State-of-the-science on hydrology and erosion: How are these processes represented in a widely used soil erosion model?

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"The NSERL – to provide the knowledge and technology needed by land users to conserve soil and water resources for future generations."

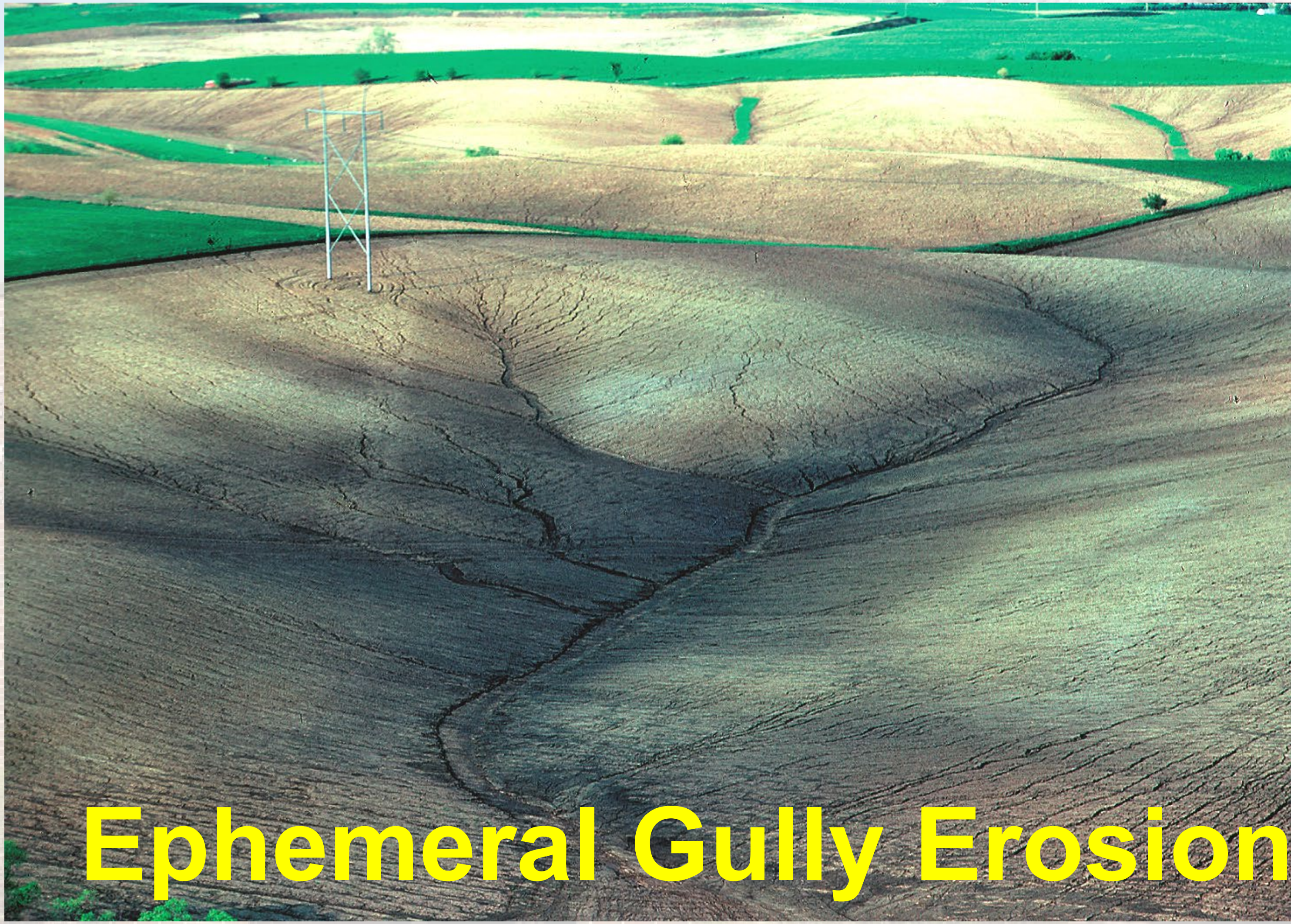
Building dedicated 1/15/1982

Presentation Outline

- Important hydrologic and water erosion processes at field and farm scales.
- Water Erosion Prediction Project (WEPP) model
- Hydrology processes in WEPP
- Erosion processes in WEPP
- WEPP status and current projects

Rainfall / Runoff / Erosion Event

Sheet & Rill Erosion



Scales of interest

0.01 to 1 ha – Hillslope scale

Hillslope profiles in agricultural fields, forested areas, rangeland parcels, landfills, mines, highways, construction sites, etc.

1 to 1000 ha – Field, farm scale

Small watersheds in agricultural fields, on farms, in forested catchments, construction sites, etc. Channels such as ephemeral gullies and grassed waterways.

Important Processes at these Scales

- **<u>Precipitation</u> (and weather in general) – rainfall occurrence, volume, storm duration, intensity**

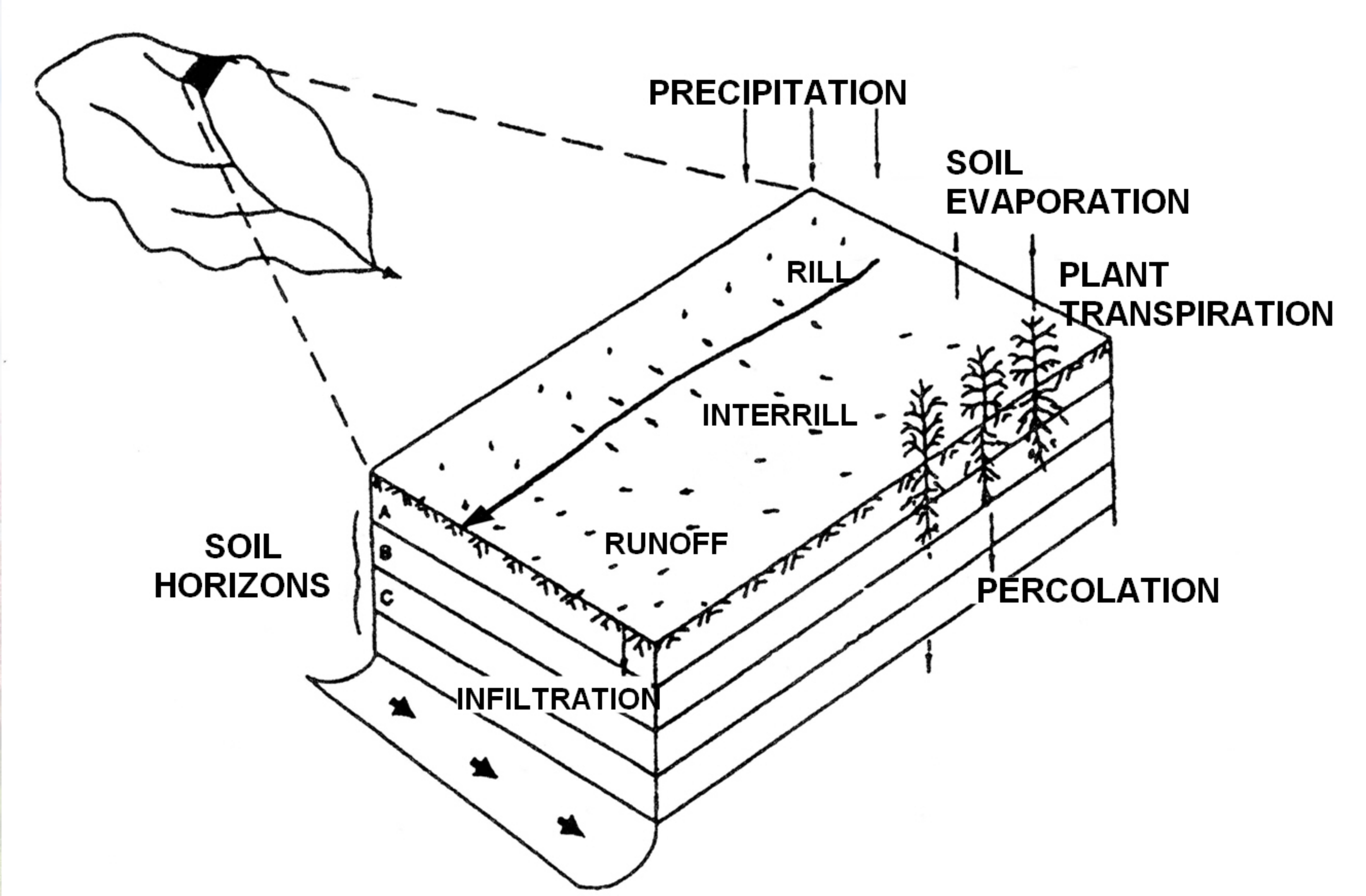
- **<u>Surface hydrology</u> – infiltration, pondage, ET, runoff**

- **<u>Subsurface hydrology</u> – percolation, seepage, lateral flow**

- **<u>Hillslope erosion processes</u> – detachment by rainfall, shallow flow transport, rill detachment by flow shear stress, sediment transport, sediment deposition**

- **<u>Channel erosion processes</u> – detachment by flow shear stress, sediment transport, downcutting to a nonerodible layer, sediment deposition**

Hillslope region from a small watershed



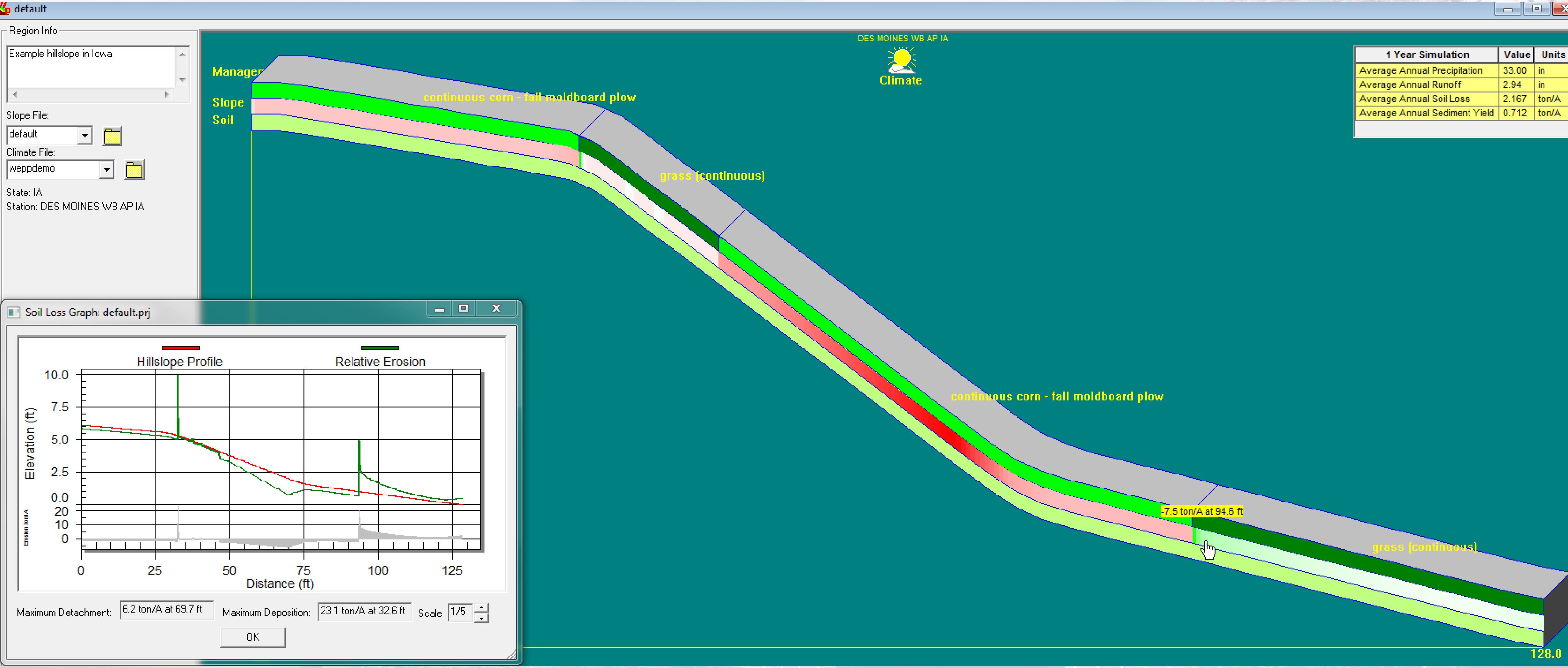
Water Erosion Prediction Project (WEPP)

- Large national project by USDA initiated in 1985 to develop process-based erosion prediction technology for use by federal action agencies and others. Product meant to replace USLE-based technologies.
- Main model development from 1985-1995.
- Validated WEPP model with full documentation publicly released in 1995.
- Extensive model updates, and interface and database efforts since 1995.
- USDA Forest Service major user of WEPP, particularly for determination of remediation efforts following wildfires.
- USDA Natural Resources Conservation Service implementation project since 2013 to utilize WEPP in its field offices.

WEPP model

- WEPP is a distributed parameter, continuous simulation, deterministic, process-based soil erosion computer simulation model.
- Spatial variability in soils and/or cropping and management systems can be easily simulated in multiple Overland Flow Element (OFE) hillslopes or in watersheds with multiple hillslopes, channels, and impoundments.
- Targeted for application to hillslope profiles where overland flow resulting from rainfall, snowmelt, and/or irrigation, and sheet and rill erosion are the dominant processes. Hillslopes typically up to about 100 meters long.
- Targeted for application to small field/farm watersheds up to about 260 ha in size to additionally estimate soil loss or deposition in channels (i.e. ephemeral gullies, grassed waterways) and impoundments (ponds, culverts, etc.).

WEPP Windows interface, with 4 OFE hillslope

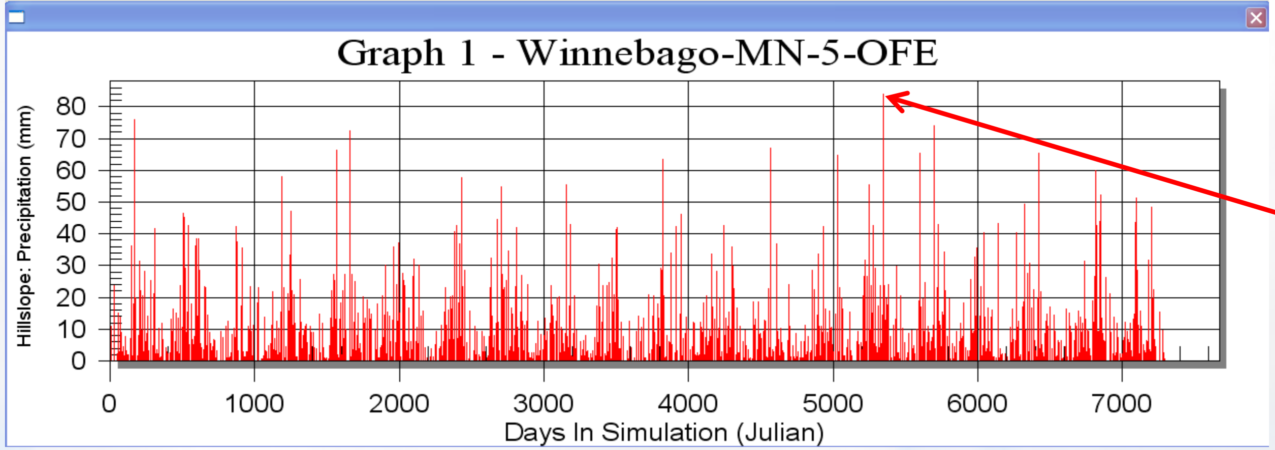


Continuous model simulations

- For long time periods, e.g. 100+ years
- Allow for long-term interactions between climate, cropping / management, and soil factors
- Return period values for precipitation, runoff, and sediment loss can be computed. These can be used in probability risk analyses.
- Also provides a research tool to examine impacts of climate change on complex hydrologic and erosion processes.
- The model can optionally be applied to individual single storms.

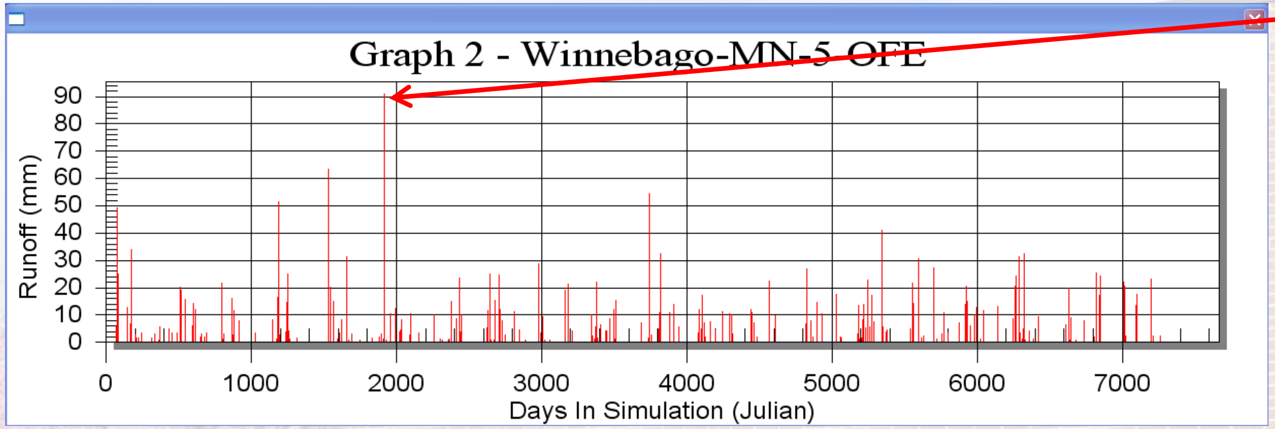
Some example WEPP outputs – from a 20-year simulation in Minnesota

Precipitation



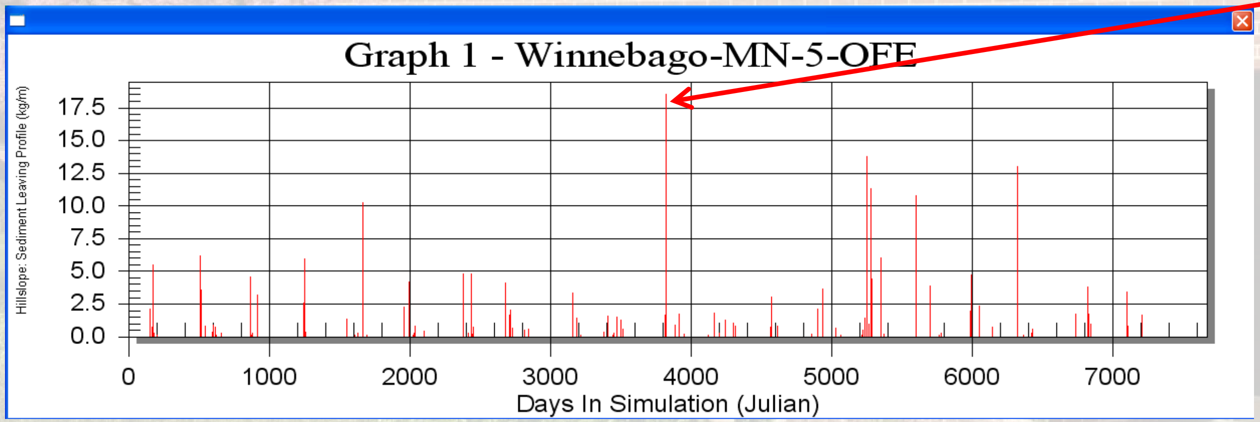
Greatest rainfall does not always produce greatest runoff!

Runoff



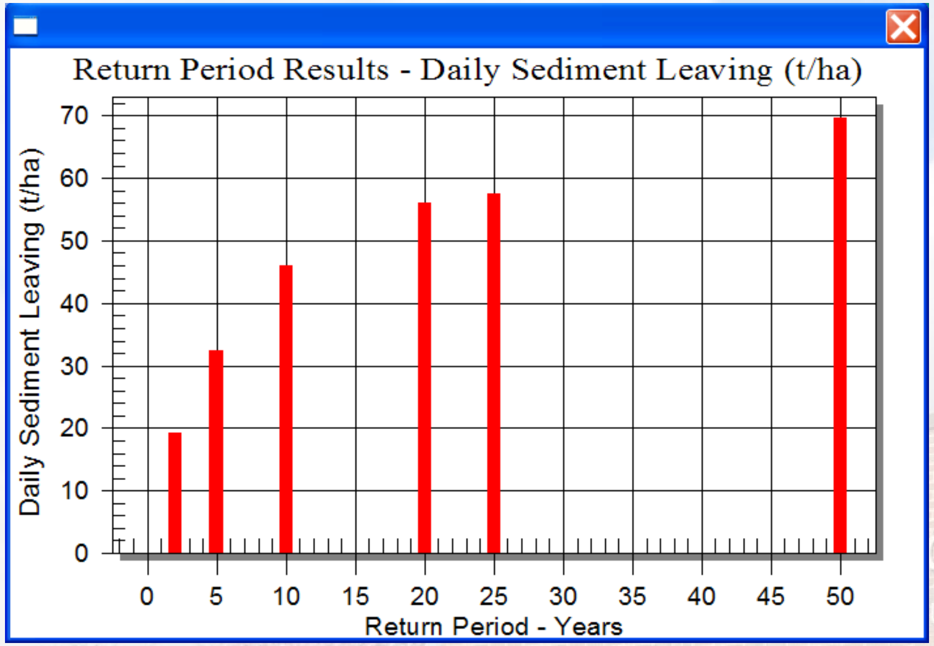
And greatest runoff does not always produce greatest sediment loss!

Sediment Loss



Demonstrates the effects of interactions of climate, crop growth, soil disturbance, soil moisture, and residue conditions through time.

WEPP - Return period results & risk analysis example



For **Conventional Tillage**, daily sediment leaving another profile was predicted to exceed 19 t/ha at least once every 2 years, and 57 t/ha at least once every 25 years. Or:

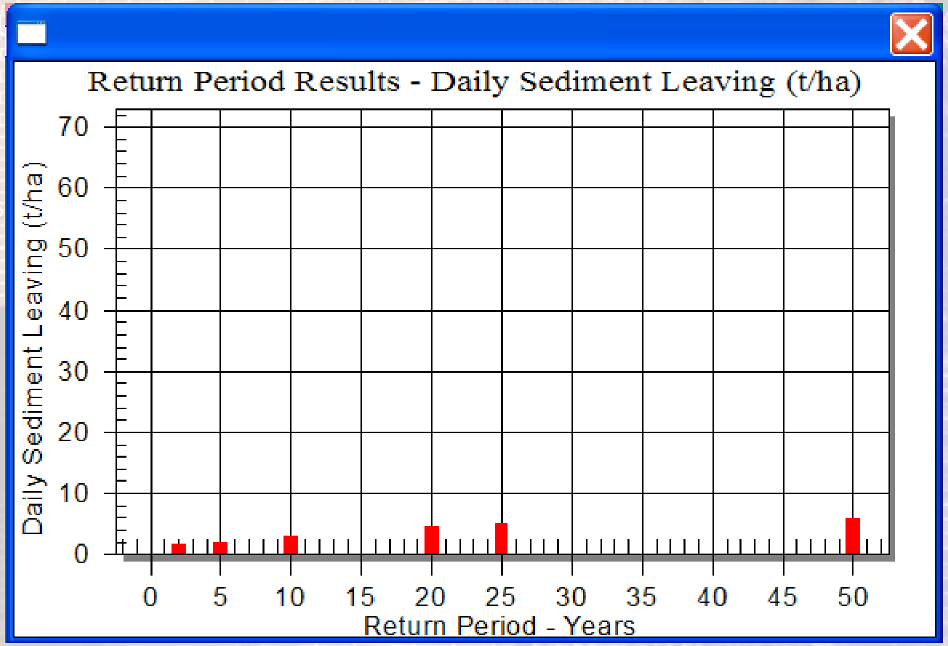
50% risk that event sediment loss will exceed 19 t/ha

4% risk that event sediment loss will exceed 57 t/ha

For **No-till cropping management**, daily sediment leaving the profile was predicted to only exceed 1.5 t/ha once every 2 years, and 5.1 t/ha once every 25 years! Or:

50% risk that event sediment loss will exceed 1.5 t/ha

4% risk that daily sediment loss will exceed 5.1 t/ha

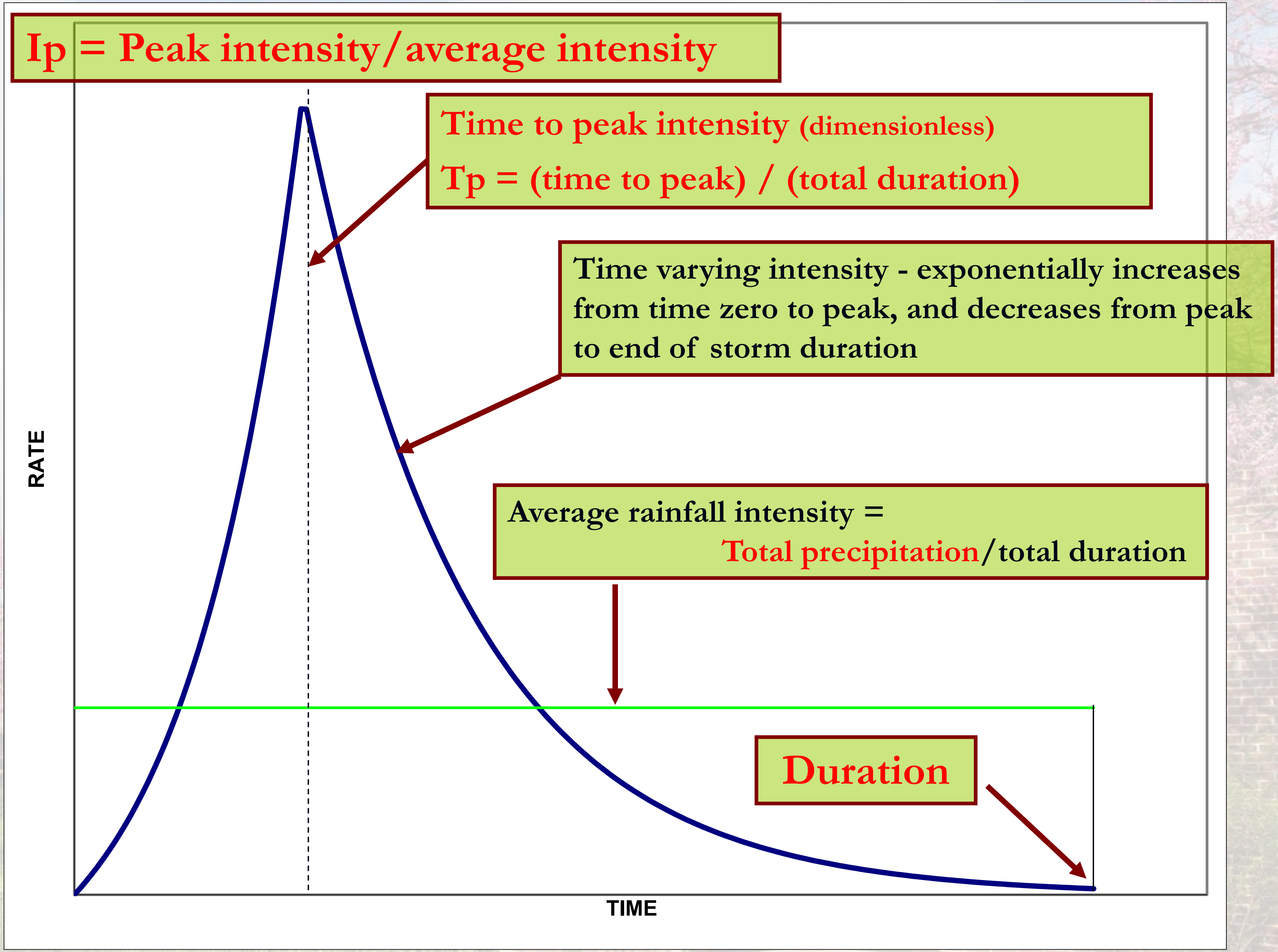


Precipitation

- WEPP model can accept either direct breakpoint precipitation inputs, or more commonly standard CLIGEN outputs.
- CLIGEN (CLImate GENerator) is a stochastic weather generator that can provide a string of daily long-term synthetic climate that approximates the long-term observed weather station statistics.
- A two-stage Markov chain method is applied in CLIGEN to determine the number and distribution of precipitation events. Weather station monthly values for 2 conditional probabilities are used: P(W|D) – probability of a wet day following a dry day, and P(D|W) – probability of a dry day following a wet day.
- Other equations are used to determine storm depth, storm duration, and peak intensity from the weather station statistical values.

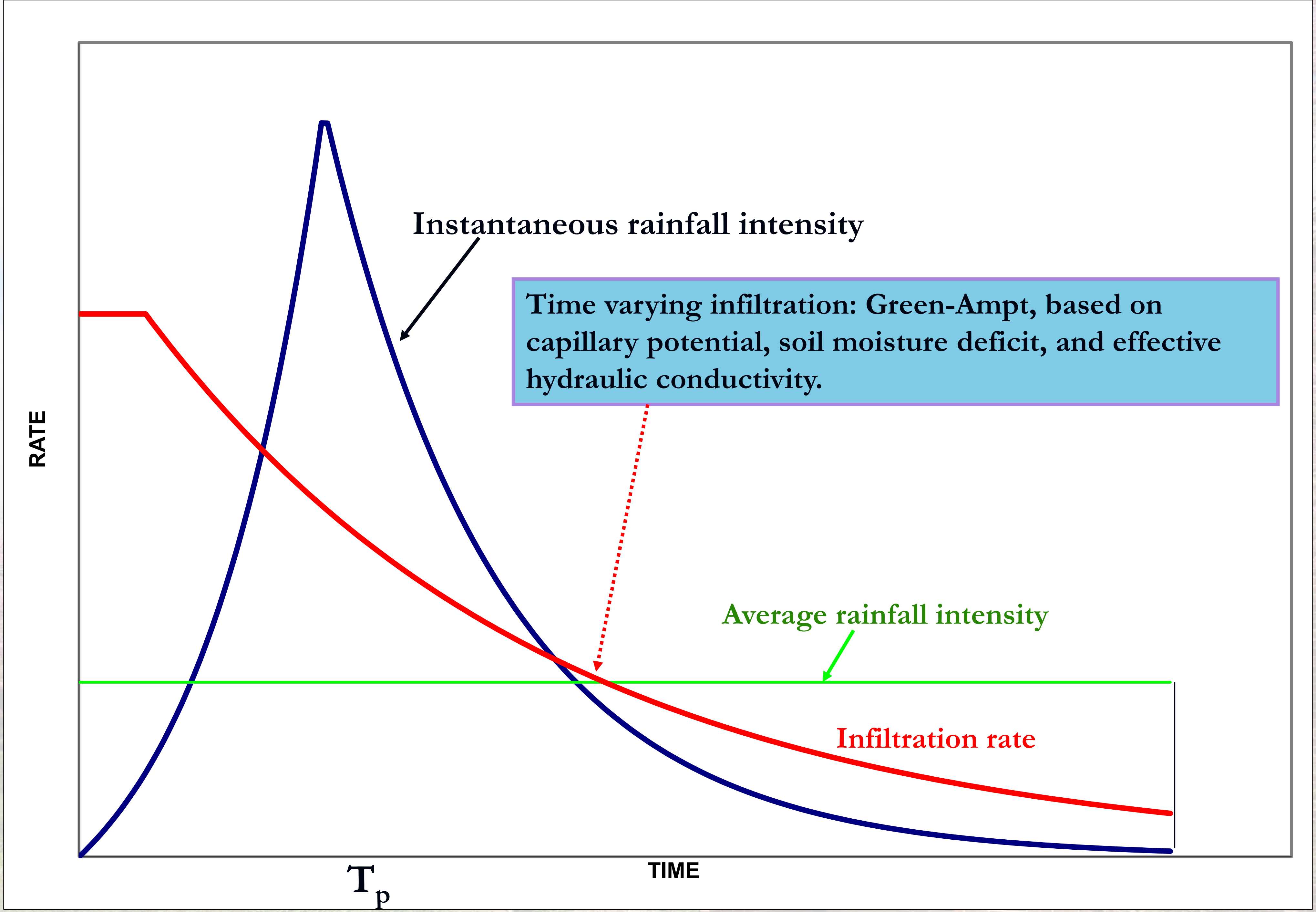
CLIGEN

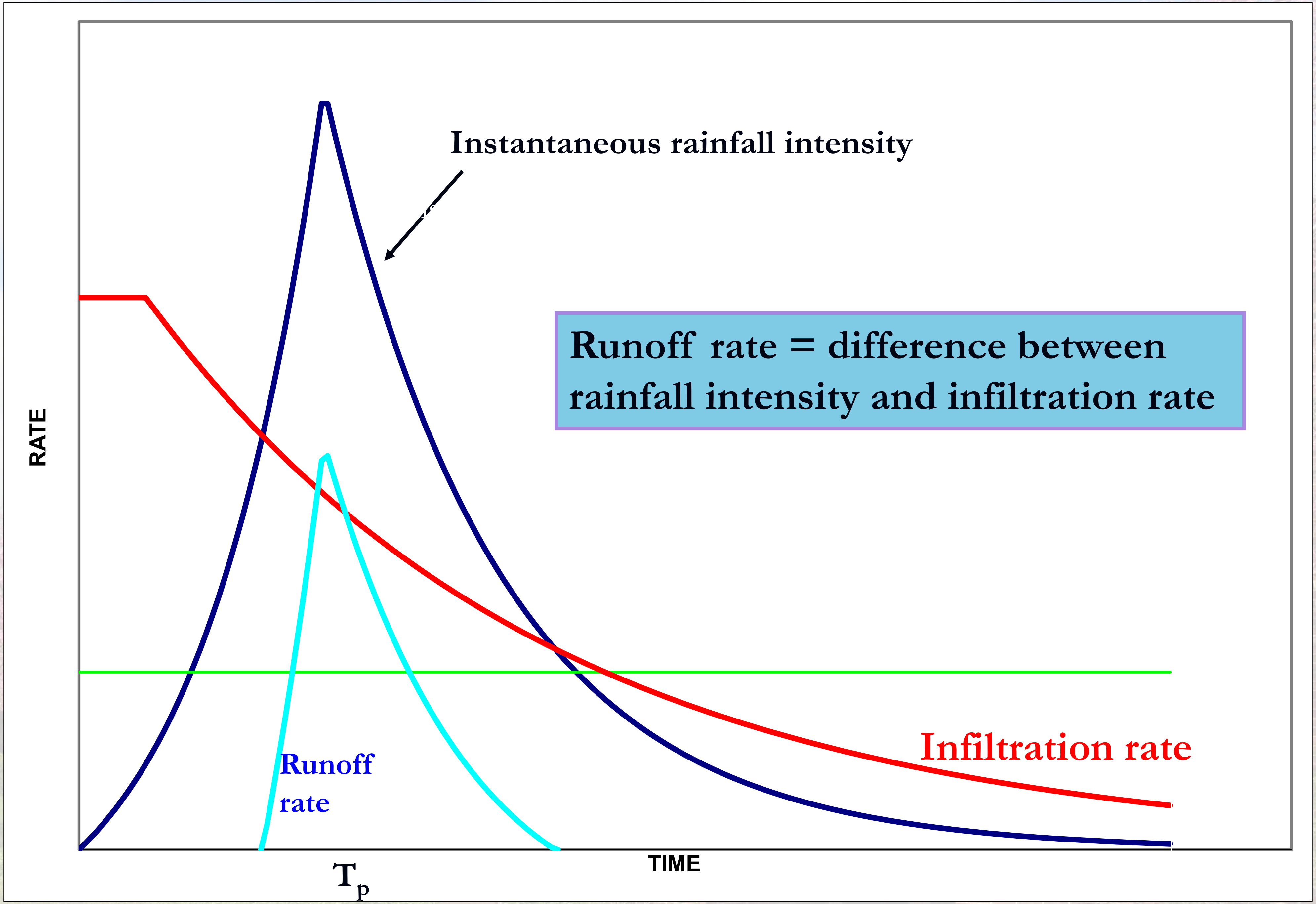
- WEPP typically uses a stochastic weather generator called CLIGEN (CLImate GENerator). CLIGEN database (2015) contains 2765 stations with temporally consistent statistics from recent 40 years (1974-2013).
- CLIGEN produces four basic daily storm inputs: storm depth (mm), storm duration (h), ratio of peak intensity to average intensity (i_p), and ratio of duration where peak intensity occurs to total storm duration (T_p).
- Internally within the WEPP model, the storm is then disaggregated into multiple intensity/duration breakpoints that approximate a double exponential storm shape.
- The storm breakpoint intensity values are then used in the subsequent infiltration, runoff, and erosion calculations.
- Another input option to WEPP utilizes storm breakpoint precipitation inputs (time, cumulative daily precipitation to that time) directly, for example from observations from a recording rain gauge at an experiment site.

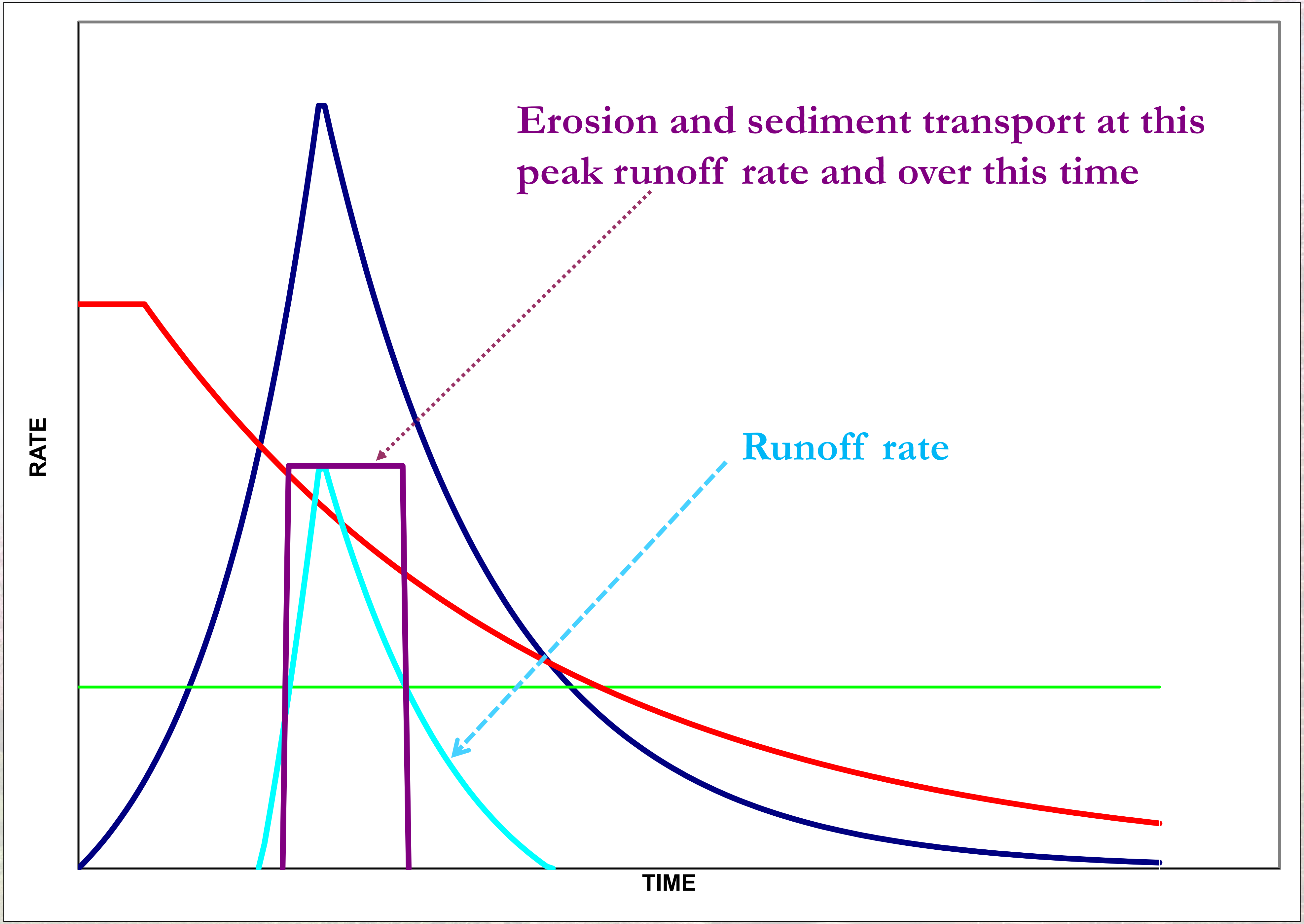

Ip = Peak intensity/average intensity
Time to peak intensity (dimensionless)
Tp = (time to peak) / (total duration)
Time varying intensity - exponentially increases from time zero to peak, and decreases from peak to end of storm duration
Average rainfall intensity =
Total precipitation/total duration
Duration
RATE
TIME

How WEPP works:

1. From climate input, determine if rainfall occurs on simulation day.
2. If rainfall occurs, determine storm characteristics and breakpoint rainfall inputs to model hydrology component.
3. Calculate infiltration, and any surface runoff from storm.
4. If runoff occurs, determine effective rainfall intensity, peak runoff rate, flow shear stress, etc.
5. Calculate sediment load down the hillslope profile, at a minimum of 100 evenly-spaced points. Determine net soil loss or deposition at each point, and sediment leaving profile.
6. Tabulate and store all temporal and spatial soil loss and sediment yield results for each storm, for use in output results and statistics.
7. Update infiltration and erodibility parameters daily, based on any changes in soil disturbance, soil moisture, plant growth, and residue.
8. Go to next day (step #1).


Instantaneous rainfall intensity
Time varying infiltration: Green-Ampt, based on capillary potential, soil moisture deficit, and effective hydraulic conductivity.
RATE
Average rainfall intensity
Infiltration rate
TIME
T_p


Instantaneous rainfall intensity
Runoff rate = difference between rainfall intensity and infiltration rate
RATE
Infiltration rate
Runoff
rate
TIME
T_p


Erosion and sediment transport at this peak runoff rate and over this time
Runoff rate
RATE
TIME

WEPP Surface Hydrology

- <u>Green-Ampt Mein-Larsen infiltration equation</u> is used, modified for unsteady rainfall. Infiltration is a function of soil capillary potential, soil moisture deficit, and effective hydraulic conductivity.
- Runoff volume is predicted from rainfall excess adjusted for surface depressional storage.
- <u>Runoff rates are predicted using a kinematic wave equation</u>, through solution using the method of characteristics.
    - For single storm simulations, the entire runoff hydrograph is generated.
    - For continuous simulations, an approximate method is used to only determine the peak runoff rate (needed for the steady-state erosion calculations).
- Effective rainfall intensity is calculated based upon summation of intensities during all periods where runoff is generated in an event.
- Full water balance is calculated daily, and water can also leave the surface through soil evaporation and plant transpiration.

WEPP Subsurface Hydrology

- Soil is divided into layers. Top two layers are 10 cm thick, and remaining layers are 20 cm thick to the bottom of the input soil profile (to a maximum depth of 1.8 m)
- Infiltrated water in excess of field capacity water content is percolated to next lower layer.
- Water can exit the bottom of the soil profile as deep seepage.
- Plant growth and roots can extract water from subsurface soil layers, decreasing the soil moisture content.
- Subsurface lateral flow is also calculated, and subsurface water can exit bottom of hillslope (and contribute to channel flow).
- Tile drainage can also be simulated in WEPP, to reflect the effects of artificial subsurface drainage on reducing soil profile water content.

WEPP Hillslope Erosion

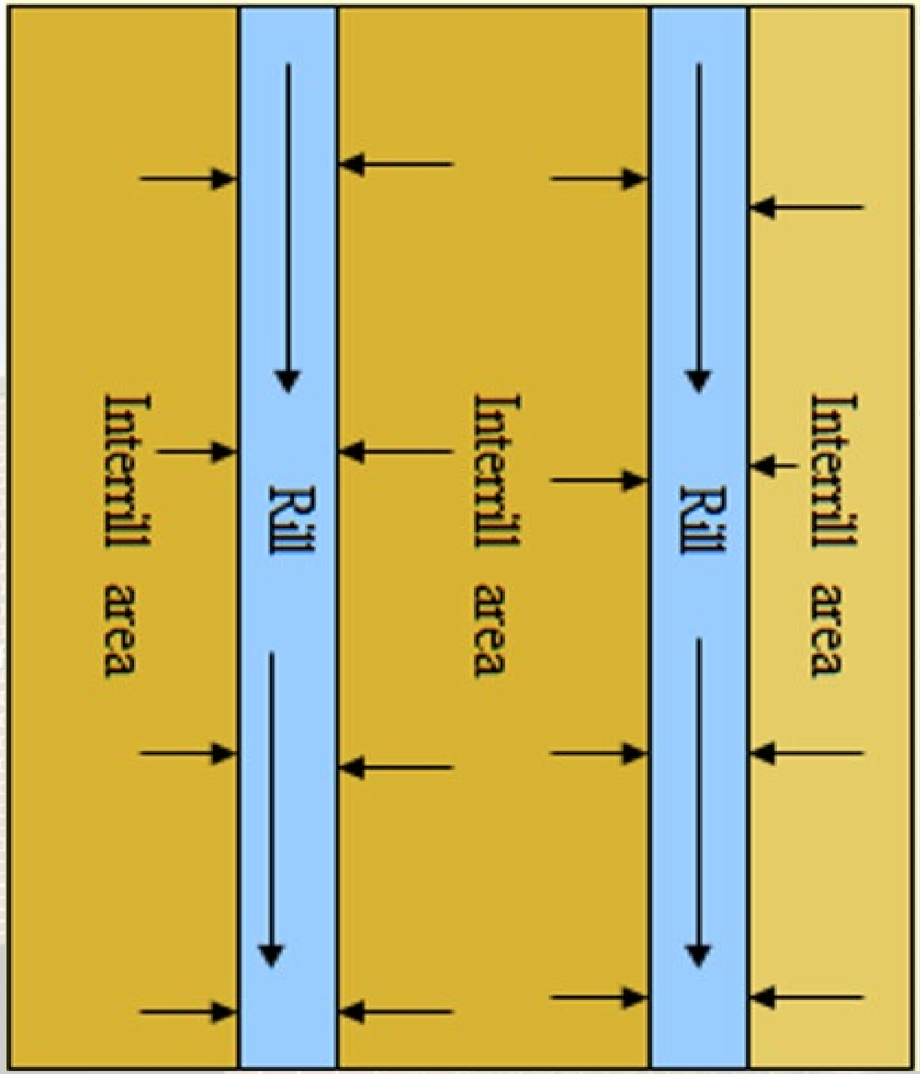
- Model uses a steady-state sediment continuity equation. Assumes that a storm’s effective rainfall intensity and peak runoff rate can be used with effective durations to represent erosive potential.
- Main equation is:

$$\frac{dG}{dx} = Df + Di$$

G is sediment load
x is distance downslope
D_f is rill detachment/deposition rate (can be positive or negative)
D_i is interrill sediment delivery rate to rills (always positive)

Rill and Interrill Erosion

Rills assumed to be regularly spaced rectangular channels



Interrill areas provide water and sediment laterally along rills

Rill Detachment Equation
(used when $T_c > G$)

$$D_f = K_r (\tau - \tau_c) [1 – G/T_c]$$

τ = Hydraulic Shear = γRS

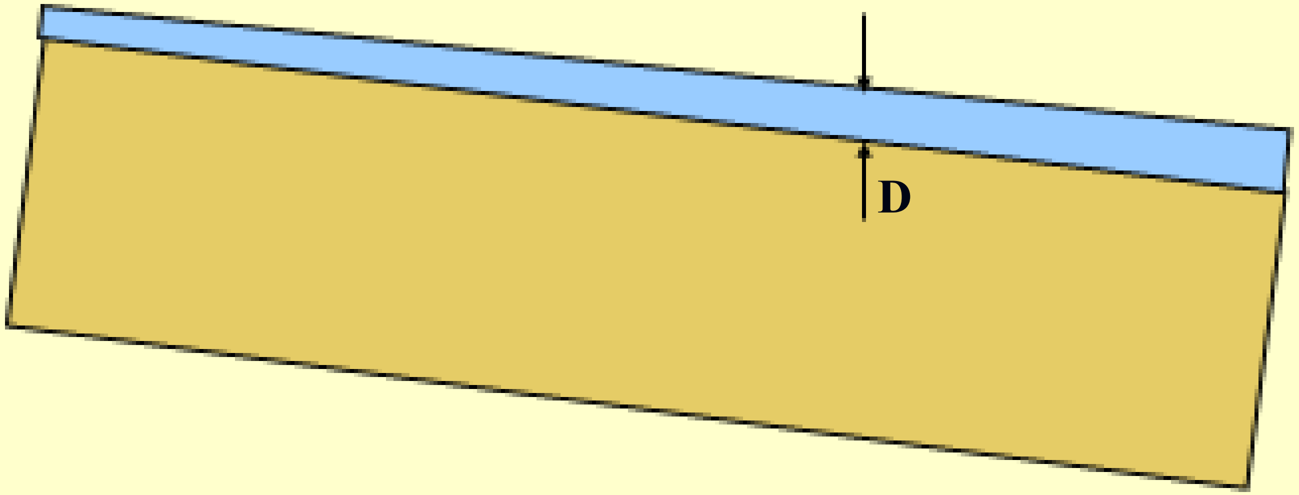
$R = A/P_w \sim D$

K_r = Rill erodibility

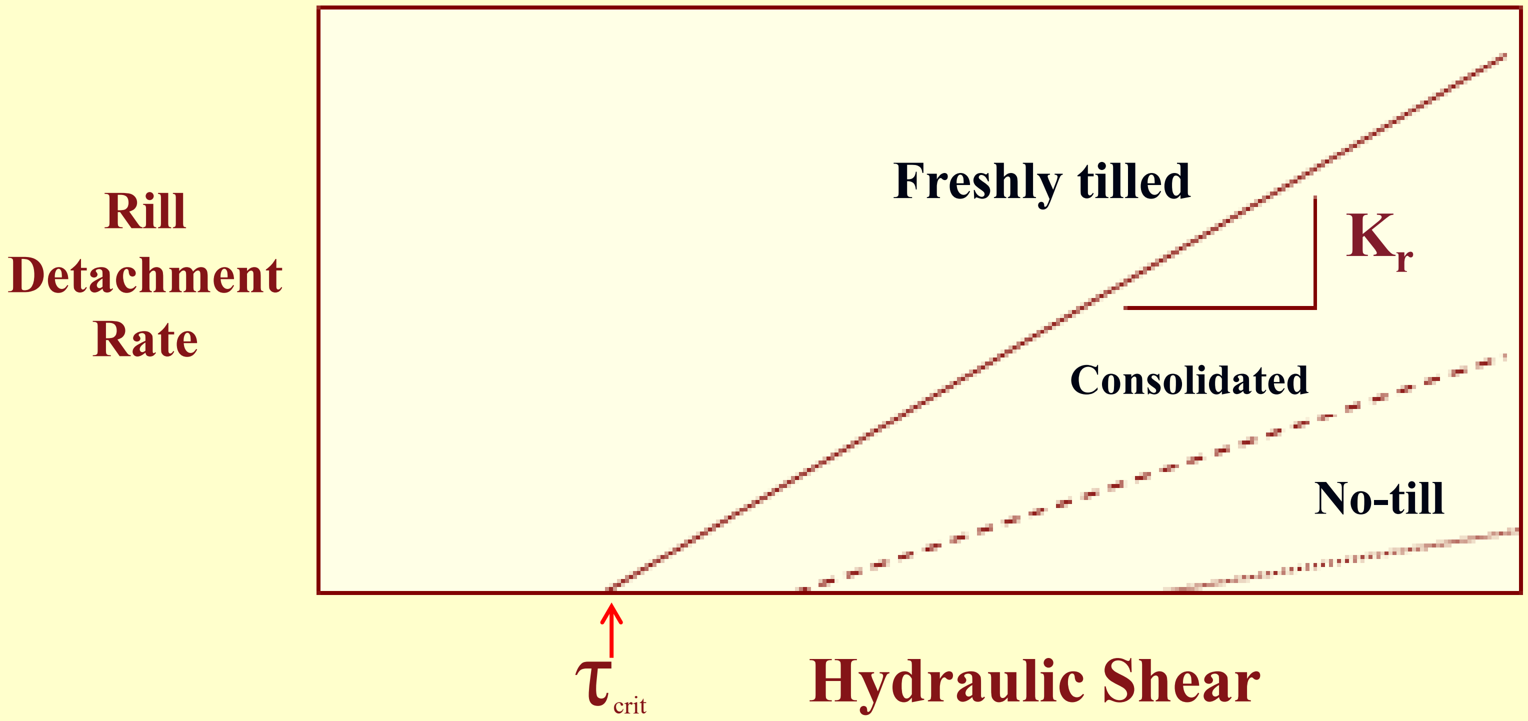
τ_c = Critical hydraulic shear

G = Sediment load

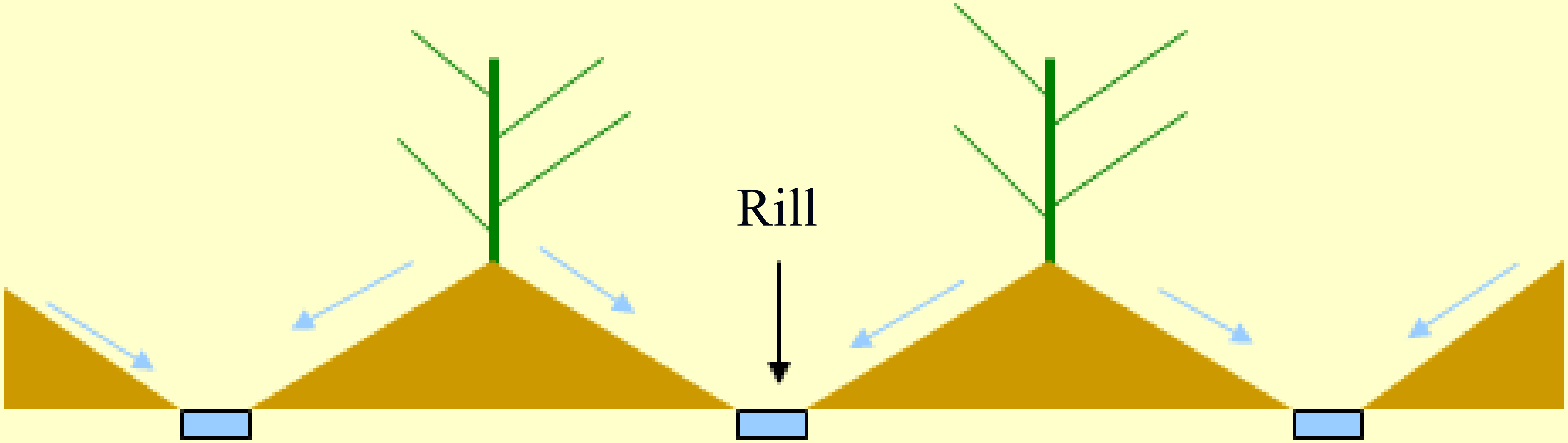
T_c = Sediment transport capacity



Rill Erodibility Parameters



Interrill Detachment & Sediment Delivery to Rills



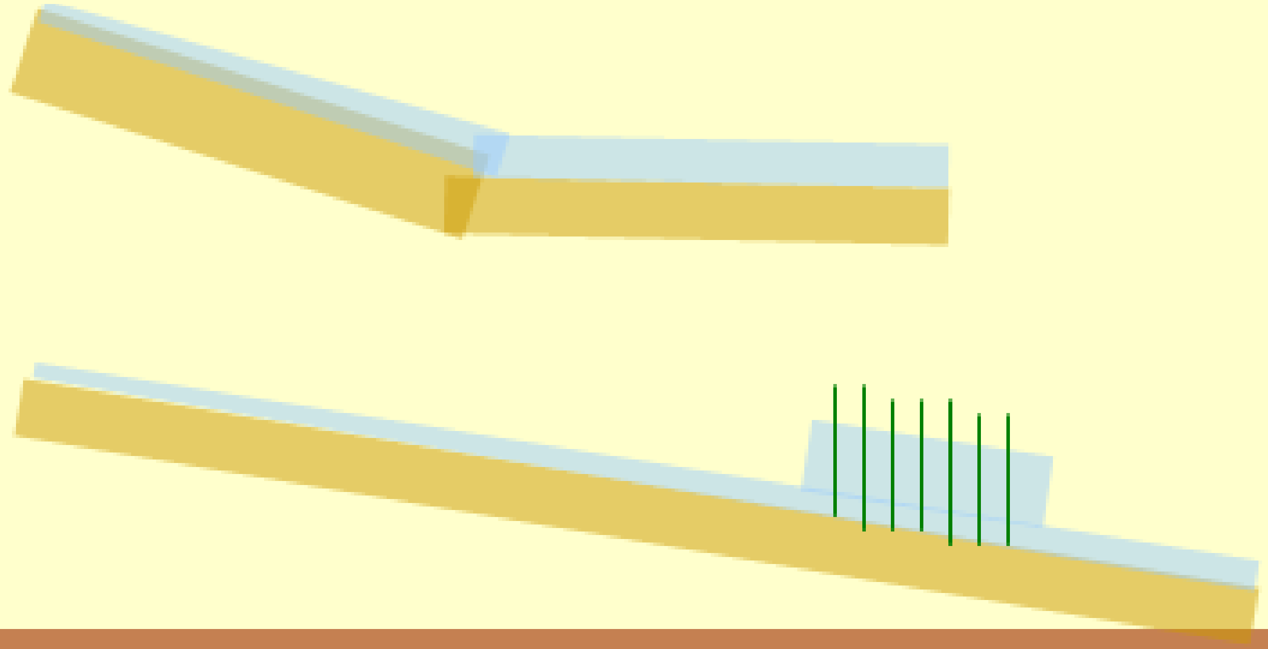
$$D_i = K_i \, I_e \sigma \, S_f \, ADJ$$

K_i - Interrill erodibility I_e- effective rainfall intensity

σ - interrill runoff rate S_f - slope factor ADJ - adjustment factors

Sediment Deposition

Deposition occurs when sediment load (G) exceeds sediment transport capacity (T_c). This may be due to slope concavities or an increase in surface roughness due to different vegetation (e.g. grass buffer strip).



Rill Deposition Equation
(used when $G > T_c$)

$$D_f = (\beta v_f / q) [T_c - G]$$

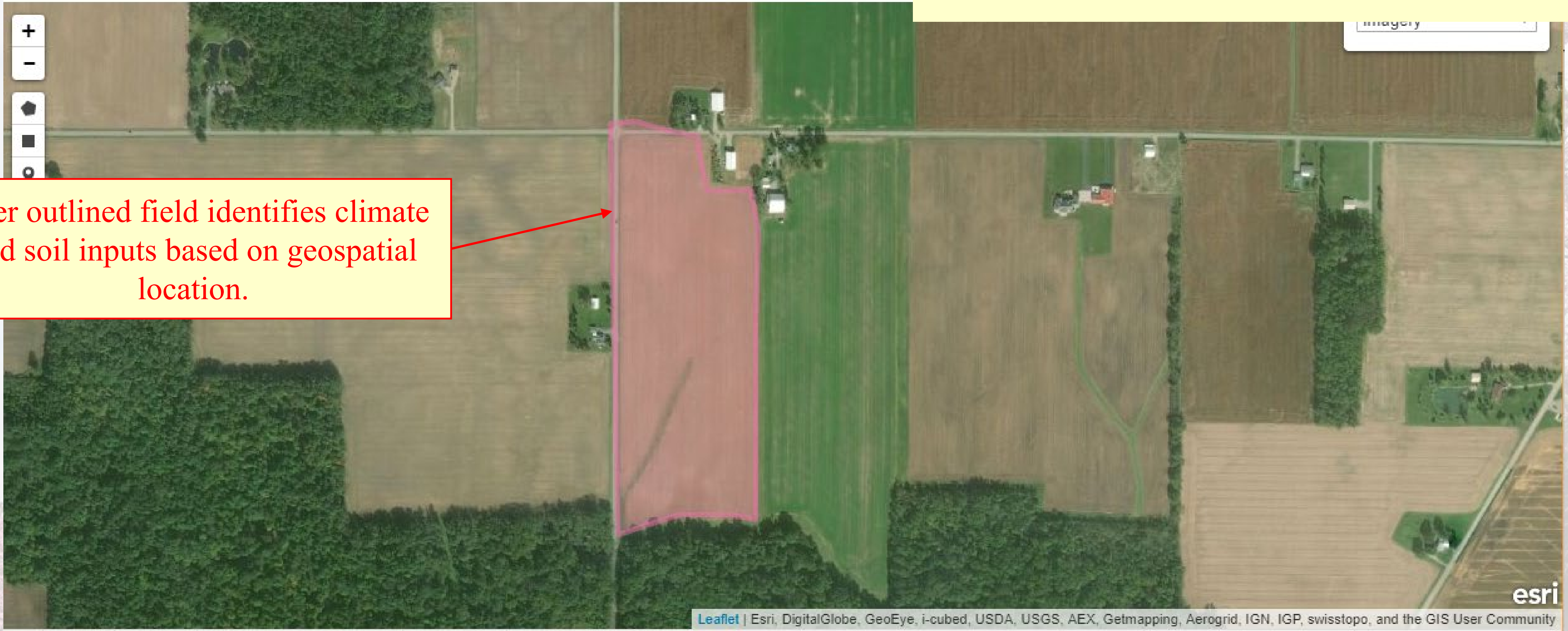
β = rainfall turbulence factor
v_f = effective particle fall velocity
q = flow discharge per unit width
G = sediment load
T_c = sediment transport capacity

WEPP Status and Current Projects

- Model is being actively maintained and updated at the NSERL.
- Major current effort is assisting NRCS with implementation, including development of web-based interfaces and databases.
- Efforts with Purdue graduate students include improvements in sediment transport calculations, improvements in subsurface drainage representation, and addition of water quality calculations.
- Work in the past two years has also involved some extensive comparison studies between WEPP and RUSLE2 erosion predictions.
- Also collaborating with other groups on use and application of WEPP technology, including Daily Erosion Project at Iowa State University.

New NRCS web WEPP interface

WEPP NRCS 9/8/2018 | Project | Results Analysis | History | Map | Managements | Help



User outlined field identifies climate and soil inputs based on geospatial location.

	Load	Name	County	Area(Ac)	Soil	Latitude	Longitude
✖		Field 1	HANCOCK COUNTY	26.6	GsB|Glynwood-Blount-Houcktown complex, 1 to 4 percent slopes(4.00T)	41.135916302296344	-83.59160989522934

To define a field to use with WEPP zoom to the area of interest and select the polygon tool to outline the field. Give the field a name in the popup window. The soil with the largest percentage based on area is selected along with the county where the field is located. The maximum size area for a field is about 320 acres.

To use a field in a project click the load icon in the row. **The field boundaries are not currently saved.**

When the **Draw a Marker** icon is used a point location will be used to represent the field. The location will only be used to define the climate used in the simulation. In this case since the soil for the area is not defined by the map it can be selected on the main project page.

NRCS web WEPP interface main screen & I/O

WEPP NRCS 9/8/2018 Project Results Analysis History Map Manag

Client Name: Kevin
Field Name: Field 1
Location (Latitude): 41.135916302296344
Location (Longitude): -83.59160989522934

State: Ohio **County:** HANCOCK COUNTY Change
Climate Database: 2015 Run Years 100
Use PRISM Adjustments Map
Latitude and Longitude represent center of delineated field.

Soil GsB|Glynwood-Blount-Houcktown complex, 1 to 4 percent slopes(4.00T)

Slope Shape Uniform Steepness (%) 4 Aspect/Direction South
Length (ft) 200

Strips/Barriers 0 - None
Contouring a. rows up-and-down hill

Managements (Total Slope Length: 200 ft) Repeat Strips

Num			Name
1			Corn FC Disk Fld Cult- Soybeans NT Dbl Disk Opners fluted coulters- Wheat NT

WEPS Erosion 0 (t/ac/yr) (for final SCI)

Run Save Local Upload Local Example Projects

Results

NRCS Soil Loss for Planning(t/ac/yr)	1.99	Fuel (gal/a/yr)	2.87
Average Annual Soil Loss (t/ac/yr)	1.99	Annual STIR	36.20
Average Annual Sediment Delivery(t/ac/yr)	1.99	SCI	0.55
Average Annual Runoff(in/yr)	6.02	SCI OM Subfactor	0.61
Average Annual Precipitation(in/yr)	35.64	SCI FO Subfactor	0.64
Average Annual Irrigation(in/yr)	0.00	SCI ER Subfactor	0.22
Average Annual Sediment Deposition(t/ac/yr)	0.00		

PDF Summary of Simulation

Crop Calib

Crop Name
Wheat, wint
Corn, grain
Soybean, g

Note: Calib
managemen
length is co
for success

Special PDF output report for NRCS

USDA NRCS Natural Resources Conservation Service

WEPP Profile Erosion Calculation Record

Info:
Client Name: Kevin
Field Name: Field 1
Simulation Run Date: Mon Nov 05 2018 16:55:09 GMT-0500 (Eastern Standard Time)

Inputs:

Location/Climate	Latitude	Longitude	Slope length (horiz) (ft)	Slope Shape	Avg. slope steepness, %	Aspect
Ohio-HANCOCK COUNTY	41.14	-83.59	200.0	Uniform	4	180

Soil: Component key of 17058540 GsB|Glynwood-Blount-Houcktown complex, 1 to 4 percent slopes(4.00T)
Soil T value: 4.00 (ton/A/yr)

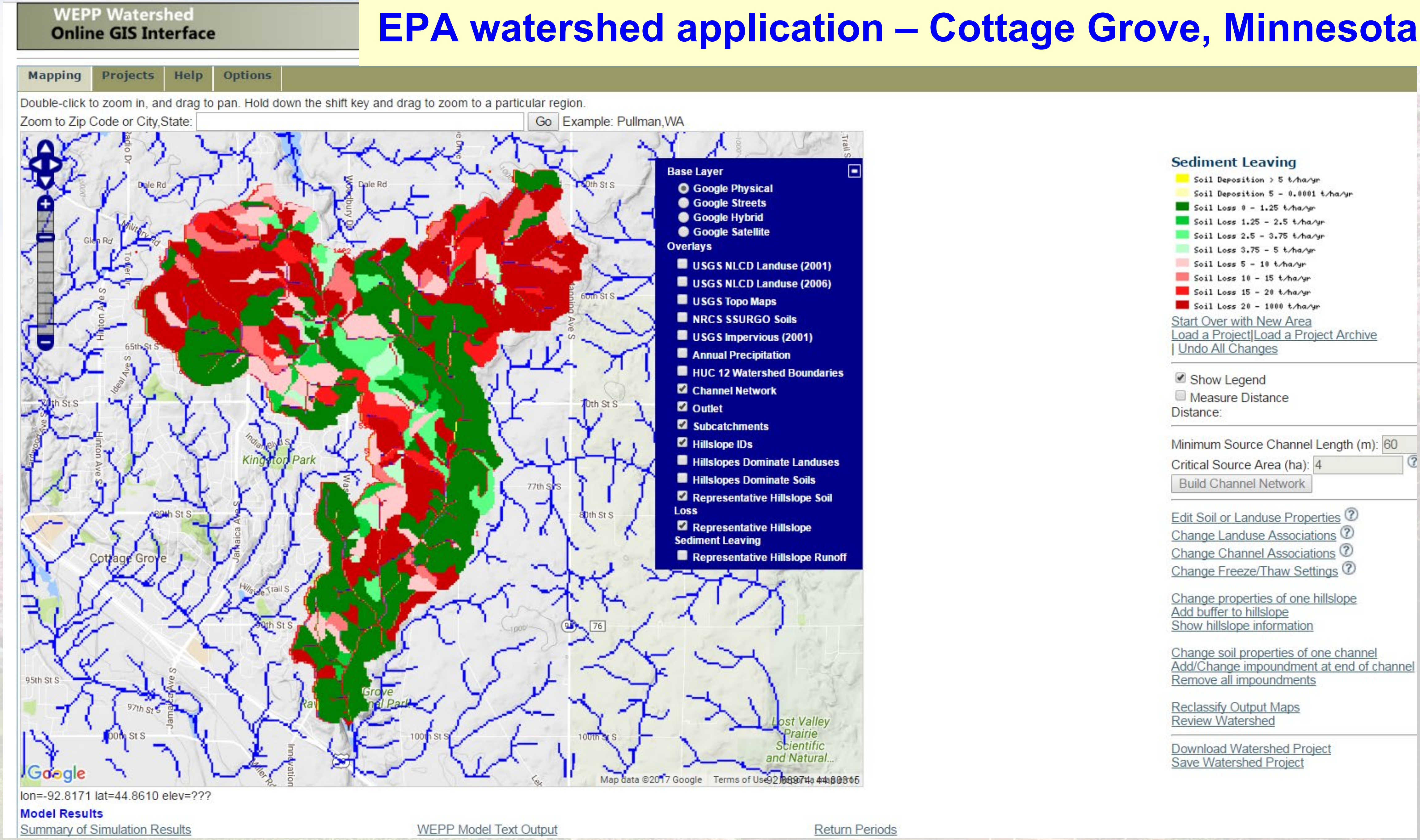
Management	Vegetation	Yield units	# yield units, #/ac	target yield	Yield %Moisture	%Yield Attained	Calibrated?
Corn FC Disk Fld Cult- Soybeans NT Dbl Disk Opners fluted coulters- Wheat NT	Wheat, winter, grain	bu/ac	58.1	65.0	11.1%	90.1	Yes
Corn FC Disk Fld Cult- Soybeans NT Dbl Disk Opners fluted coulters- Wheat NT	Corn, grain, seed	bu/ac	182.1	175.0	16.1%	104.1	Yes
Corn FC Disk Fld Cult- Soybeans NT Dbl Disk Opners fluted coulters- Wheat NT	Soybean, grain	bu/ac	53.1	60.0	13.1%	89.1	Yes

Contouring	Strips/barriers
None	None

Outputs:

Precipitation	Irrigation	NRCS soil loss	Soil loss erod.	Runoff	Sediment delivery	Sediment

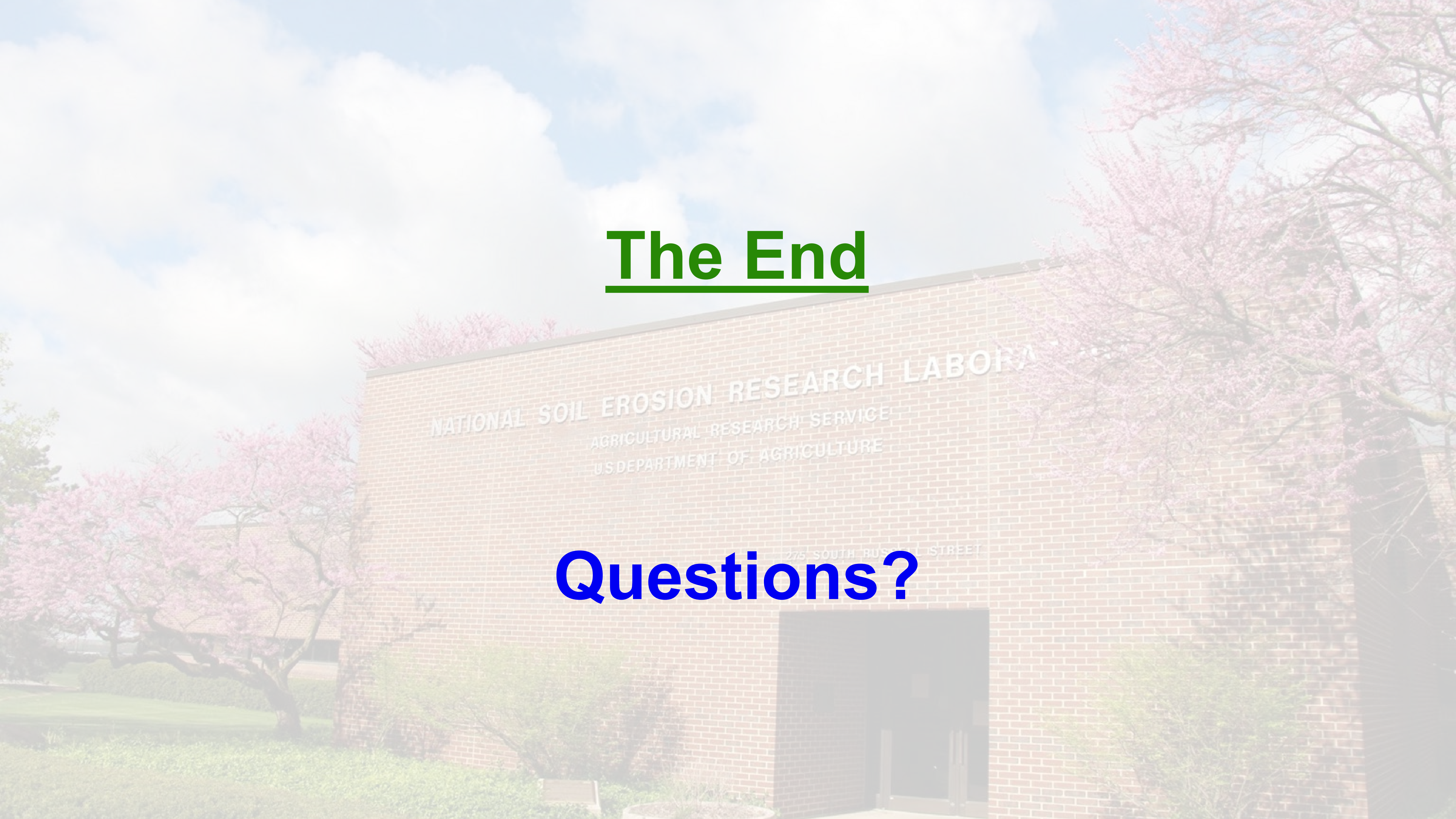
EPA watershed application – Cottage Grove, Minnesota



Summary

- Process-based models allow simulation of important physical processes controlling sediment losses, as well as interactions.
- Fundamental physical processes related to hydrology and soil erosion are represented within the WEPP model computer code logic.
- Continuous simulations with WEPP allow for effects of multiple interactions between climate, soils, and cropping/management systems. Long simulations also allow for return period and probability risk analyses.
- Work continues to expand WEPP applications with the USDA-FS, NRCS, and others.

The End



Questions?