Mechanistic Load Restriction Decision Platform for Pavement Systems Prone to Moisture Variations

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Outline

- Introduction to System Dynamics
- Vensim Software
- System Dynamics Framework for Post-Flooded Pavement Assessment
- Example: Simple Infiltration Problem
- Upcoming Tasks
- Discussion

Introduction to System Dynamics

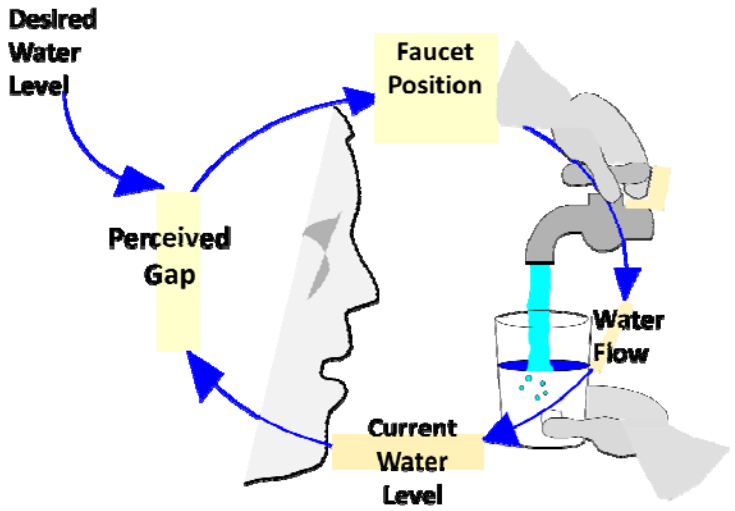
❑ What is system dynamics?

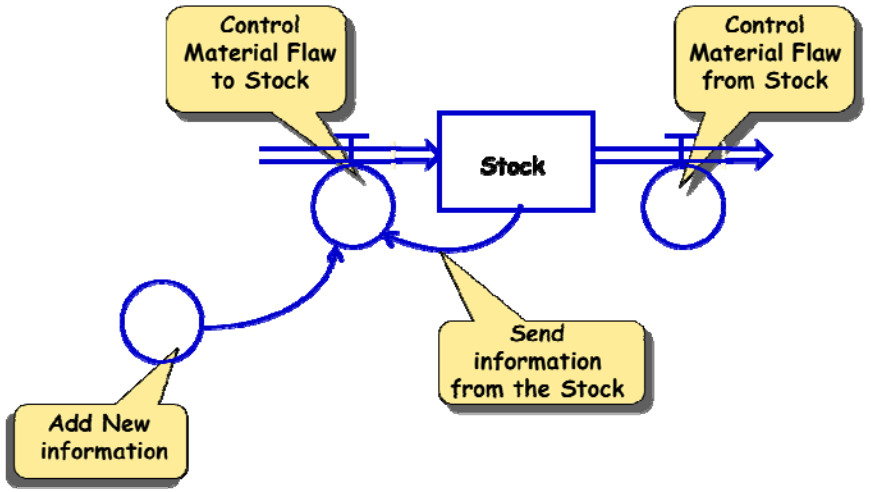
System dynamics is an approach for studying and managing complex systems (*includes multiple structures and components*) that change over time.

- ✓ Identify interactions among system structures
  - ✓ Structures → Subset of a system (e.g. hydrological analysis)
- ✓ Quantitative and qualitative (visual) assessment
- ✓ Modeling across disciplines (e.g. hydrology, pavement mechanics, geotech, climate, etc.)

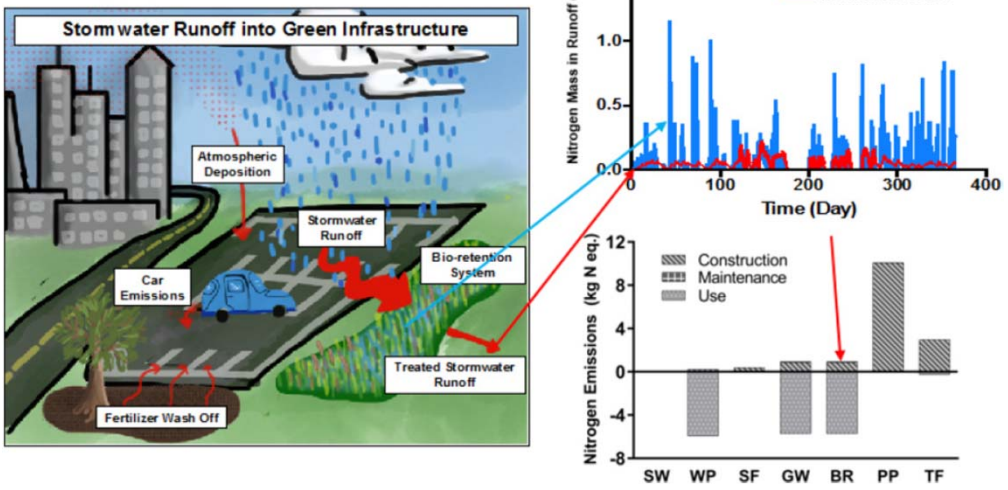
Introduction to System Dynamics

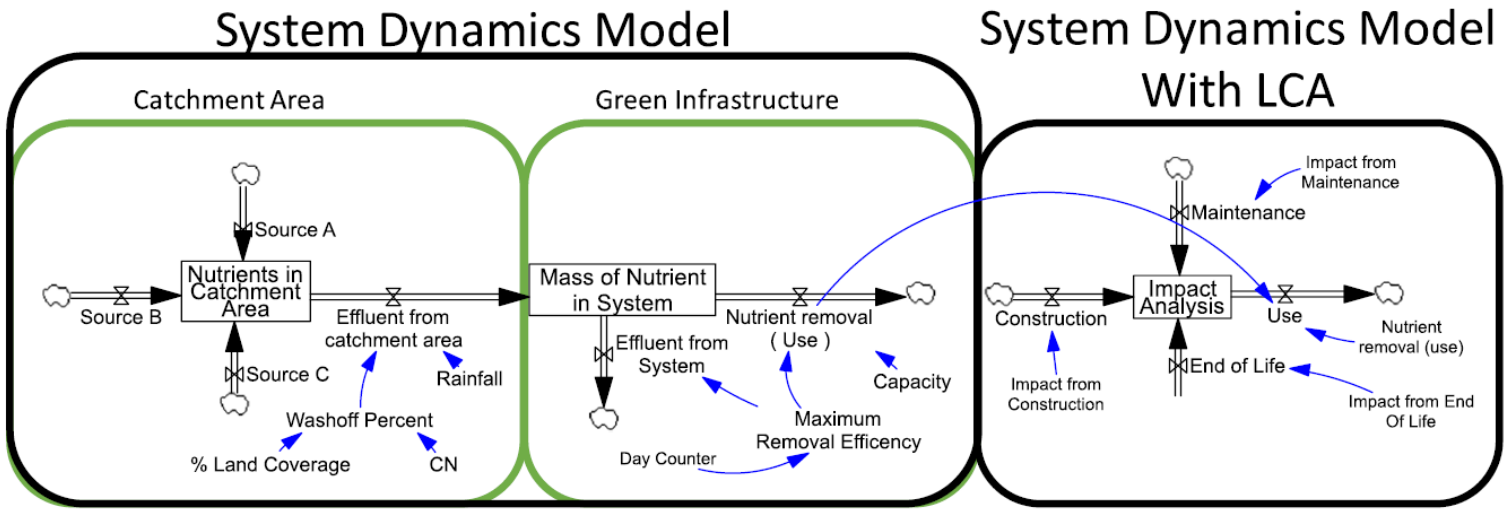
- **Basic components**
  - ✓ Stock/level Variable
  - ✓ Flow Variable
  - ✓ Information Flow
  - ✓ Material Flow
  - ✓ Time Delay





Introduction to System Dynamics





Bixler et al. (2019)

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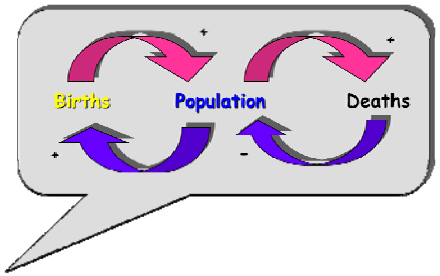
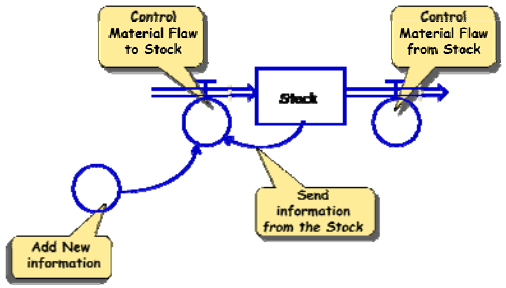
Vensim Software (1/4)

- **Vensim** is a visual modeling tool that allows to conceptualize, document, simulate, analyze, and optimize models of dynamic systems



- **Features:**

1) **Causal Loop Diagrams**
2) **Stock and Flow Diagrams**

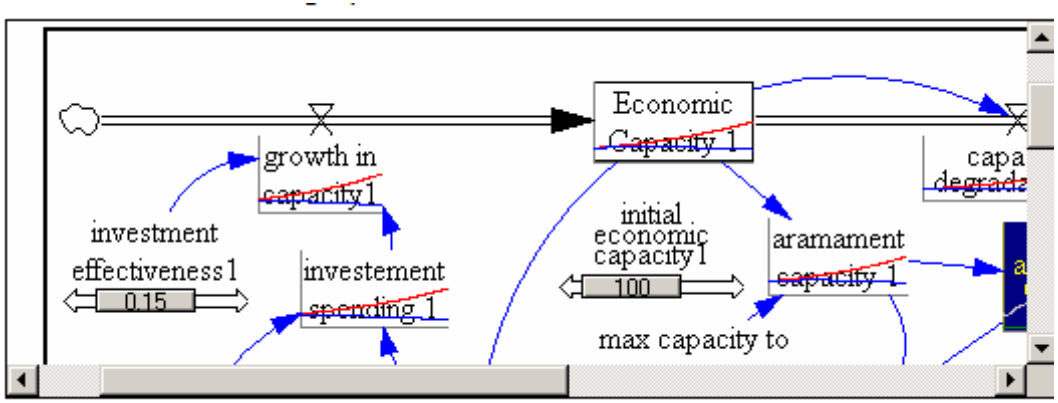


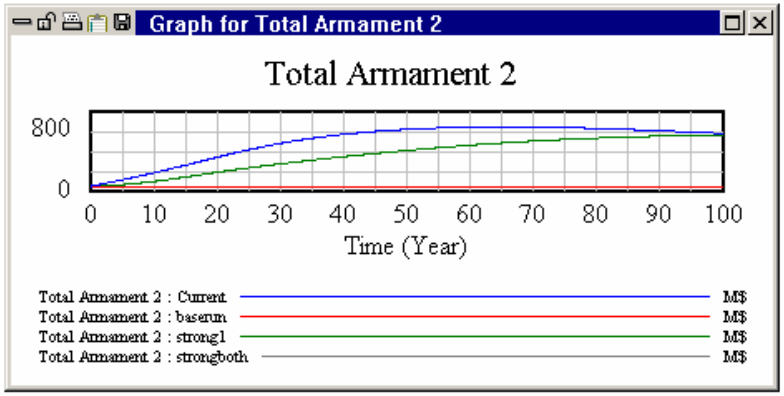
3) **Functions** (IF THEN ELSE, random number generations, etc.)

Vensim Software (2/4)

4) Simulation and Analysis

Vensim has built-in tools for displaying simulation results, and analyzing and comparing the results. Vensim has simple mechanism for entering and recording changes to assumptions for comparing different models and inputs.





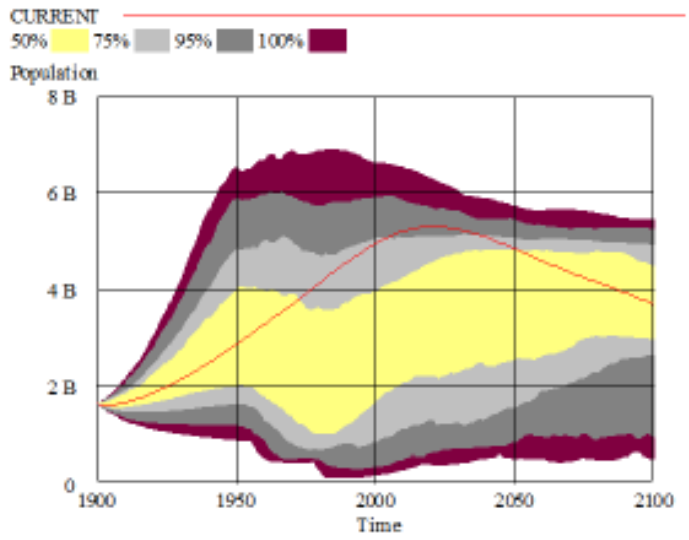
Vensim Software (3/4)

5) Data Use

Vensim is designed to make extensive use of varied forms of data (time series, data with missing values, subjective data) both as inputs to models as well as for testing and validating model behavior.

6) Sensitivity Testing

Multivariate sensitivity simulations



Vensim Software (4/4)

7) Reality Check

- ✓ A tool that allows to test simulation models against our understanding of a problem.
- ✓ It uses the statements about conditions and the consequences that must follow, such as "if there is no rain, there is no ponded water"

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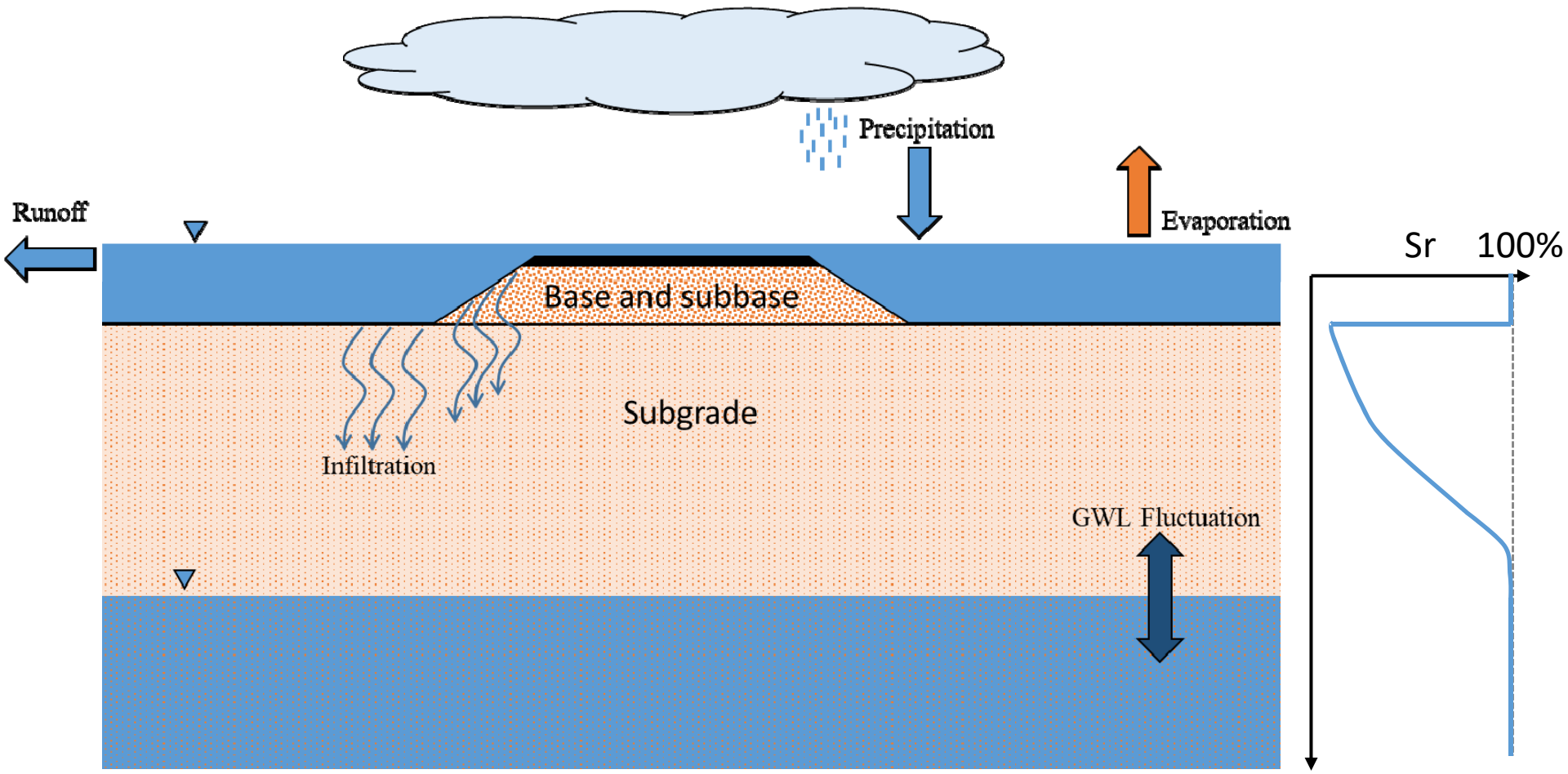
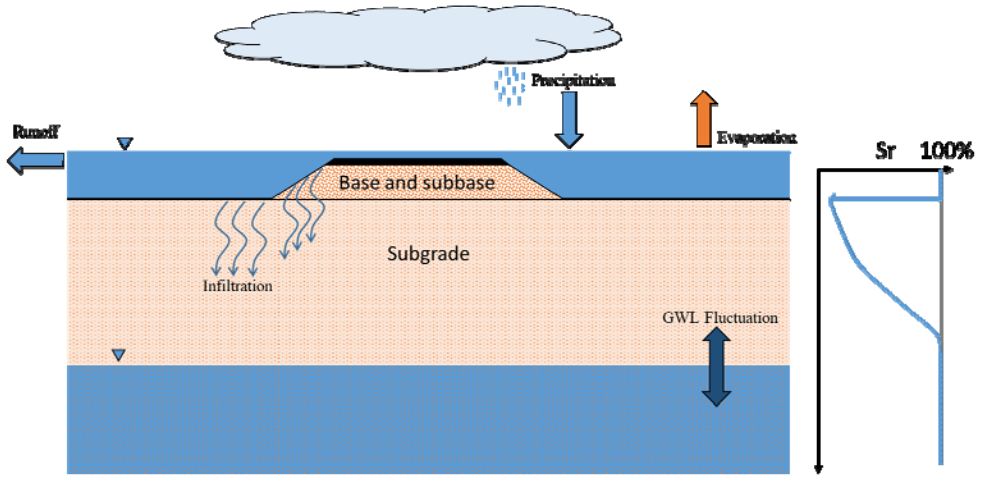
Flooded Pavement System



Flooded Pavement System

- A complete flooded pavement system dynamics framework should include the following structures:

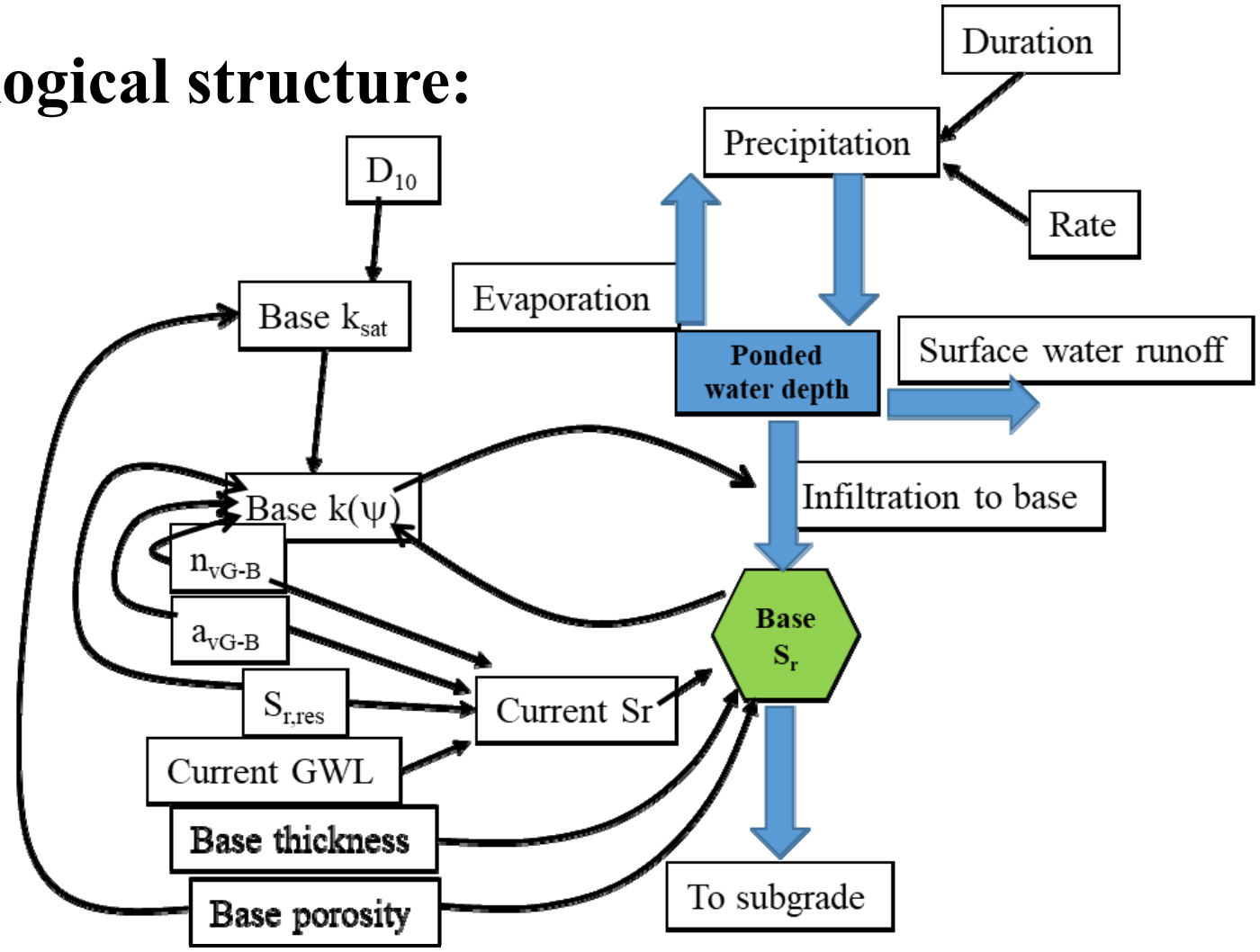
  - ✓ Hydrological
  - ✓ Geotechnical
  - ✓ Pavement response



System Dynamics framework

✓ **Hydrological structure:**

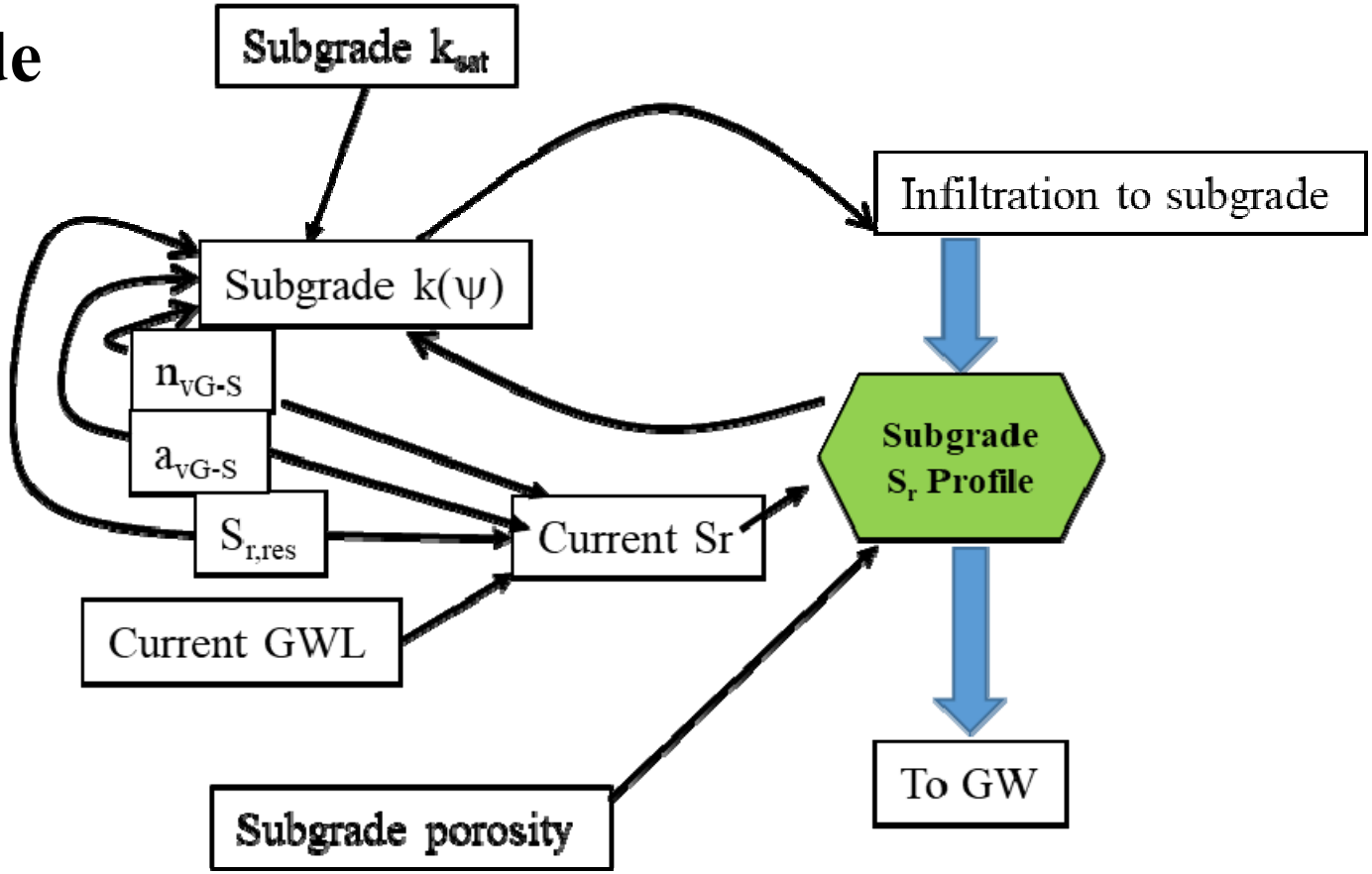
a) Base



System Dynamics framework

✓ **Hydrological structure:**

b) Subgrade

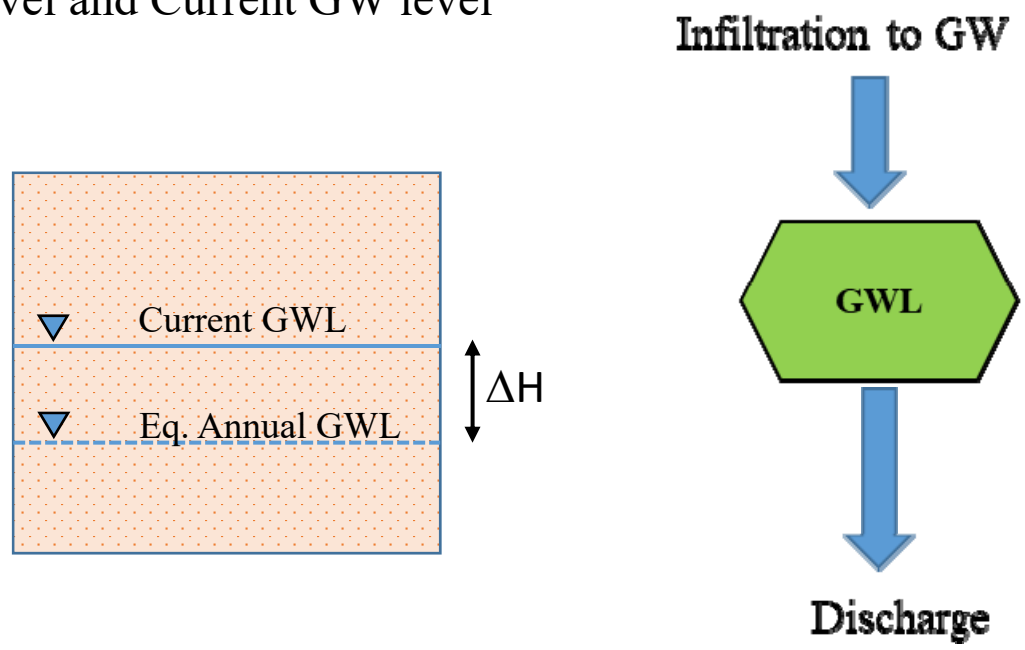


System Dynamics framework

✓ Hydrological structure

c) Groundwater Level

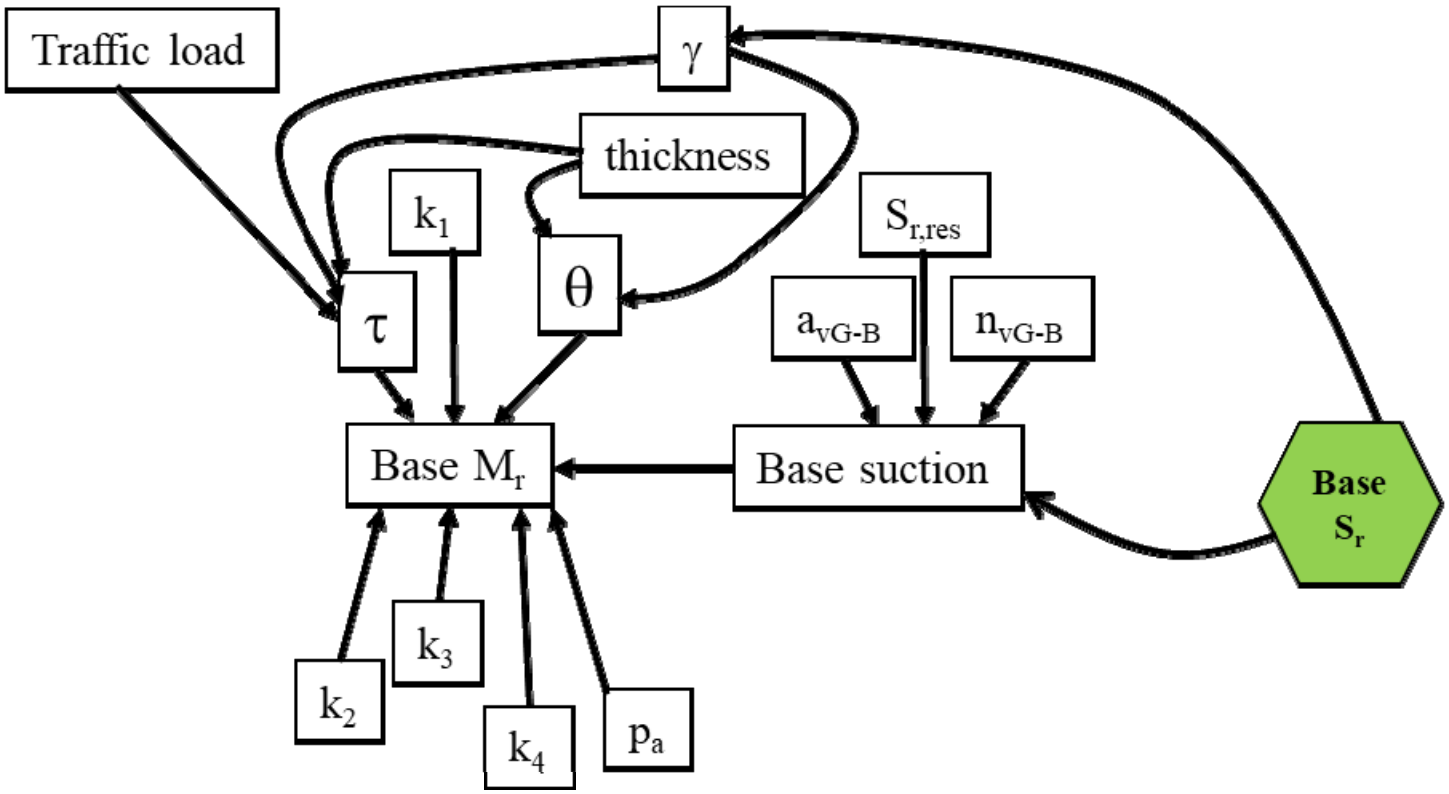
✓ Discharge from ground water is modeled by considering the head difference between equivalent Annual GW level and Current GW level



System Dynamics framework

✓ Geotechnical:

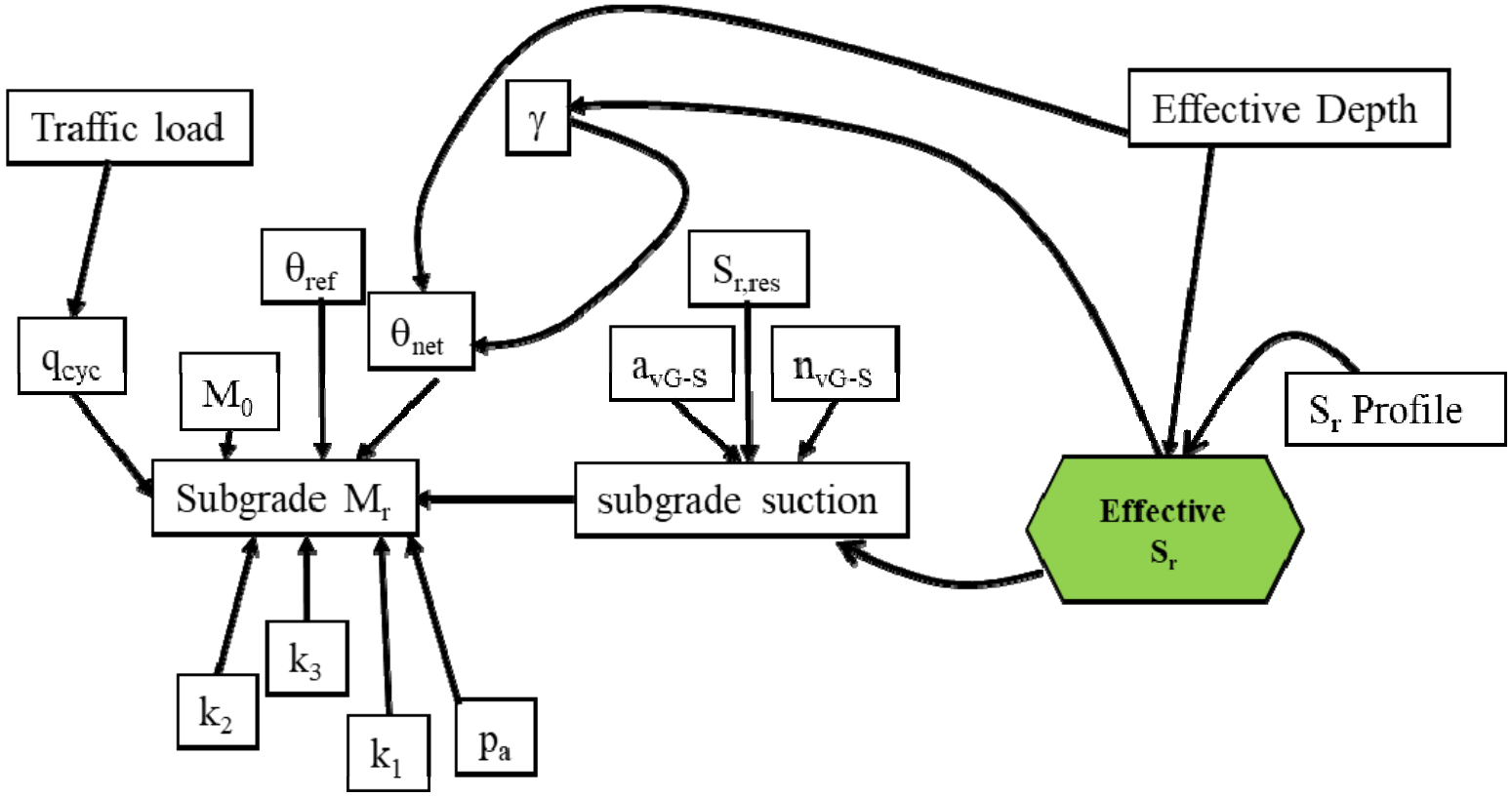
$$M_R = k_1 P_a \left(\frac{\theta_b + 3k_4\psi\theta}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a} + 1\right)^{k_3}$$ (MEPDG, 2004)



System Dynamics framework

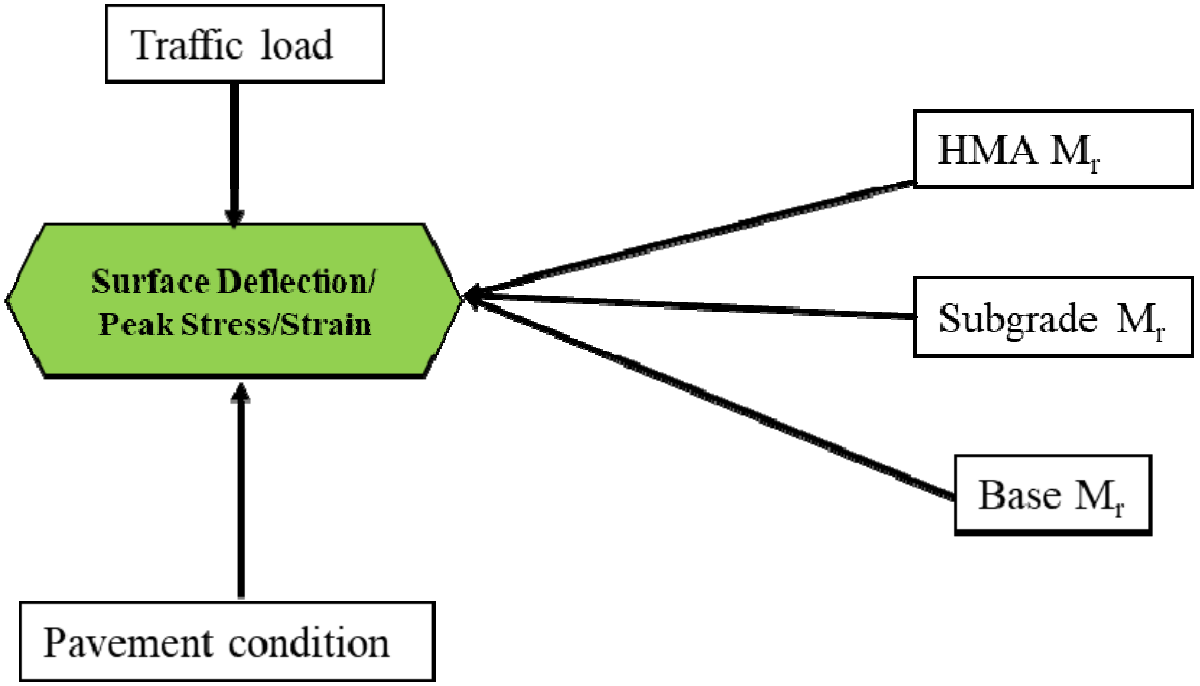
✓ Geotechnical:

$$M_R = M_0 \left(\frac{\theta_{net}}{\theta_{ref}}\right)^{k_1} \left(\frac{q_{cyc}}{\theta_{ref}}\right)^{k_2} (1 + \frac{\psi}{\theta_{net}})^{k_3}$$ (Ng et al. 2013)

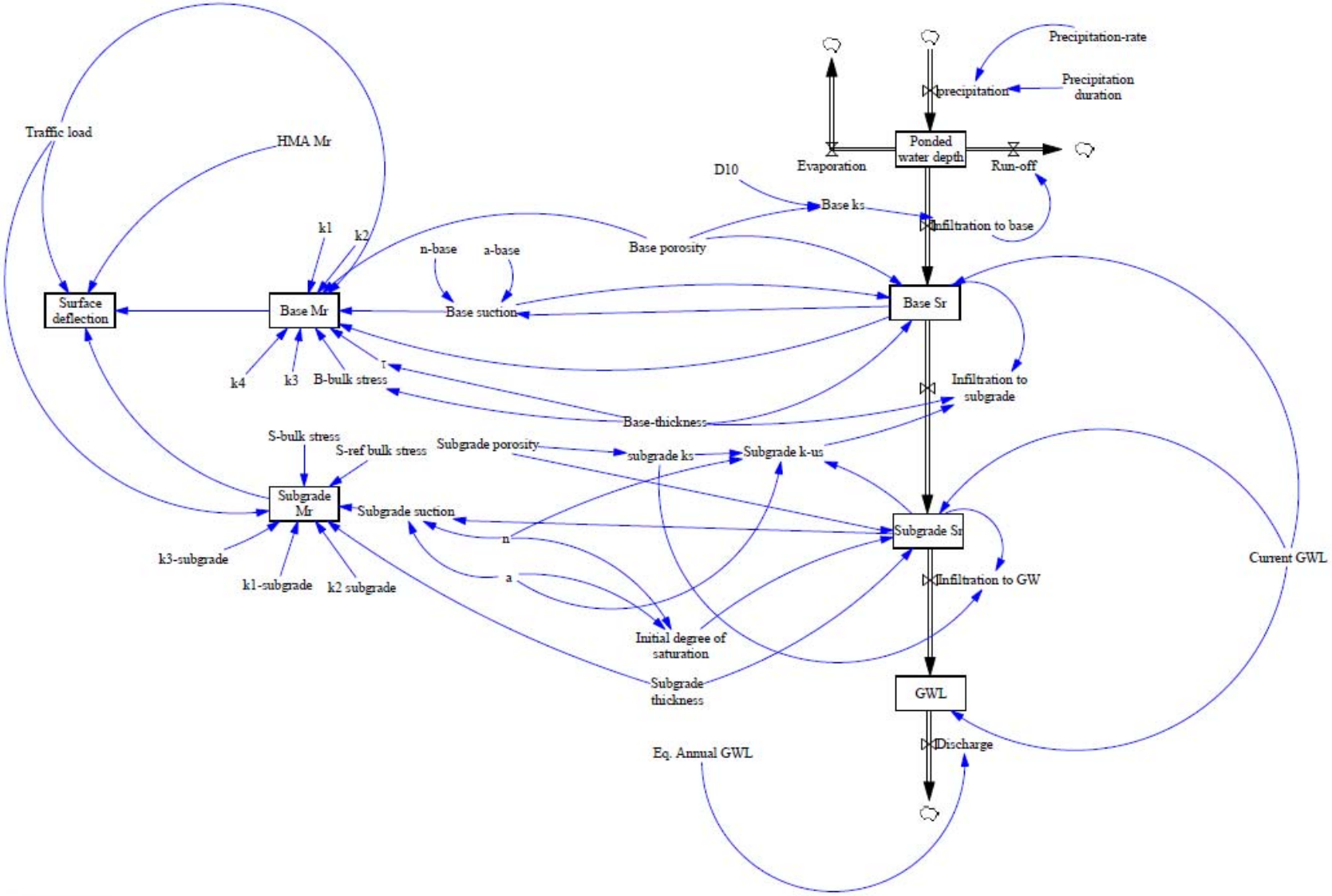


System Dynamics framework

✓ Pavement Response



System Dynamics framework: Overall



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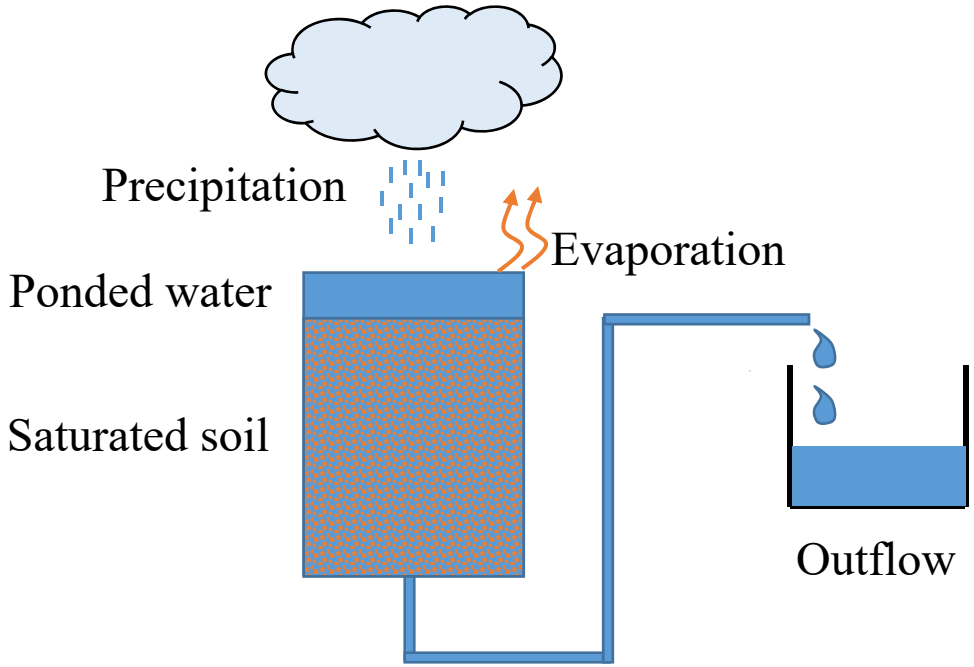
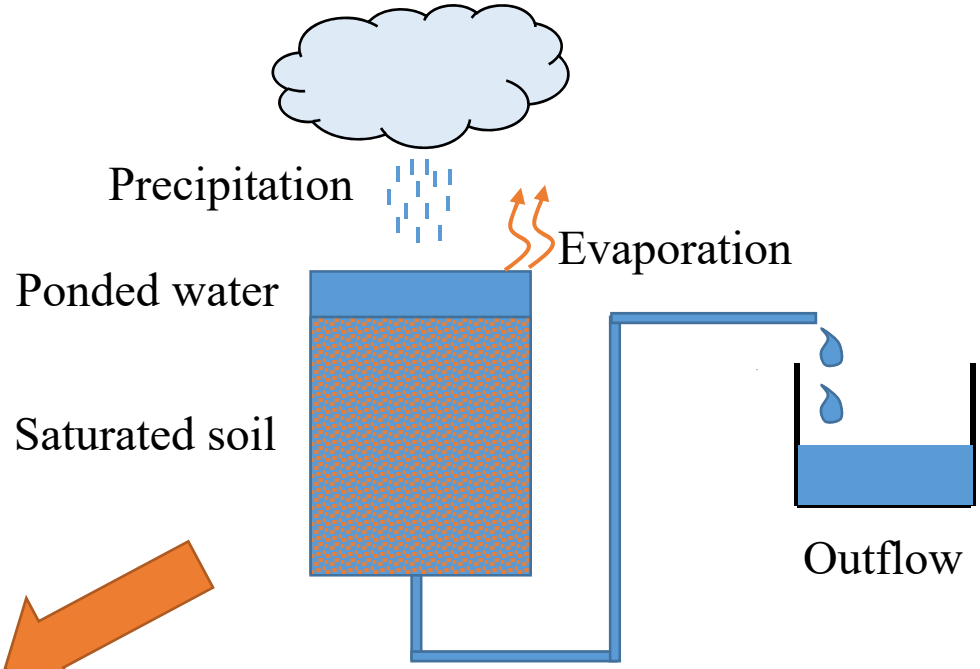
Simulation example (1/7)

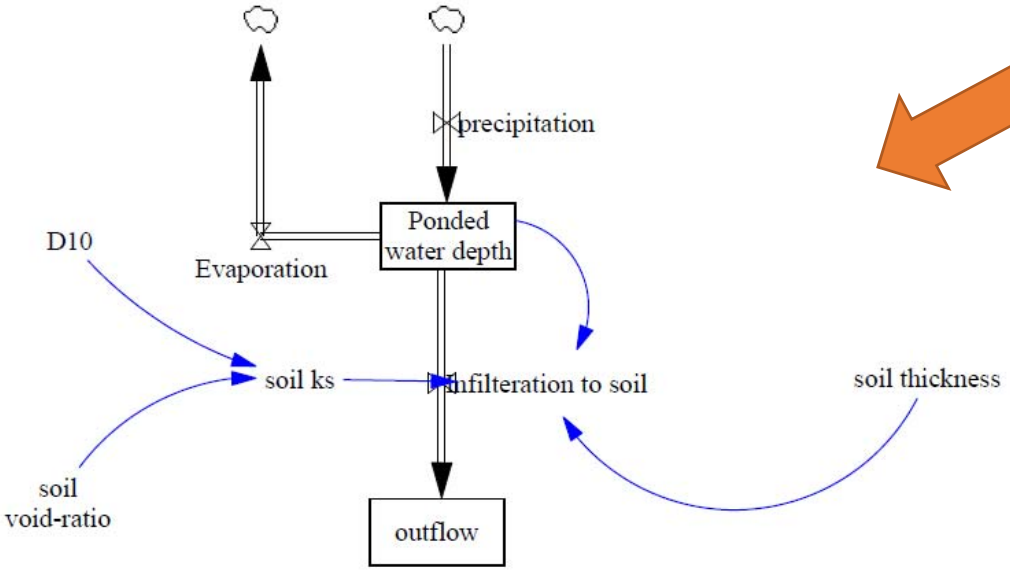
- ✓ **Saturated coarse grained soil**
- ✓ **Inflow at constant rate**
- ✓ **1-D infiltration**



Simulation example (2/7)

❑ System model

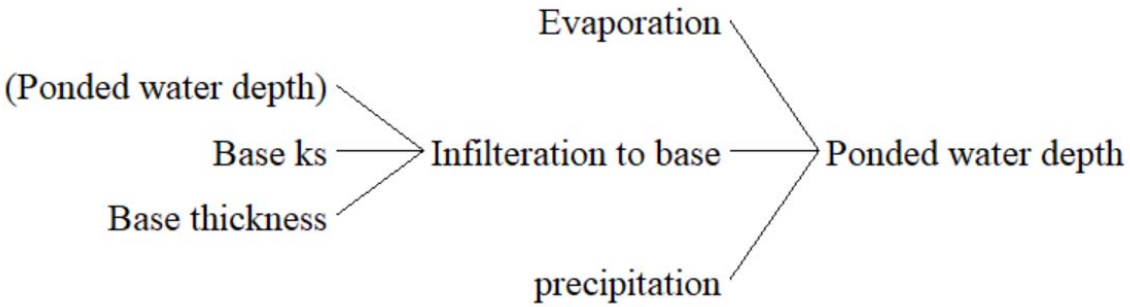


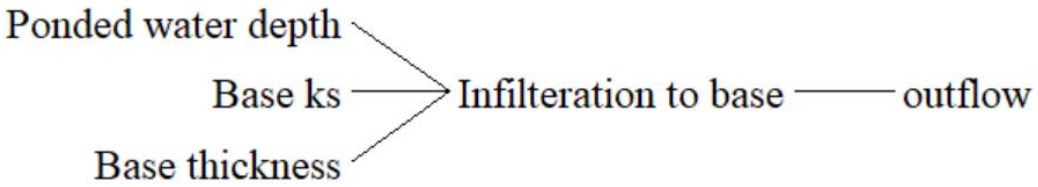


Simulation example (3/7)

❑ System model

✓ Causal tree





Simulation example (4/7)

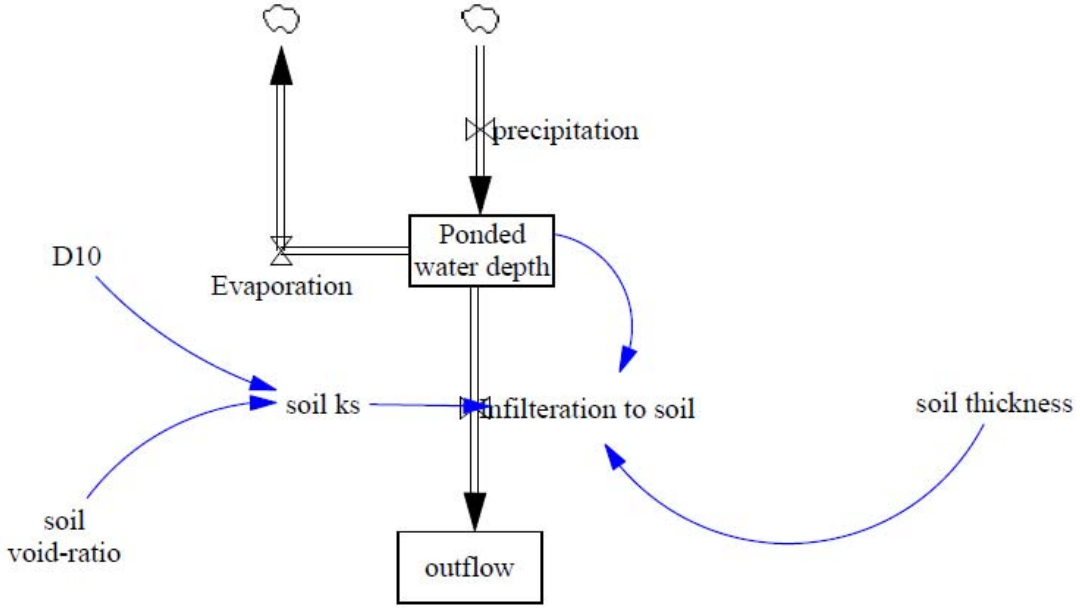
❑ Variable ranges

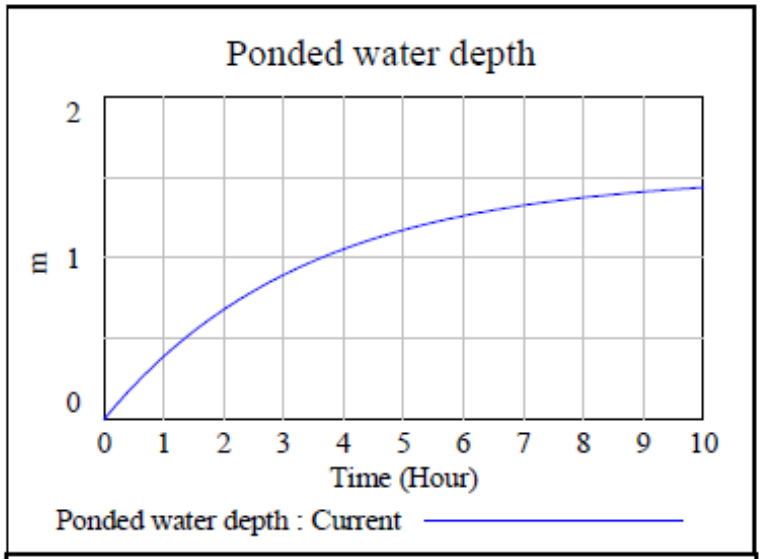
- ✓ Precipitation rate: 0.5 m/hour
- ✓ Evaporation rate 0.05 m/hour
- ✓ Infiltration rate: $V_I = k_{sat}(\frac{h_{ponded-w}}{Thickness})$ (m/hour)
- ✓ Soil hydraulic conductivity:

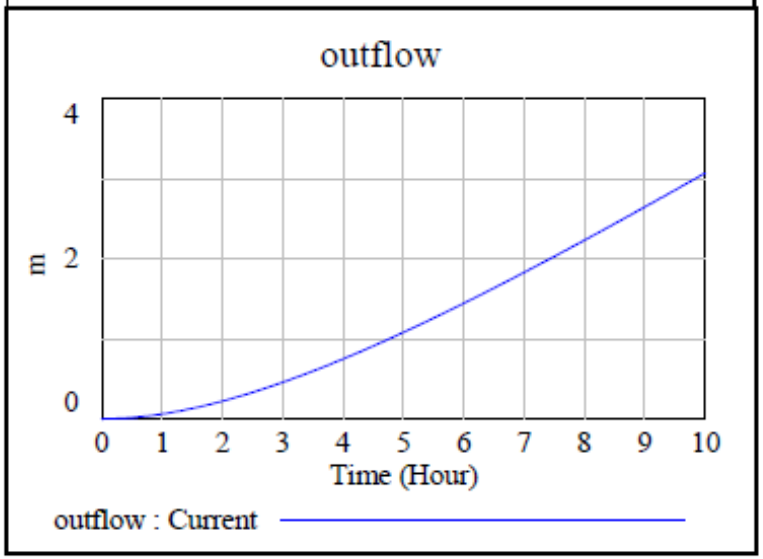
$\boldsymbol{k_{sat}} = 88.6(D_{10}^2 \frac{e^3}{1+e})^{0.78}$ (m/hour) (Chapuis 2004)

- ✓ D_{10}= 0.2 mm, e= 0.6
- ✓ Soil thickness: 0.5 m
- ✓ Ponded water depth: ∫ (precipitation−evaporation−infiltration)dt
- ✓ Outflow: ∫ (infiltration)dt

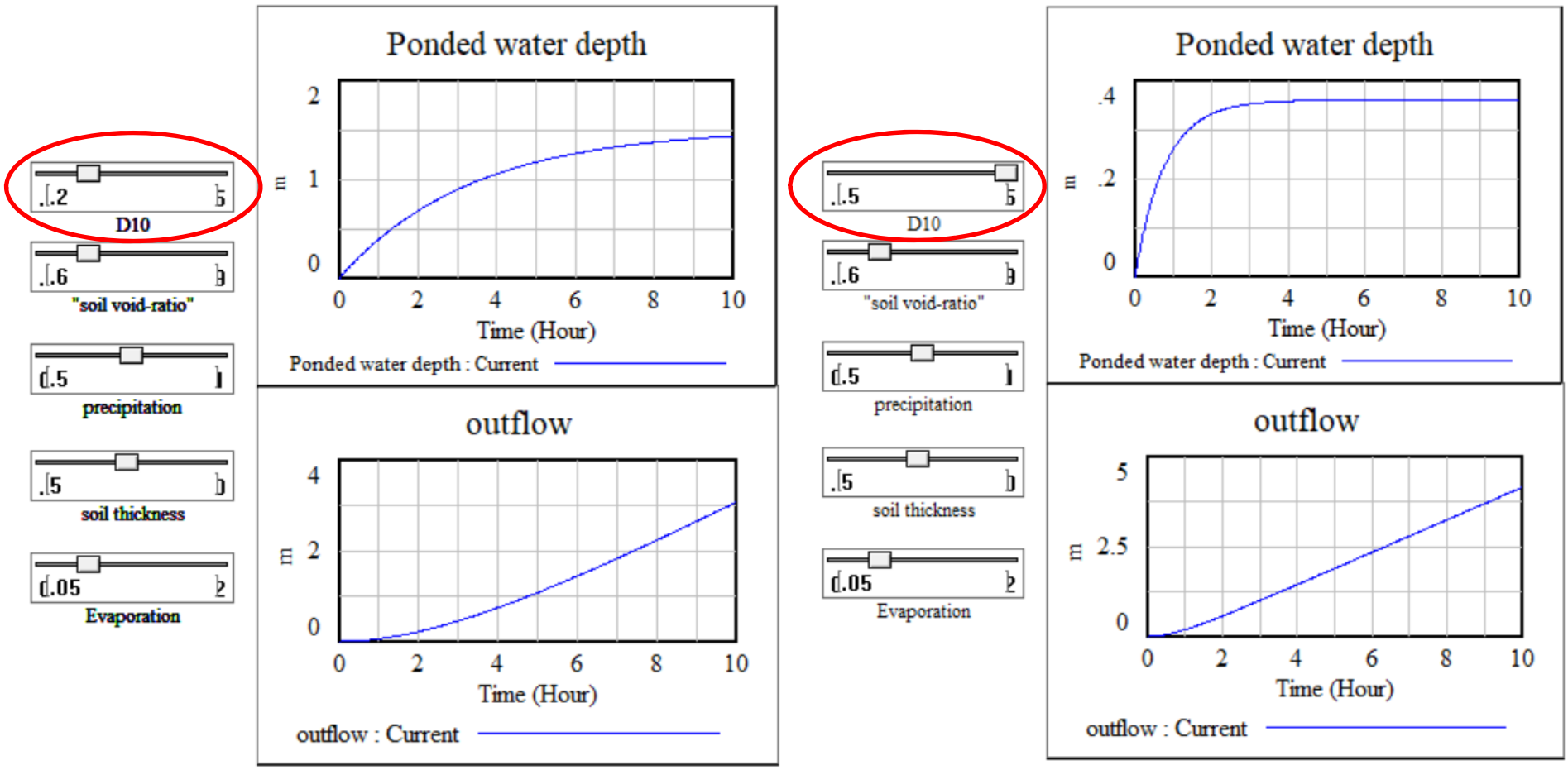
Simulation example: Time Series (5/7)





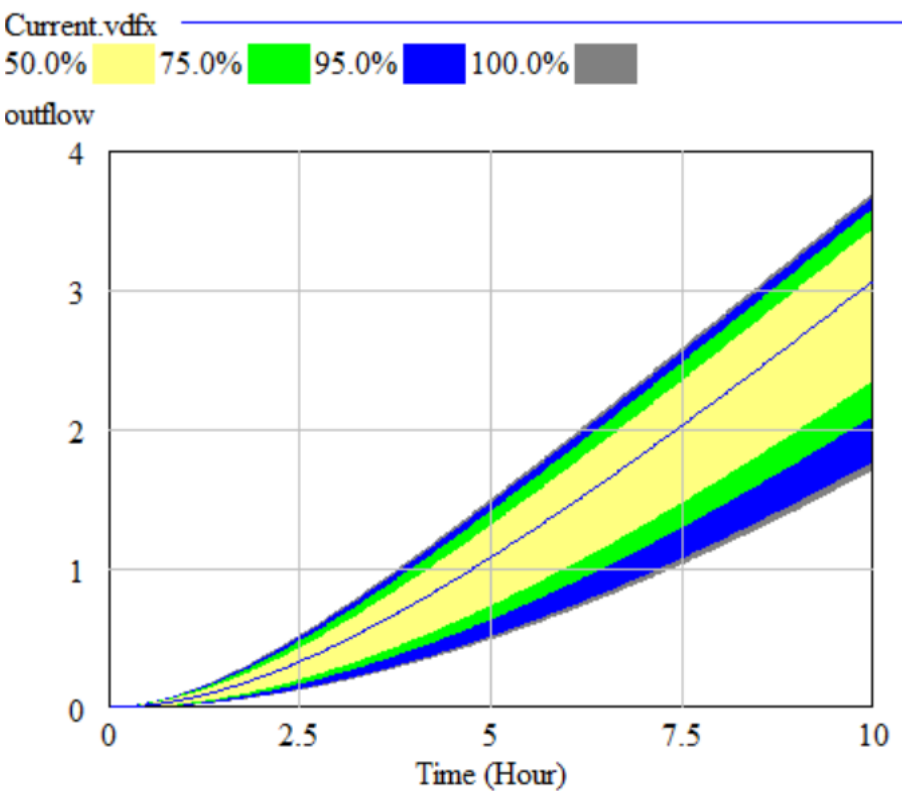


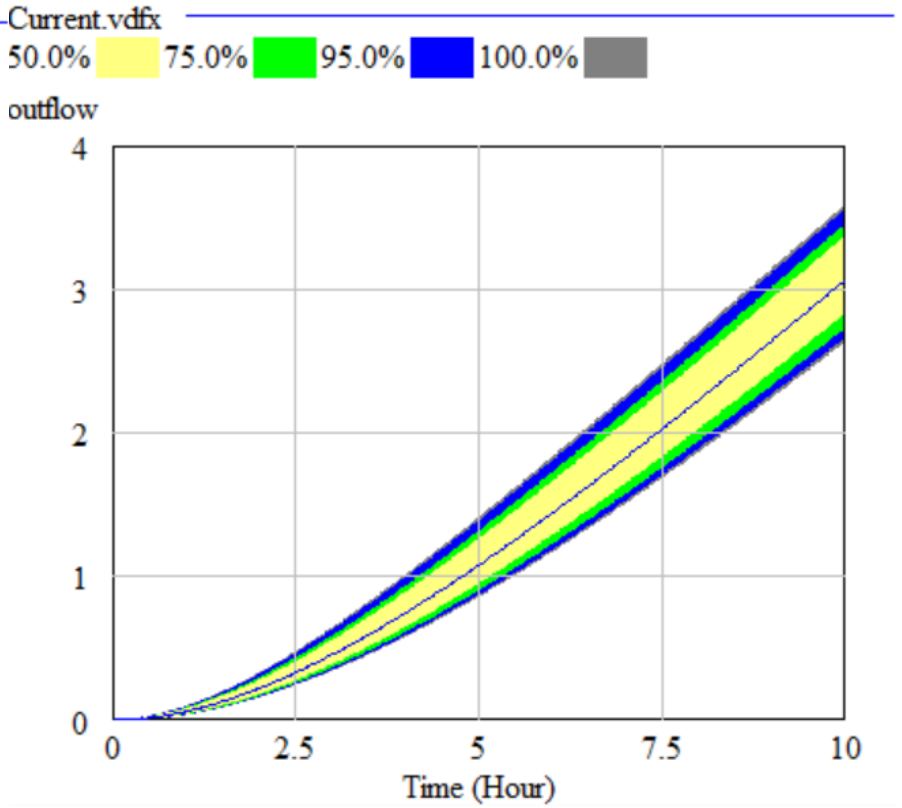
Simulation example: Time Series (6/7)



Simulation example: Sensitivity Analysis (7/7)

❑ Example: Sensitivity to D_{10} and soil thickness





D_{10} = 0.1 to 0.3

Soil thickness: 0.3 to 0.7 m

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Upcoming Tasks and Open Discussion

❑ Task 3:

- ✓ Incorporate TAP feedback on system dynamics framework
- ✓ Finalize the “flows” (relations) and inputs
- ✓ Construction of individual structure
- ✓ Conduct “Reality Checks”
- ✓ Integrate different structures in one system

❑ Task 4:

- ✓ Perform full sensitivity analysis


Thank you!
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