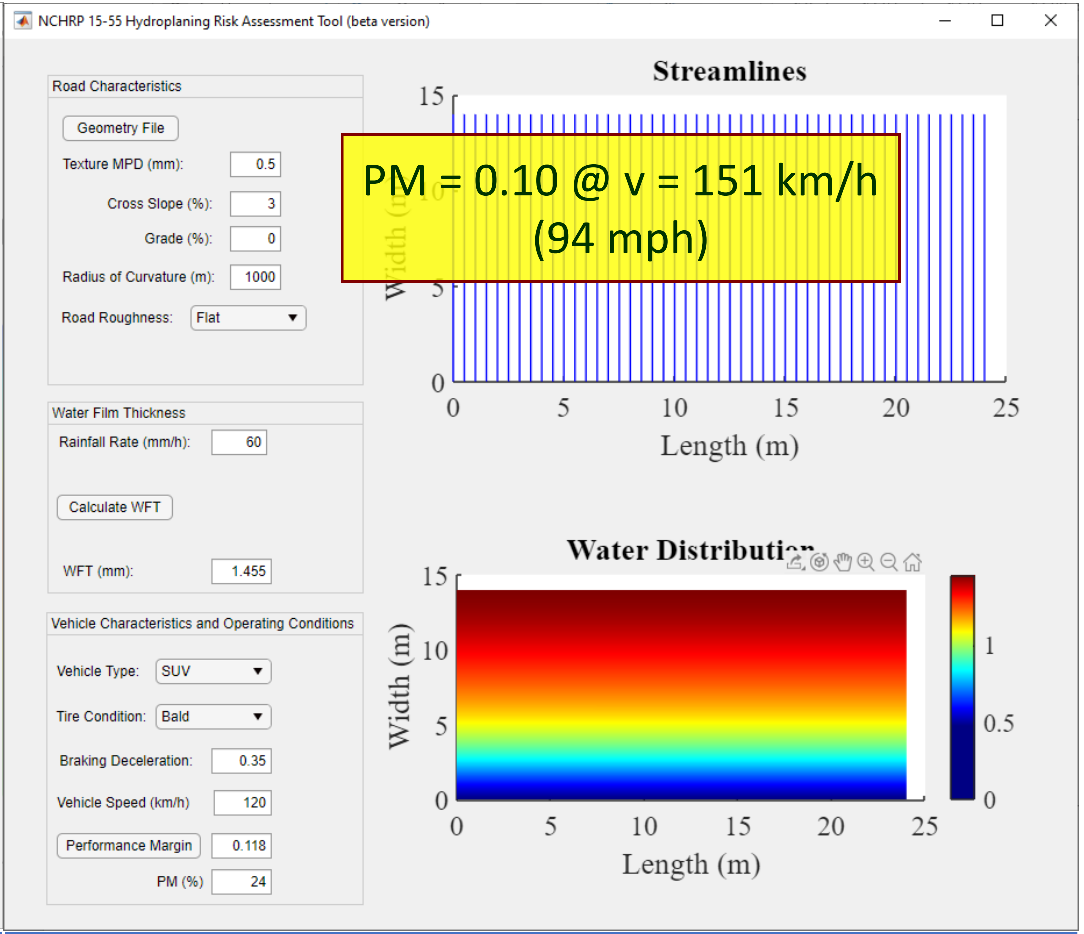


MPD = 0.5 mm; WFT = 1.57 mm; $PM_{136km/h}$ = 0.098

MPD = 1.8 mm; WFT = 0.58mm; $PM_{136km/h}$ = 0.122

Example 2 - 4-lane section with uniform and accentuated transversal





Uniform S_y = 2% slope;
WFT = 1.60; PM = 0.112

Increasing S_y = 3% in the outer lanes;
WFT = 1.46; PM = 0.118

Possible Continuation Efforts (RNS)

1. Refine and verify the models to predict water accumulation
   - Field Measurements

https://www.lufft.com/products/road-runway-sensors-292/marwis-umb-mobile-advanced-road-weather-information-sensor-2308/

2. Refine and verify the models that predict hydroplaning potential for full suite of tire treads and vehicle types
   - Field Measurements

3. Enhance the Hydroplaning Risk Assessment Tool using data from tasks 1 and 2 and available crash data

5. Final Thoughts

http://garak.wimp.com/images/thumbs/2014/06/66effb01da776d2c3fce3228eb28cb58_record_506_332.jpg

Final Thoughts

- ✓ The accumulation on water on the pavement impact the vehicle performance and safety and the comfort of drivers
- ✓ ***Hydroplaning*** is difficult to measure directly but it can be modeled
- ✓ NCHRP 15-55 proposed a novel definition of ***Hydroplaning Potential*** in terms of the ***Performance Margin***, which is defined as the additional performance capability that can be drawn upon beyond that which is demanded by the current operating condition.
- ✓ The project also developed a computer ***Risk Assessment Tool*** that can be used to identify roadway sections in need for interventions and the potential impact of various treatments

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