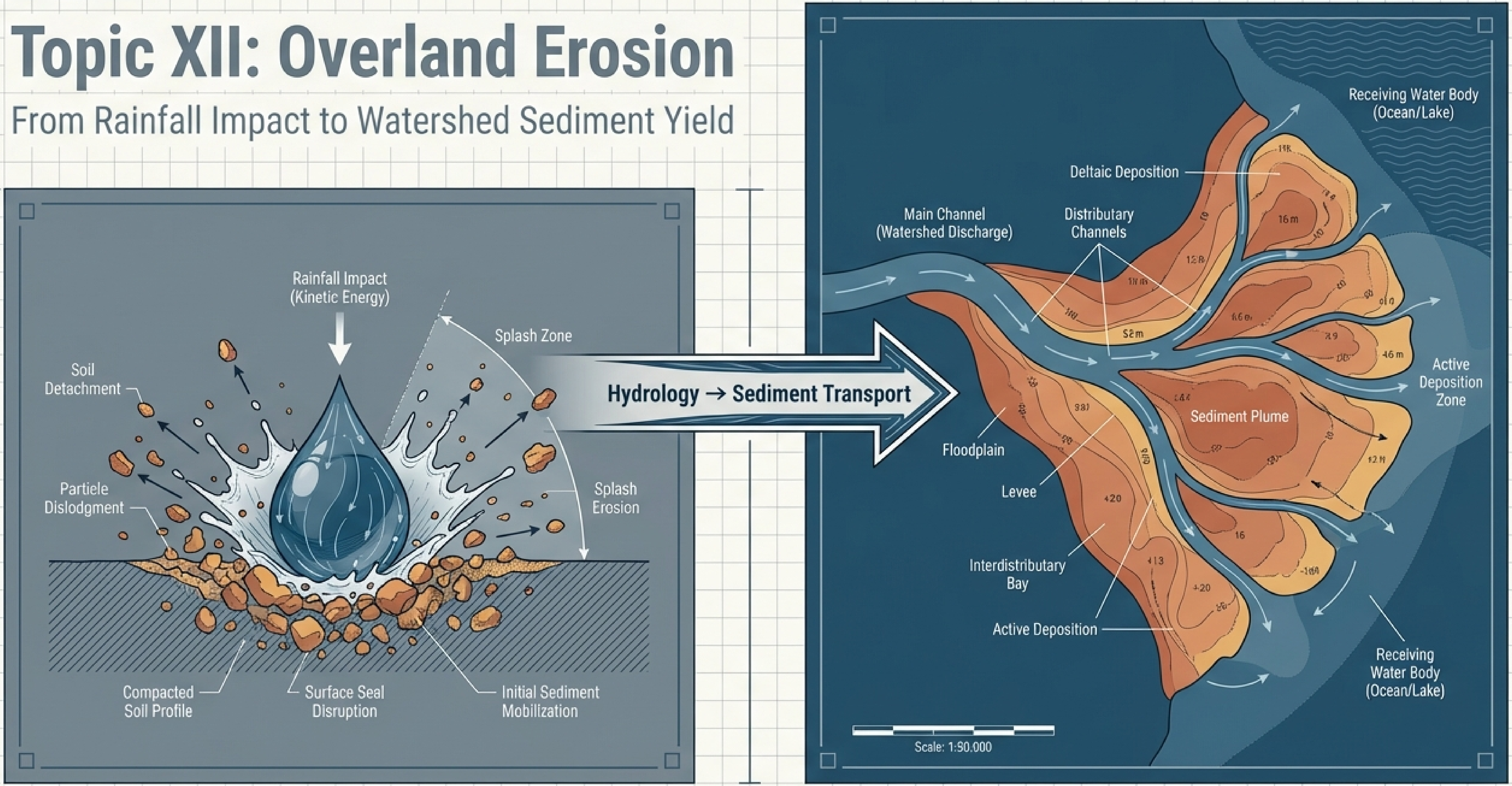
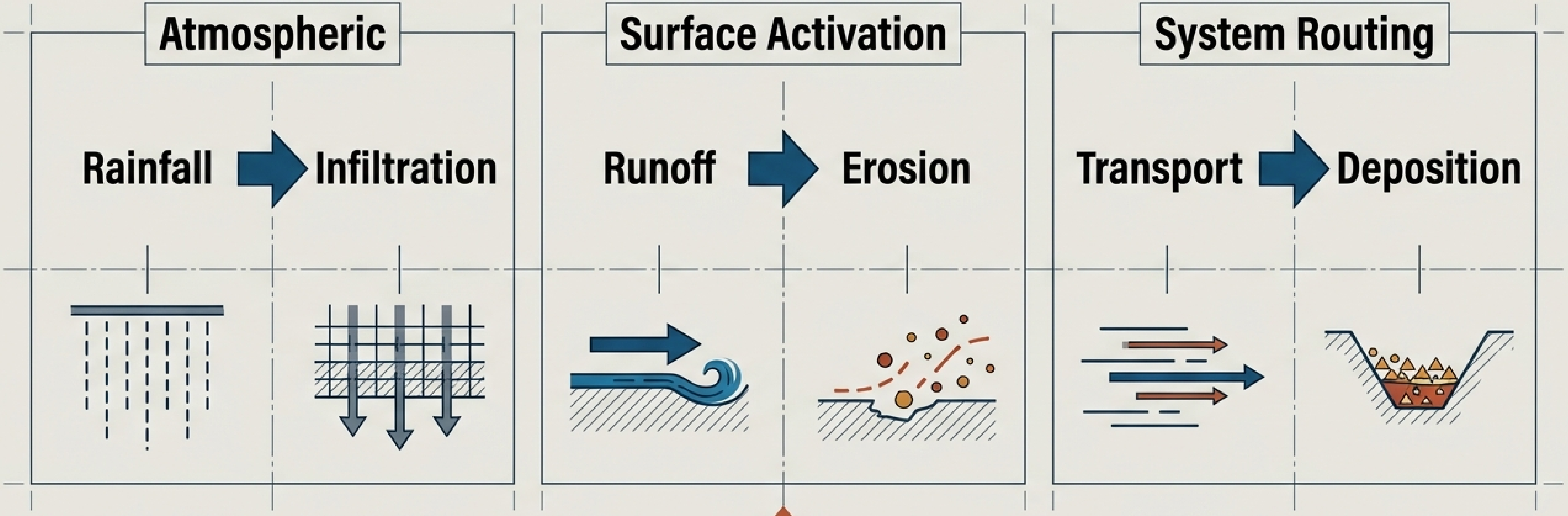
Topic XII: Overland Erosion

From Rainfall Impact to Watershed Sediment Yield



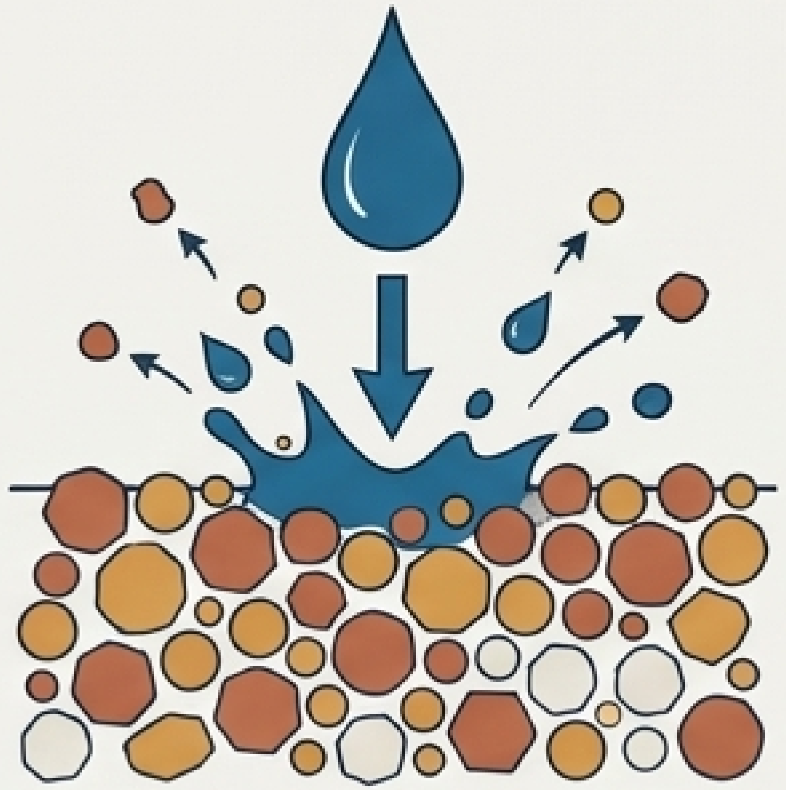
The Physical Continuum of Overland Flow



Key Insight: Erosion completes the hydrologic system. Once infiltration capacity is exceeded, water transitions from a solvent to a **mechanical transport mechanism**.

Morphologies of Overland Erosion: A Progression of Energy

Splash Erosion

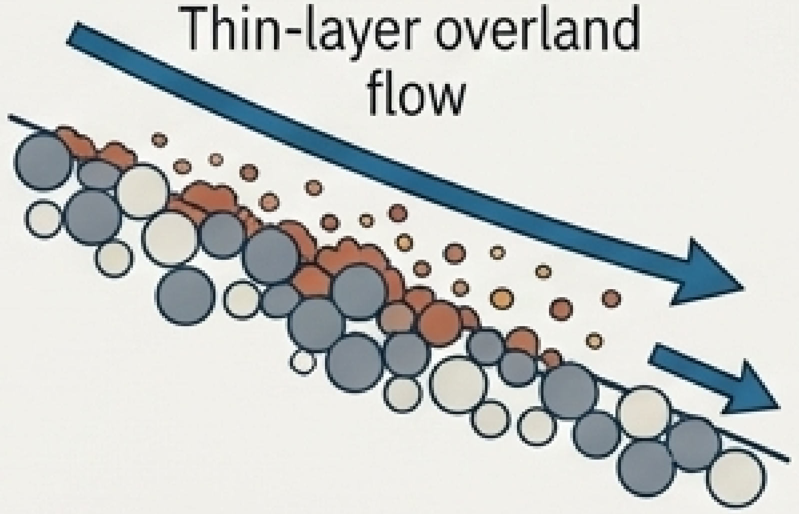


Raindrop impact detaches particles.

Condition: Kinetic Energy > Cohesion + Adhesion.

Dependent on intensity and soil type.

Sheet Erosion

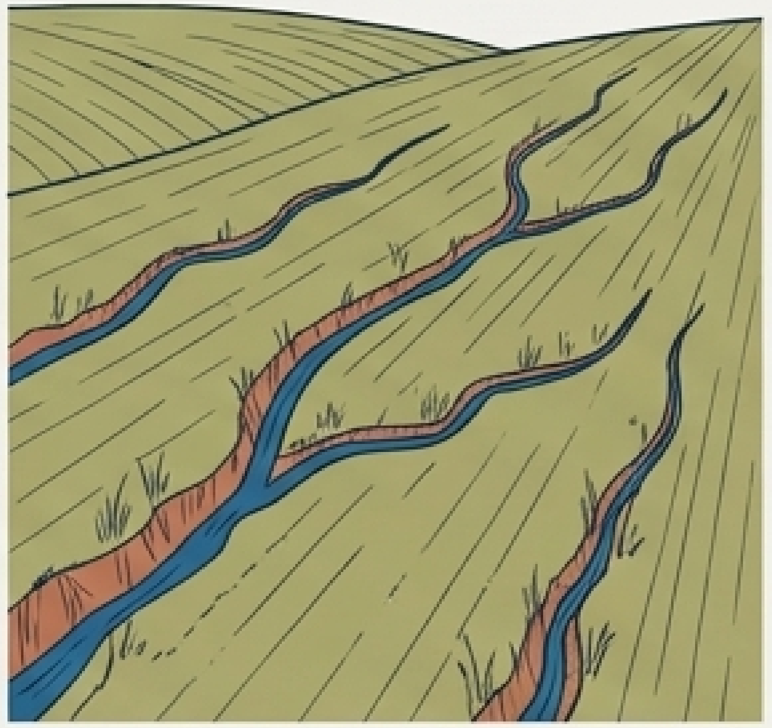


Thin-layer overland flow selectively removes fine grains.

Detachment → Transport transition.

Coarse particles remain, forming an armor layer.

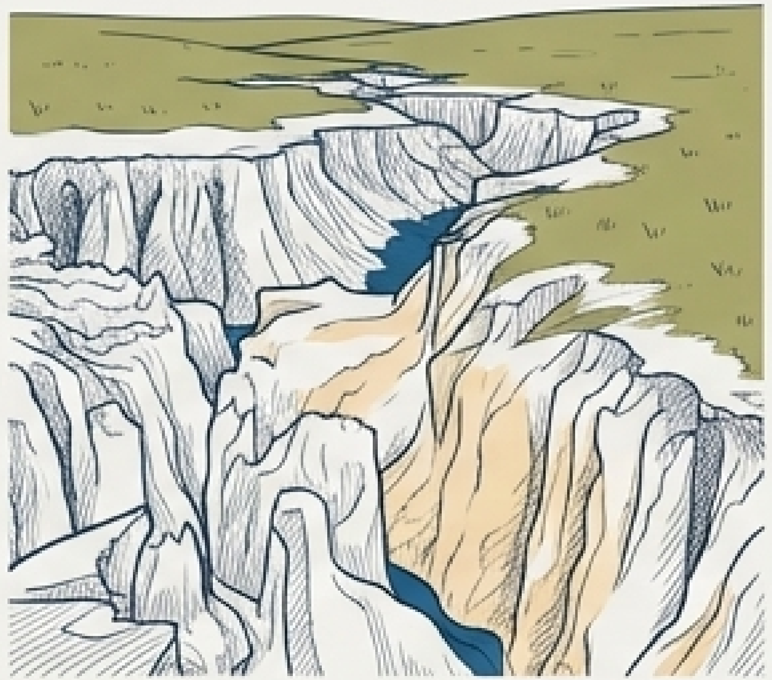
Rill Erosion



Concentrated, fast-moving runoff cuts small, well-defined channels.

Temporary, early-stage (correctable by tillage).

Gully Erosion



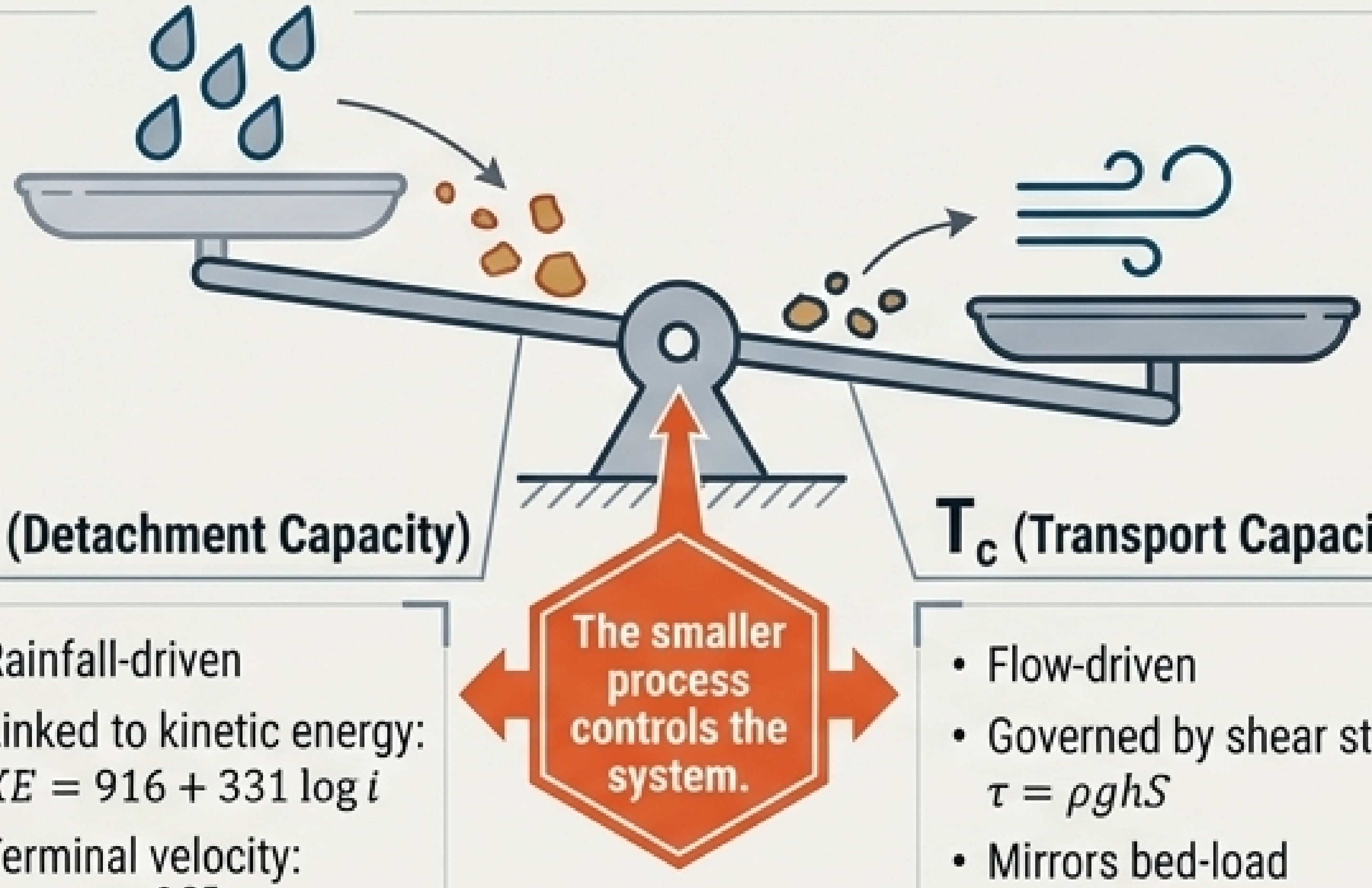
Severe degradation.

Channels exceed 300mm depth.

Destroys structural integrity and lowers water quality.

The Governing Framework: Detachment vs. Transport Capacity

$$E = \min(D_c, T_c)$$

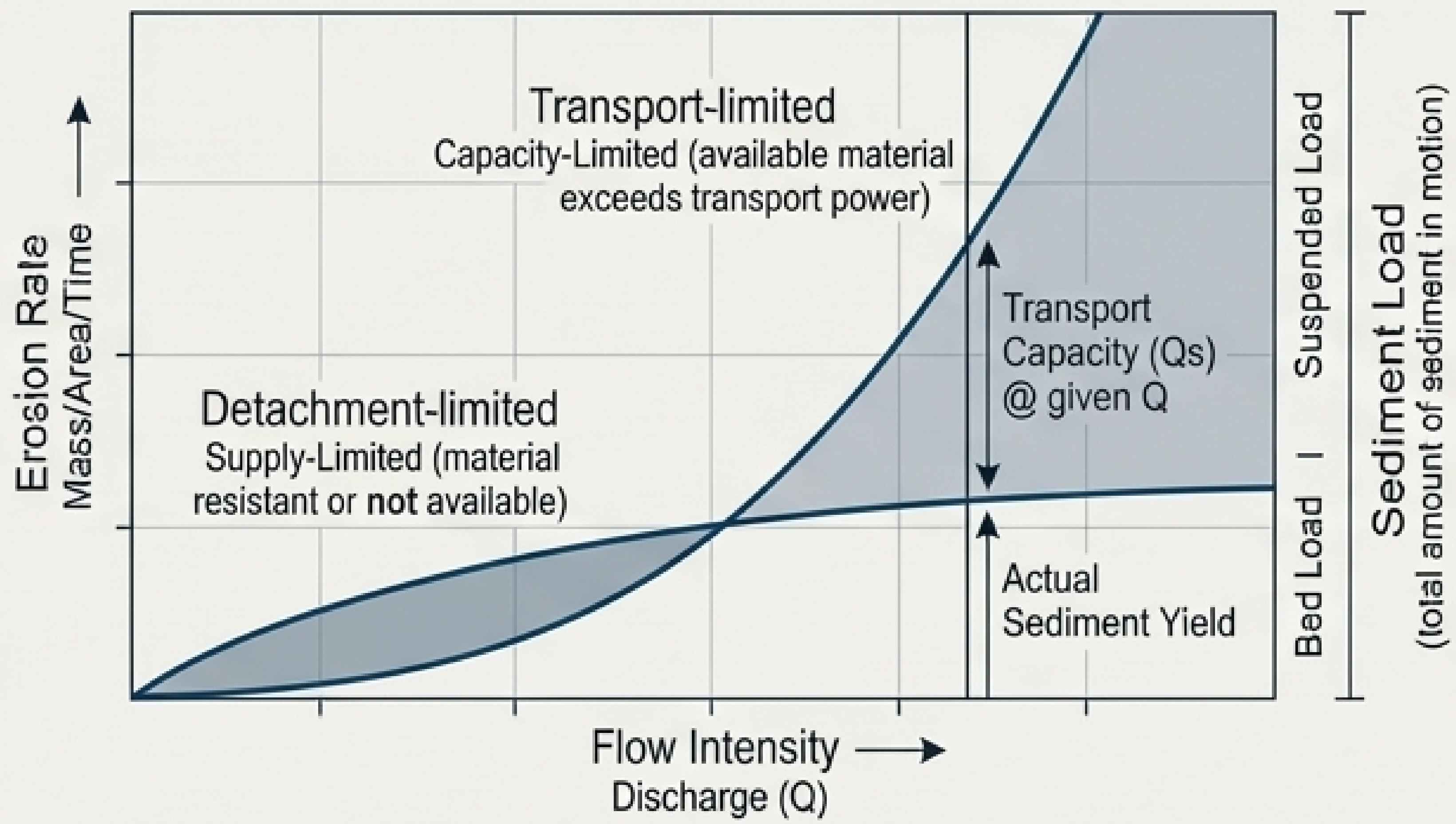


D_c (Detachment Capacity)

- Rainfall-driven
- Linked to kinetic energy: $KE = 916 + 331 \log i$
- Terminal velocity: $V_t = 20d^{0.35}$

T_c (Transport Capacity)

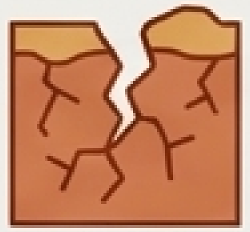
- Flow-driven
- Governed by shear stress: $\tau = \rho g h S$
- Mirrors bed-load mechanics



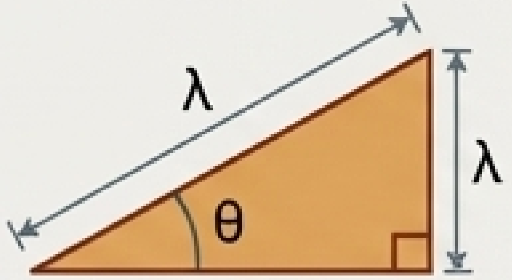
Deconstructing the Universal Soil Loss Equation (USLE)

$$E = R\ K\ L\ S\ C\ P$$

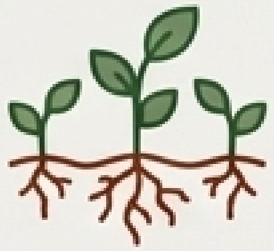
R Factor:
Rainfall Erosivity
(Intensity + Frequency)



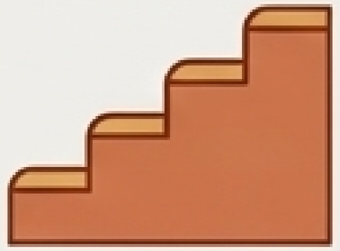
K Factor:
Soil Erodibility
(Geologic vulnerability)



LS Factor:
Topographic Factor
(Slope length λ and steepness θ)



C Factor:
Vegetation Cover
(Crop stage & residue)



P Factor:
Conservation Practice
(Contouring, terracing)

System View:
Climate × Soil × Topography × Land Use × Management

System Warning ⚠

MODEL LIMITATIONS
- Empirical baseline.
- Plot-scale only.
- No deposition modeling.

Unpacking USLE Variables in Practice

R Factor: Geographic Mapping

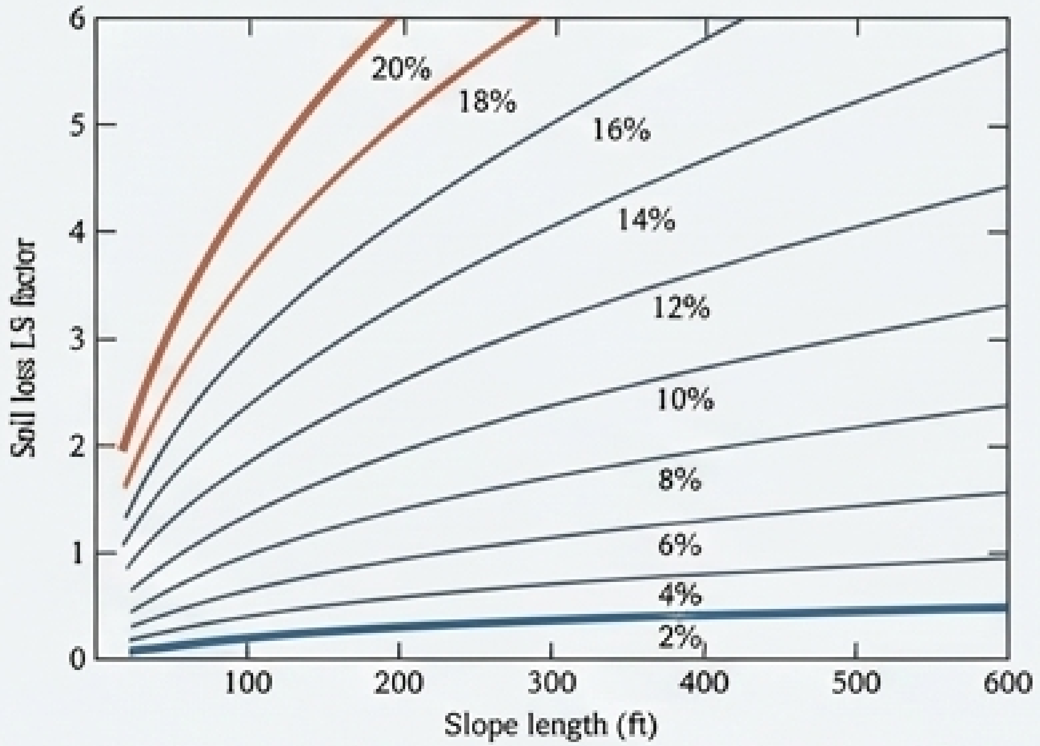
Iso-erodent maps provide baseline rainfall intensity and frequency data.

K Factor: Geological Referencing

	Soil	Location	K factor
1	Dunkirk silt loam	Geneva, NY	0.69
2	Fayette silt loam	LaCrosse, WI	0.38
3	Albia gravelly loam	Beemerville, NJ	0.03

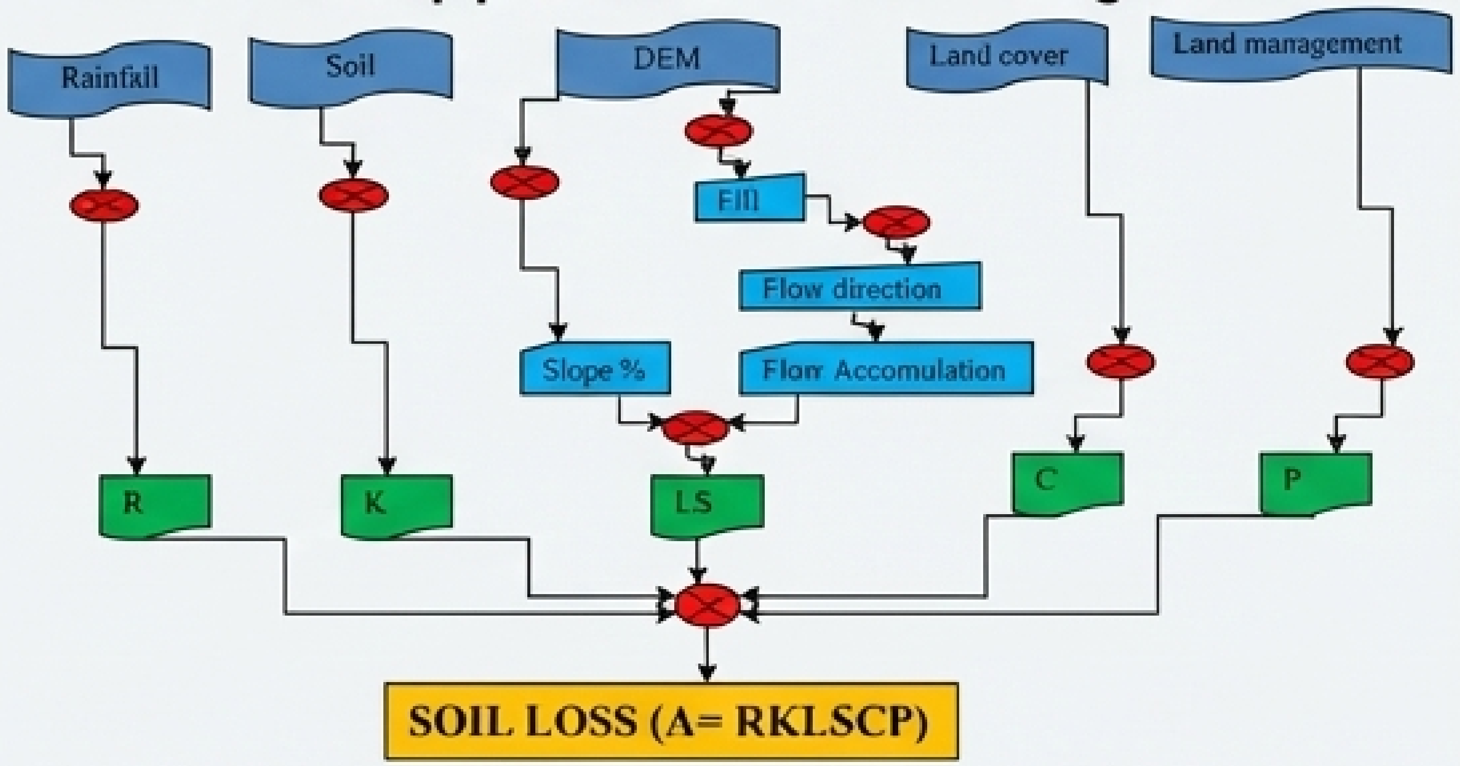
Standardized tables define relative erodibility.

LS Factor: Topographic Curves



Empirical curves convert length and steepness into a scaling factor.

Modern Application: GIS Integration



Modern workflows compute factors automatically via spatial data overlays.

Evolutionary Modeling: Beyond the USLE Baseline

Dimension	USLE Baseline	WEPP / RUSLE2
Approach	Empirical observation	Process-based deterministic model
Simulation Dynamics	Annual Average only	Continuous event dynamics & 100-year statistical analysis
Spatial Scope	Plot-scale, land-use independent	Distributed parameter (climate, hydrology, plant growth sub-models)
Sediment Routing	No deposition calculated	Calculates total sediment delivery to the end of the slope

Modern tools simulate the full mechanistic sequence: rainfall → infiltration → runoff → shear → detachment → transport.

The Watershed Scale: Gross Erosion vs. Sediment Yield

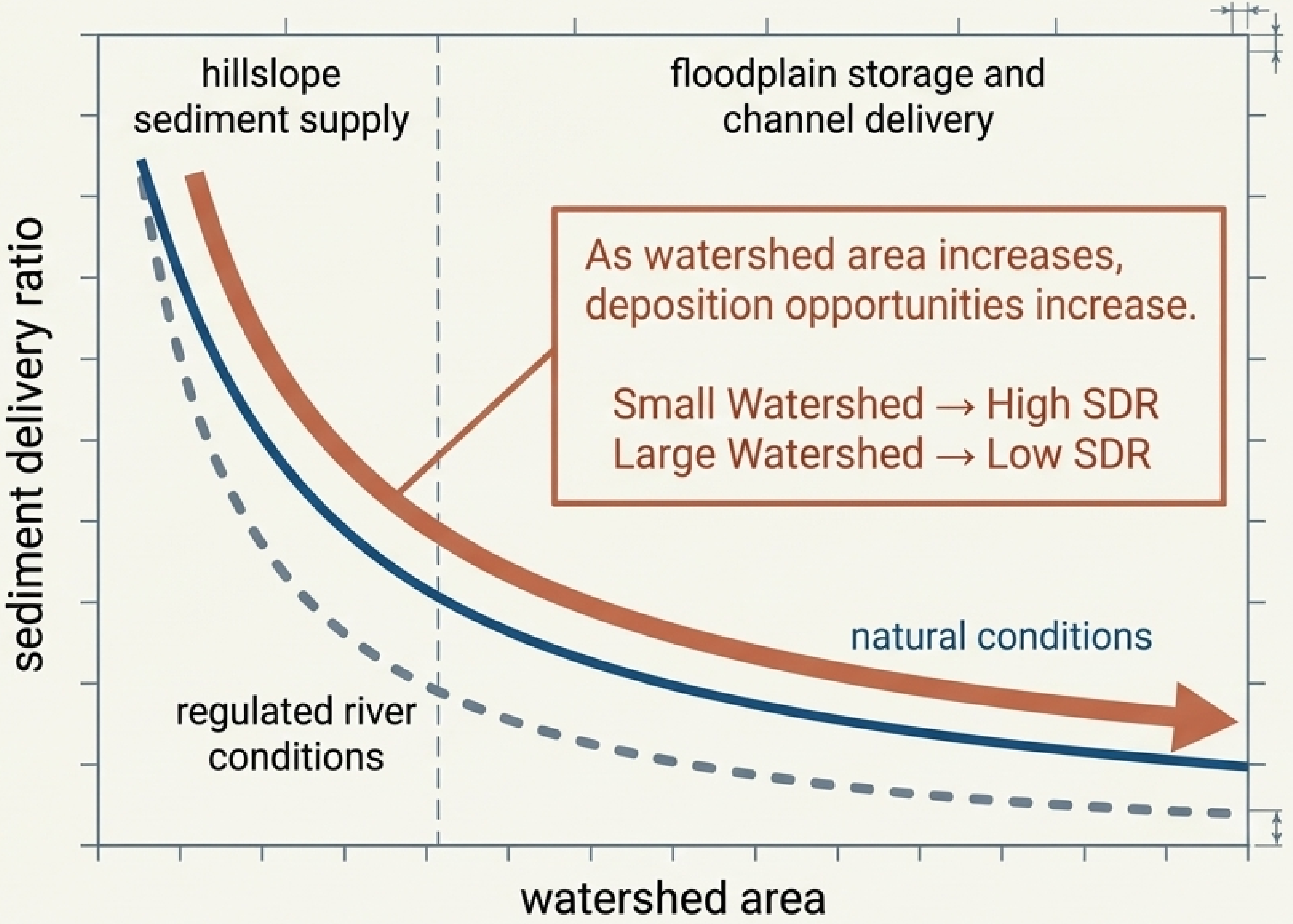
Gross Erosion

Total soil detached and moved from watershed surfaces.

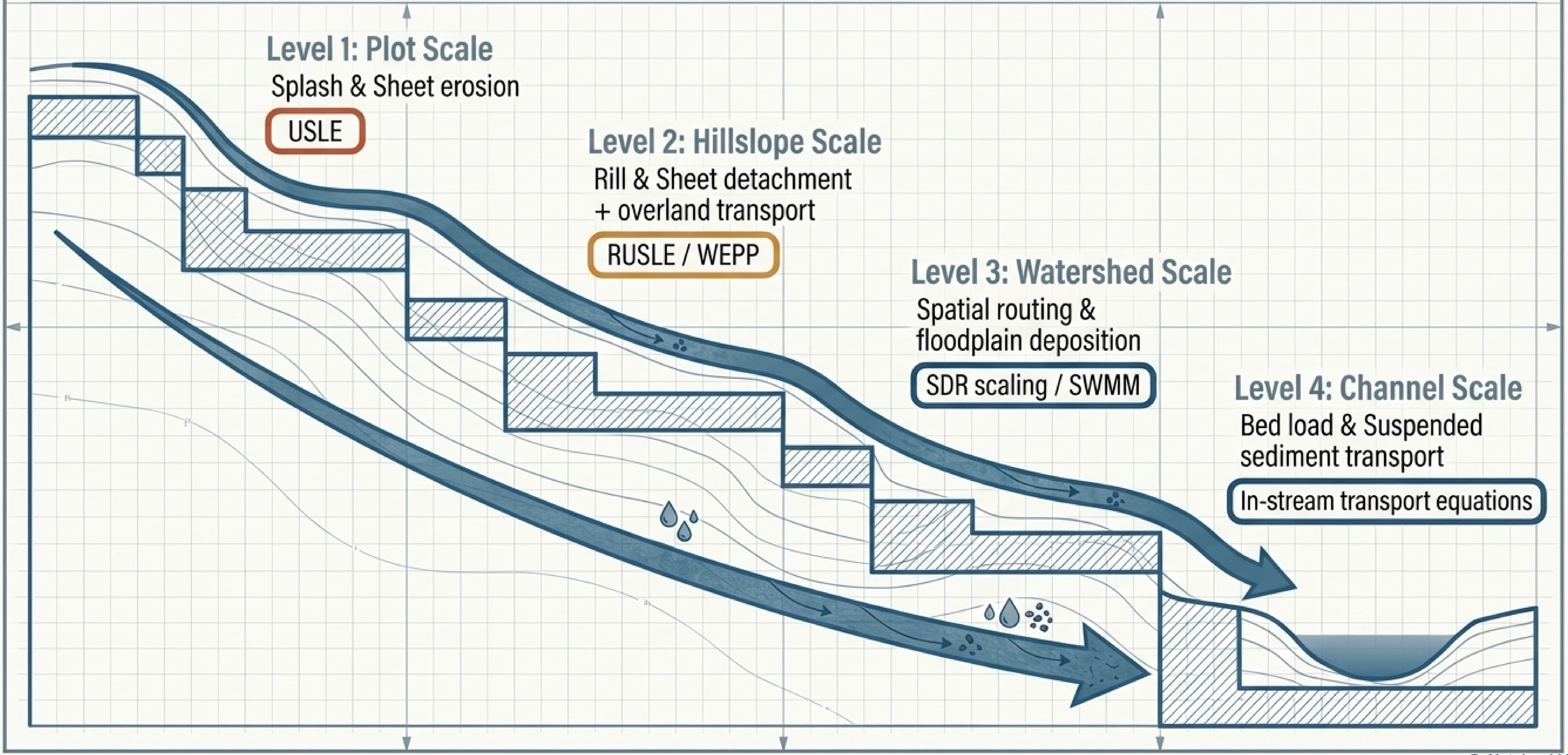
Sediment Yield

The specific portion of eroded material that survives the journey to a downstream control point (e.g., a reservoir).

$$\text{SDR} = \frac{\text{Sediment Yield}}{\text{Gross Erosion}}$$



Synthesis: Scale-Dominant Processes & Tooling



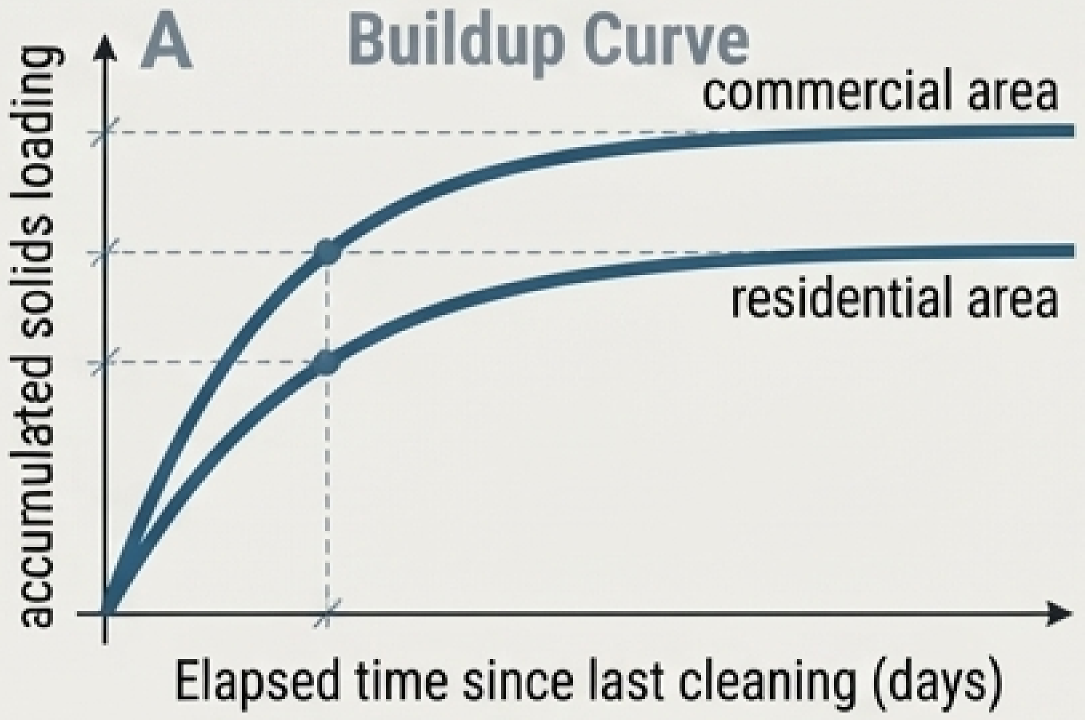
Urban Erosion Dynamics & Temporal Washoff

Construction Site Vulnerability (Surface Condition Impacts)

Surface Condition With no Cover	Factor P
Compact, smooth, scraped with bulldozer up/down hill	1.30
Loose, as in a disked plow layer	1.00
Rough irregular surface, equipment tracks in all directions	0.90

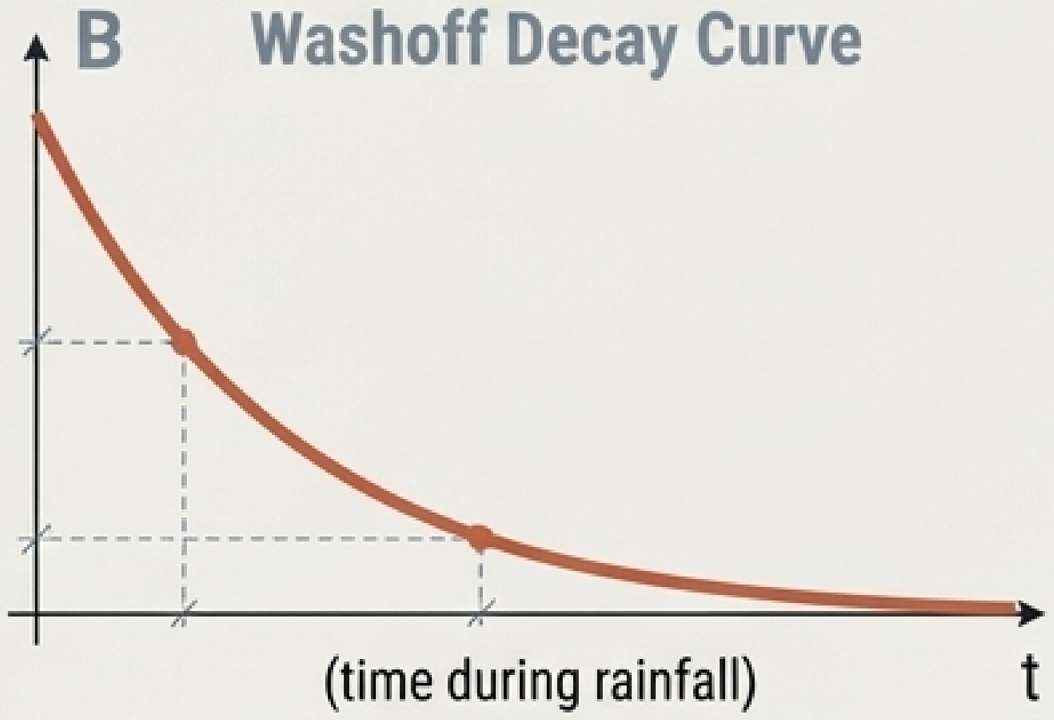
Insight: Smooth compacted soil yields exponentially higher erosion than rough surfaces.

Temporal Dynamics: Pollutant Buildup & Washoff



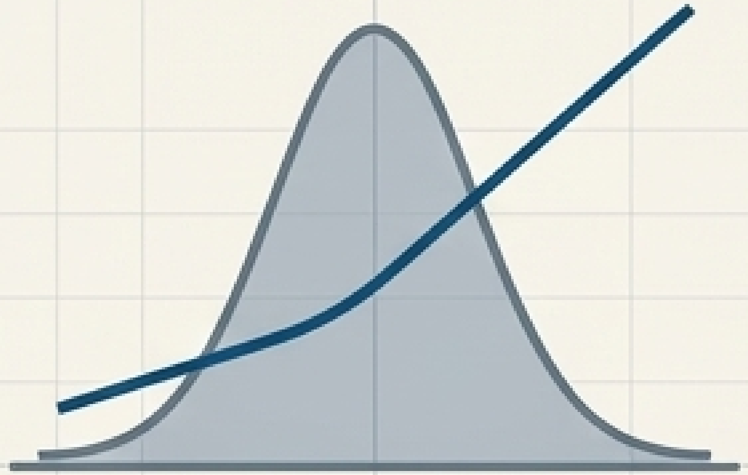
$$\text{Washoff} \propto q_m \cdot B$$

(Event-based modeling, directly contrasting USLE's annual average)



System Toolkit: Yield Estimation Methods

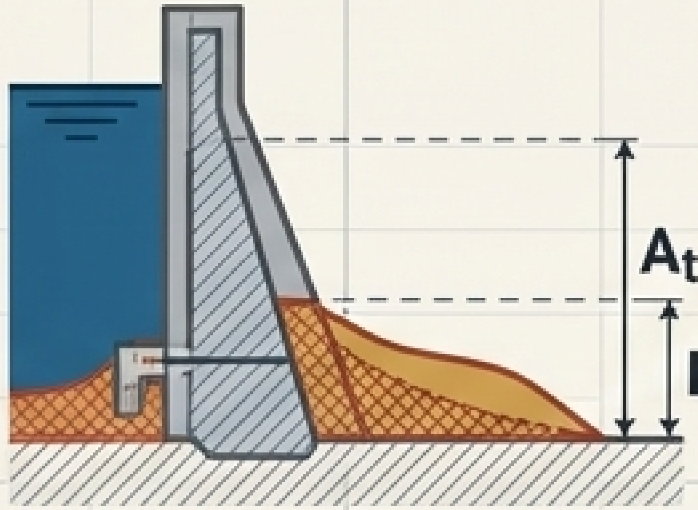
Rating Curve Method



$$Y = \int_Q Q_s \, f(Q) \, dQ$$

Combines discharge probability distributions with sediment rating curves. A robust, event-based statistical approach.

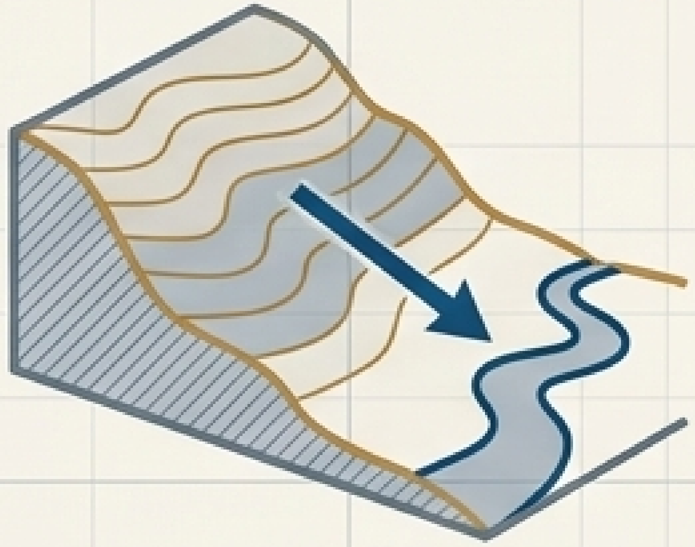
Reservoir Method



$$Y = \frac{A_t}{E_f}$$

Back-calculates historical yield based on accumulated sediment volume (A_t) divided by the trap efficiency (E_f) of the reservoir.

USLE + SDR Method



$$Y = E \cdot SDR$$

Multiplies gross hillslope erosion by the watershed's delivery ratio. The foundational predictive modeling method.

Applied Engineering Pipeline: Upland Farm to Reservoir (Part 1)

INPUT PARAMETERS: Central Illinois Farm

Area = 800 acres | Slope = 4% | Soil = Ida silt loam | Cover = Matured grass

↓

STEP 1: Calculate Plot-Scale Erosion

200 (R) × 0.33 (K) × 0.697 (LS) × 0.004 (C) × 0.5 (P) = 0.092 tons/acre/yr

↓

STEP 2: Scale to Entire Field

0.092 tons/acre/yr × 800 acres = 73.6 tons/yr

↓

STEP 3: Route via Sediment Delivery Ratio (SDR)

73.6 tons/yr × 0.417 (SDR) = 30.7 tons/yr Yield entering reservoir

Applied Engineering Pipeline: Accumulation & Volume (Part 2)

STEP 4: Calculate 10-Year Trapped Mass

Apply Trap Efficiency (Ef = 84%) to the 10-year yield (307 tons).

Result: 258 tons trapped.

STEP 5: Convert Mass to Engineering Volume

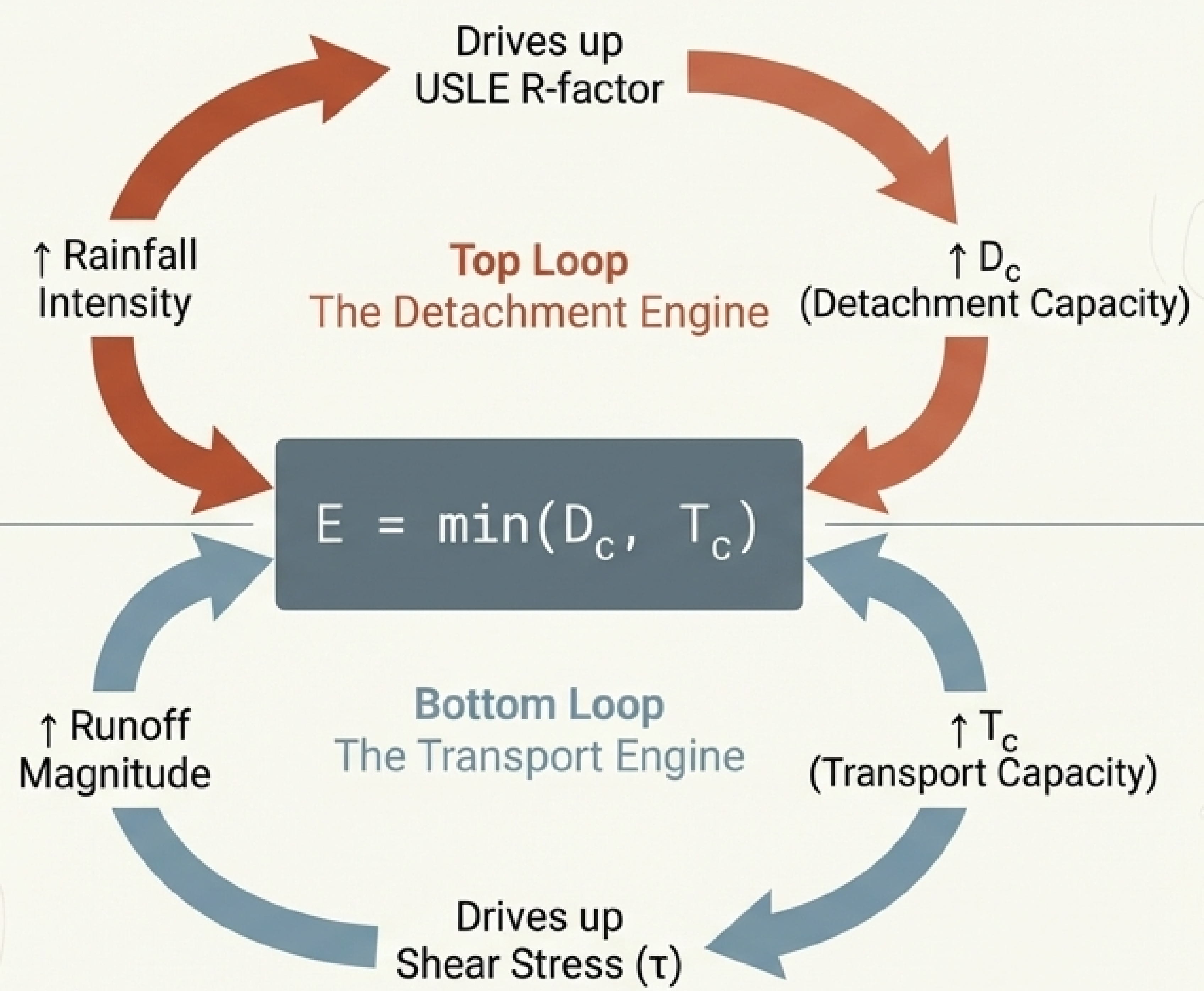
Convert 258 tons to metric (233,930 kg).

Divide by bulk density of deposited sediment (1400 kg/m^3).

FINAL VOLUME CONSTRAINT:
167 m^3 of lost reservoir capacity over 10 years.

SENSITIVITY ANALYSIS:
Most sensitive parameters governing this result are Vegetation Cover (C), Conservation Practice (P), and Watershed Routing (SDR).

The Climate Change Multiplier

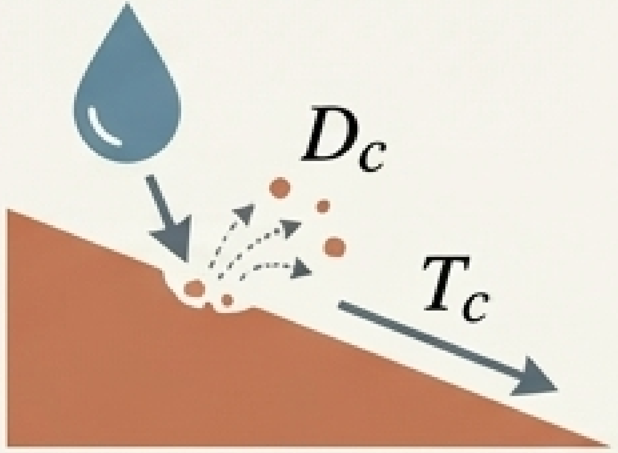


Because climate change simultaneously increases both atmospheric detachment power and hydrological transport capacity, total erosion potential scales exponentially, requiring updated design storms and drastically expanded reservoir storage.

The Overland Erosion Blueprint: System Synthesis

1. The Physics

Erosion is an ongoing bottleneck between Detachment (Dc) and Transport (Tc).



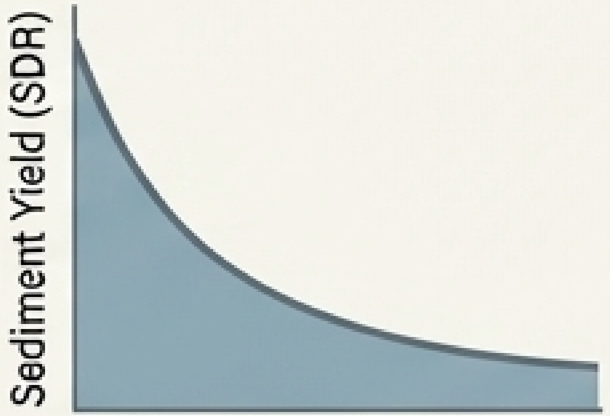
2. The Baseline Model

USLE provides the empirical calculation for plot-scale agricultural loss, relying heavily on soil (K) and cover (C) parameters.

$$E = \underline{R \times K \times LS \times C \times P}$$

3. The Macro Routing

The Sediment Delivery Ratio (SDR) bridges the gap between field erosion and actual watershed yield.



4. The Future Constraints

Urban impervious buildup and intensifying climate patterns mandate a shift toward continuous, process-based modeling (WEPP/SWMM).

Overland Erosion: The definitive link between global hydrology and fluvial sediment transport.