# Rainfall-Runoff Modeling in Arid Regions:

# Past, Present, and Future of Precipitation Loss Estimates

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# Outline

- **Introduction**
- **“Past”: Curve Numbers and Green-Ampt**
- **“Present”:  DRI’s “Bunkerville” method**
- **“Future”:  Research needs**
- **Summary**

# Introduction

- **Rainfall-runoff modeling typically used in arid regions because precipitation and discharge data are sparse**
- **Precipitation loss estimates**
  - **Curve Numbers and Green-Ampt methods used by regional flood control districts**

# SCS Curve Number Method

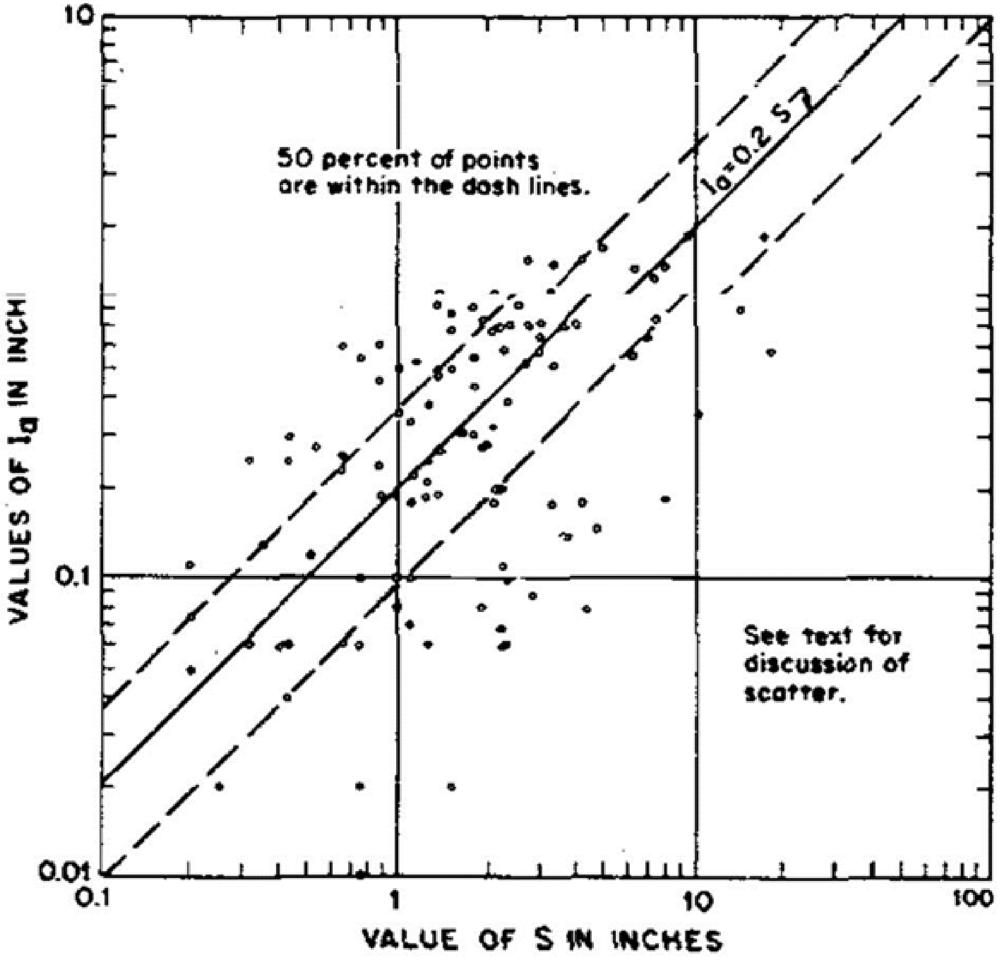
- **Commonly used to estimate precipitation losses (Mockus, 1964)**
  - **Relates soil group, vegetative cover, land use, and AMC to CN**
  - **Not a direct measure of Initial abstraction (Ia) or infiltration loss**

$$Q = \left\{ \frac{(P - Ia)^2}{[(P - Ia) + S]} \right\} \qquad S = \frac{Ia}{0.2} \qquad CN = \frac{1000}{(S + 10)}$$

- ***Q*** **is runoff volume;** ***P*** **is precipitation volume;** ***Ia*** **is initial abstraction;** ***S*** **is the “potential maximum retention” of precipitation in the soil after runoff has begun; and** ***CN*** **is the curve number**

# SCS Curve Number Method: *Issues*

- **Derived from <10 acre watersheds in mid-western and southeastern US**
- **Initially assumed for 24 hour storms, but commonly used for all durations**
- **Hjelmfeldt (1991) showed method not satisfactory in semi-arid southwestern US**
- **Relational data between S and Ia is missing; 20% assumption is problematic**



50 percent of points are within the dash lines.

See text for discussion of scatter.

# Green-Ampt Model (1911)

- Physically-based infiltration approach
    - Complex process being simulated by a simplified procedure
- Requires several soil hydraulic parameters, such as:
        - Saturated hydraulic conductivity (*Ks*) [or *Ke*]
        - Soil capillary pressure at wetting front (*S*)
        - Soil moisture deficit
- Difficult to measure soil hydraulic parameters on a watershed-scale
- Some revisions, including using a general pedotransfer function to estimate parameters

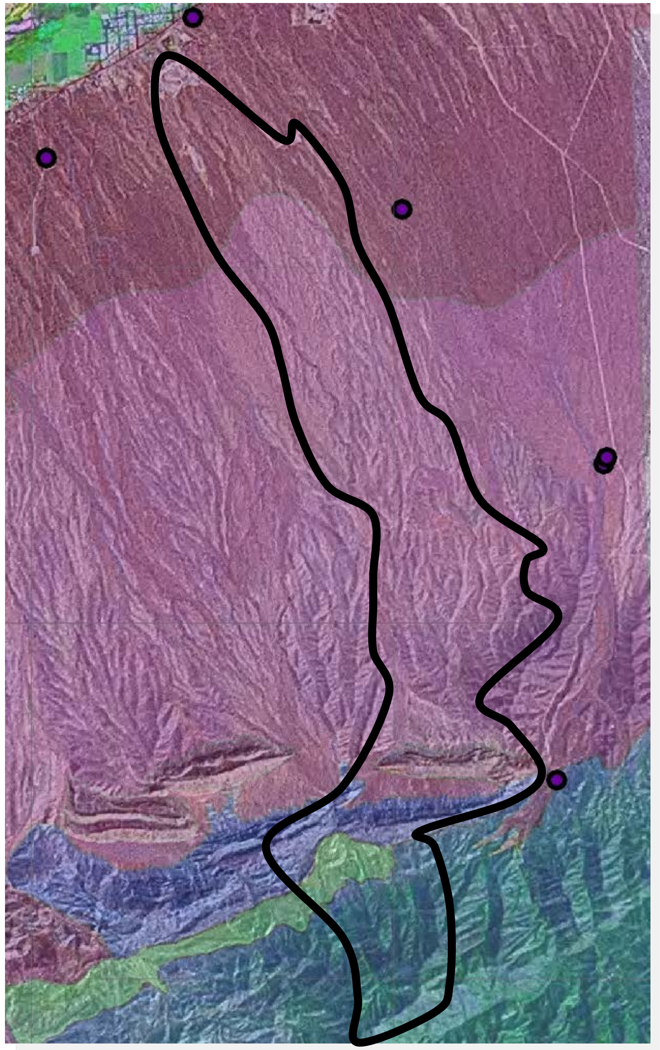
# DRI’s “Bunkerville” Approach

- Rapidly characterize hydraulic properties of desert soils at watershed scales
  - Clark County (Las Vegas), NV (including Bunkerville)
  - Mojave National Preserve, CA
  - Maricopa County (Phoenix), AZ
- Three-step process:
  - Geomorphic mapping and rapid terrain forecasting
  - Field experiments
  - Estimation of soil hydraulic properties

# DRI’s “Bunkerville” Approach

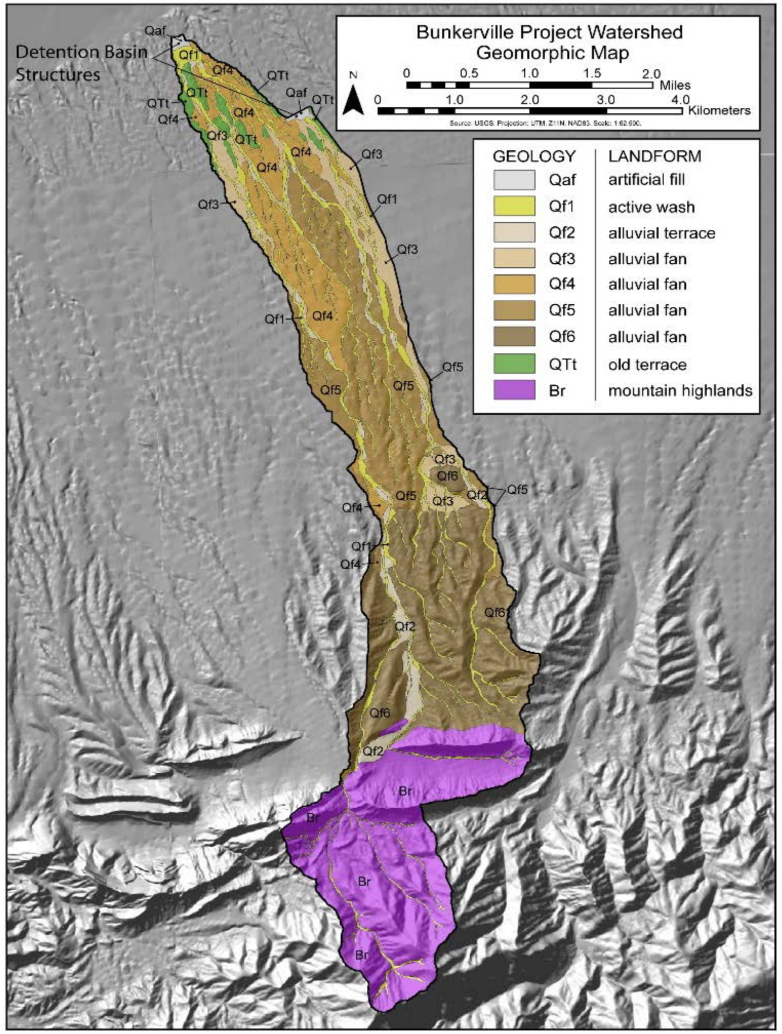
- **Can be used to develop either CNs or G-A model parameters**
- **Major advantages are the efficiency, ease of application, and predictive capabilities of soil properties from field measurements**
- **Better represents the spatial distribution of soil hydraulic properties as it fully considers the correlation between soils and geomorphic surface context**

# SSURGO (NRCS) Soils Map *vs.* Geomorphic Map



**SSURGO soils map**

**(2 alluvial units)**



**Geomorphic map**

**(7 natural alluvial units)**

# Field Measurements

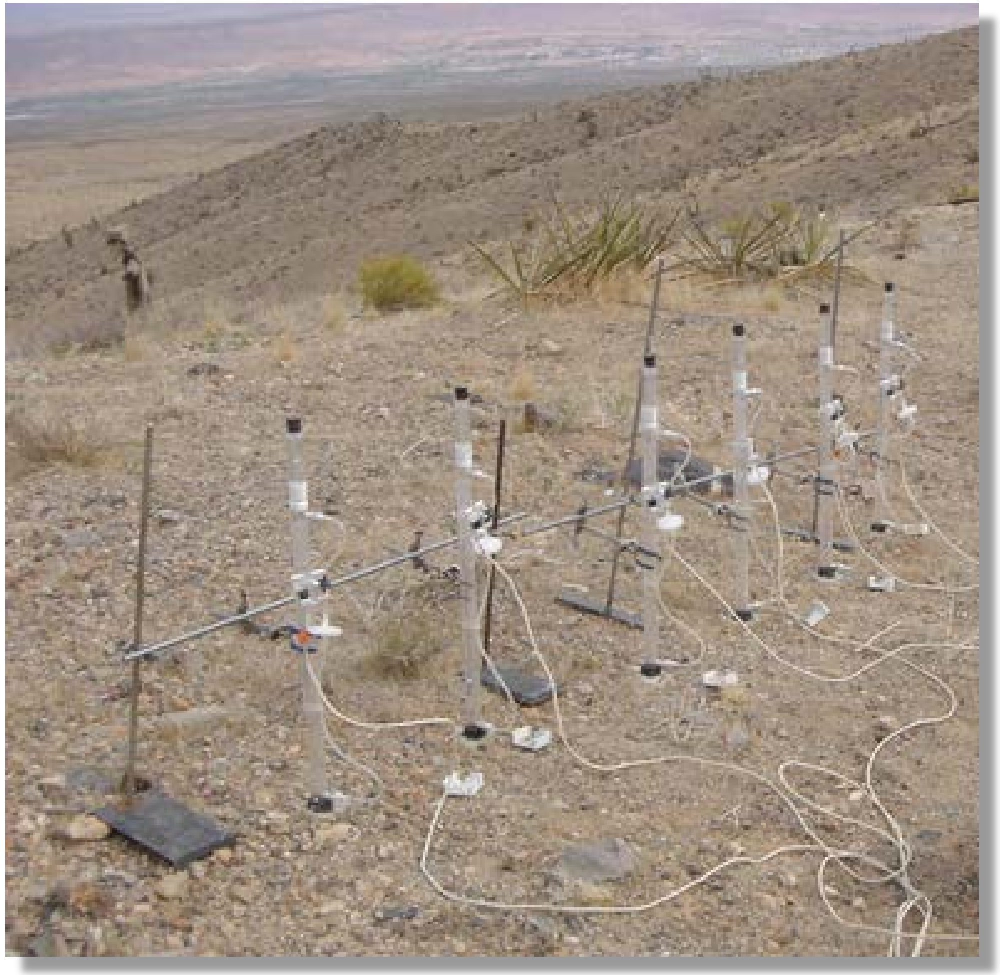
- **Rainfall simulation (RFS)**
  - **Known precipitation volume (P); measured runoff volume (Q); calculated initial abstraction (*Ia)***

$$Q = \left\{ \frac{(P - Ia)^2}{[(P - Ia) + S]} \right\}$$

  - **Soil moisture is continuously measured using TDR probe**

# Field Measurements

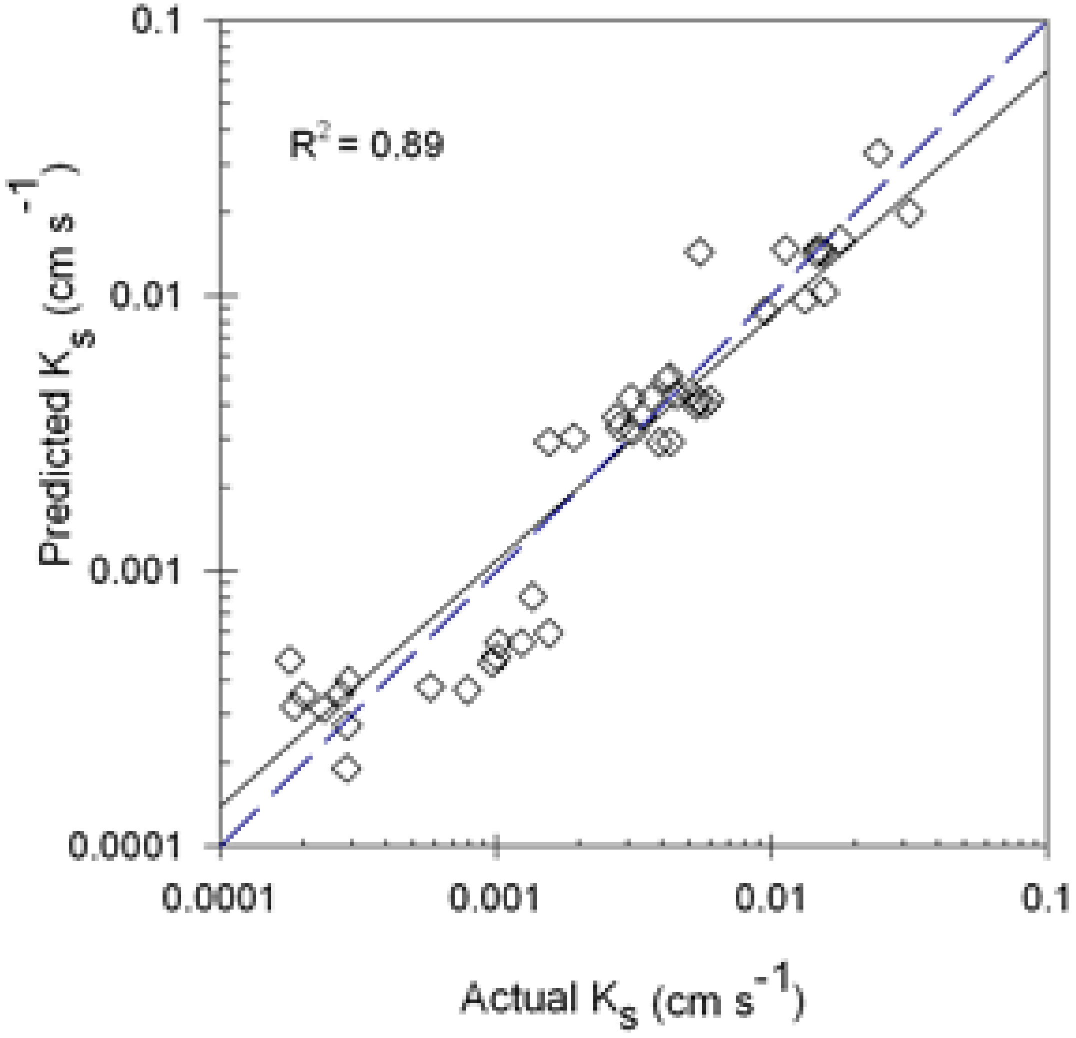
- **Mini-Disc Tension Infiltrometers (MDTI)**
  - **Measure soil hydraulic properties**
  - **3 tensions are used, ending at near-saturation**
  - **Cumulative outflow is recorded on datalogger**
  - **Saturated hydraulic conductivity (*Ks*) estimated**
  - **Soil core is removed for laboratory analysis of final water content, bulk density, and PSD**
- **Strong correlation between soil physical and hydraulic properties**



# Field Measurements

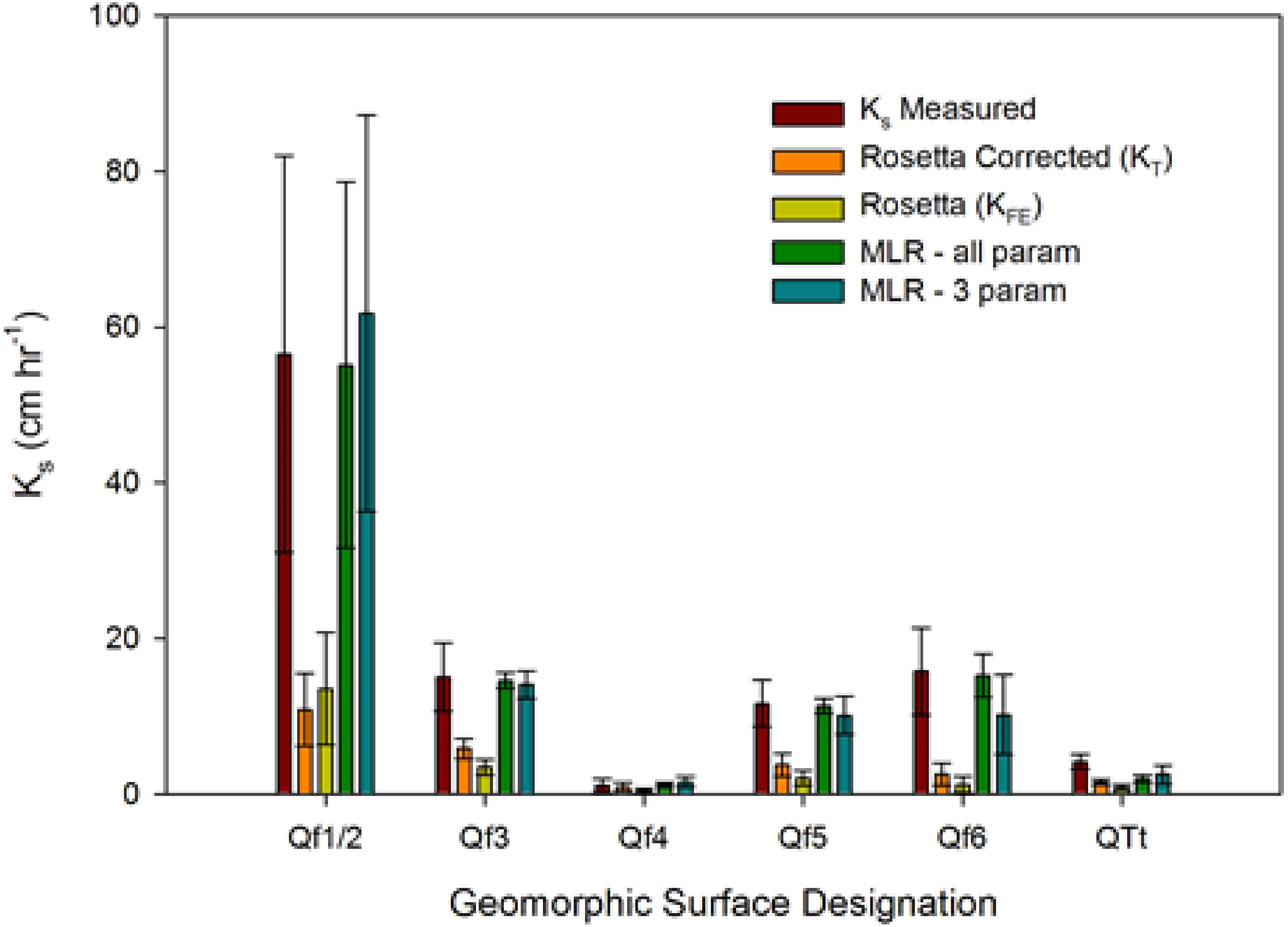
- **Soil sampling**
  - **Soil cores taken from both RFS and TI test locations**
    - **Pre- and post-testing soil water contents**
    - **Bulk density**
    - **Particle size distributions**
  - **Soil structure**

# Multiple Linear Regression PTF



**$K_s$ = 0.190 - (0.00155 * Structure) + (0.00482 * BD) - (0.00215 * %Gravel) – (0.00168 * %Sand) - (0.00234 * %Silt) - (0.00216 * %Clay) + (0.00000721 * MPD) + (0.000799 *$\sigma$)**

# PTF Results

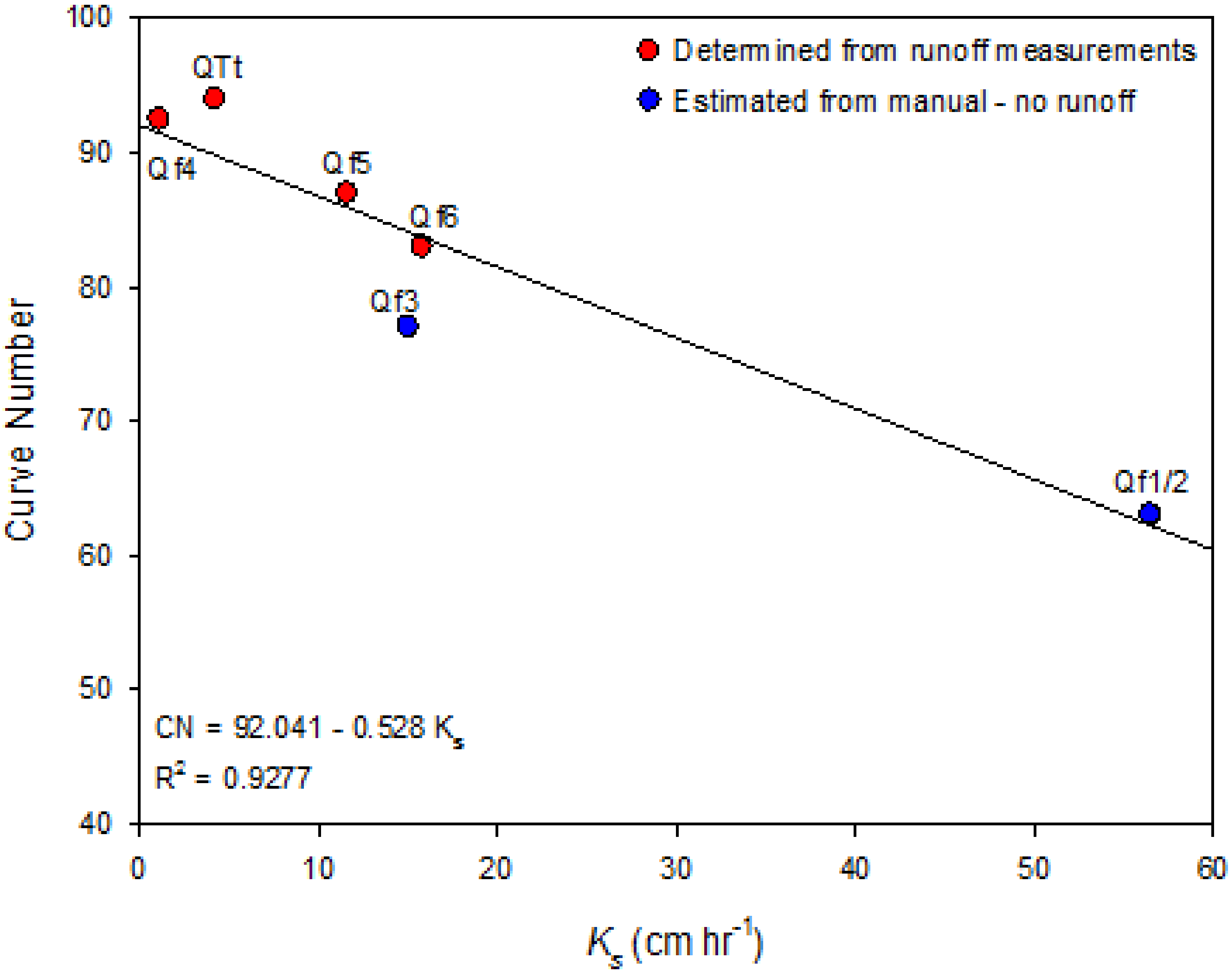


**Measured and predicted values of *$K_s$* derived from the fine-earth gravel corrected Rosetta PTF, the total soil bulk density Rosetta PFT, and the multiple linear regression (MLR) for all measured parameters and a three-parameter subset.**

# Using PTFs to develop CNs or G-A Model

- **PTFs can be used to develop either CNs or G-A model parameters**
- **To develop CNs, a regression equation is used to develop the inverse relation between CN and Ks (*i.e.*, runoff and infiltration)**
- **To develop G-A parameters, an optimization technique is used**

# CN *vs.* Ks Results



**Relationship between the average $K_s$ and CN values for each geomorphic surface**

**(confirms parameters are inversely related)**

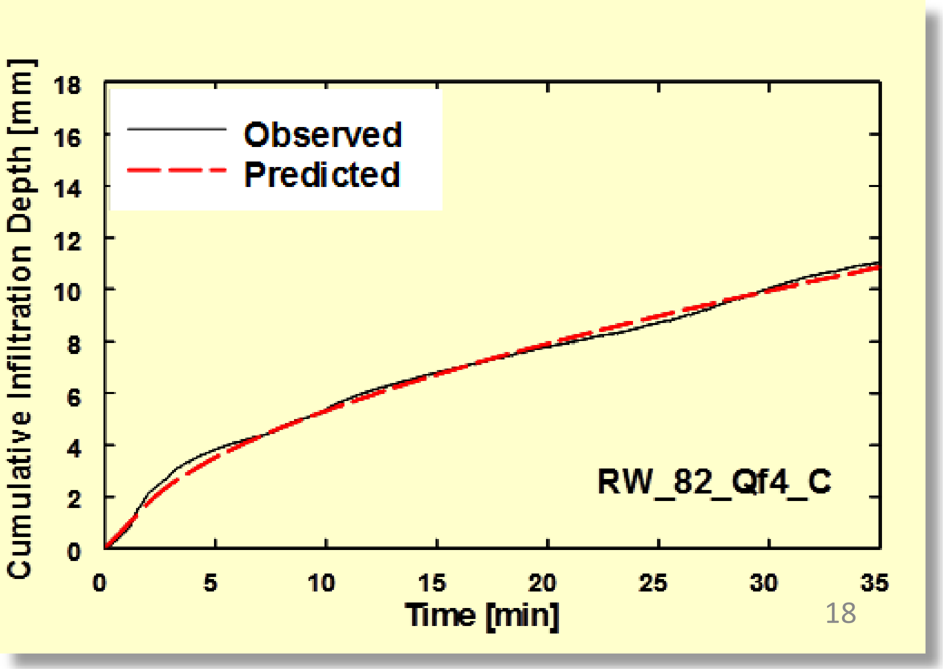
# Estimated CNs from PTF

| Unit | N | $CN_{PTF}$ | $CN_{Measured}$ | $CN_{Default}$ |
|---|---|---|---|---|
| Qf1/2 | 13 | 73.7 ± 10.5 | -- | 63 |
| Qf3 | 11 | 86.7 ± 4.3 | -- | 77 |
| Qf4 | 17 | 90.1 ± 2.9 | 92.5 | |
| Qf5 | 11 | 88.9 ± 1.9 | 87 | |
| Qf6 | 16 | 89.3 ± 1.3 | 83 | |
| QTt | 11 | 91.1 ± 1.2 | 94 | |
| Total | 79 | 86.7 ± 7.6 | | |

- **The mean PTF-derived curve numbers ($CN_{PTF}$) and standard deviation of each geomorphic surface based on the three-parameter MLR and the linear regression equation.**
- **The measured ($CN_{Measured}$) and default ($CN_{Default}$) tend to be within the two standard deviations of the $CN_{PTF}$ for most surfaces.**

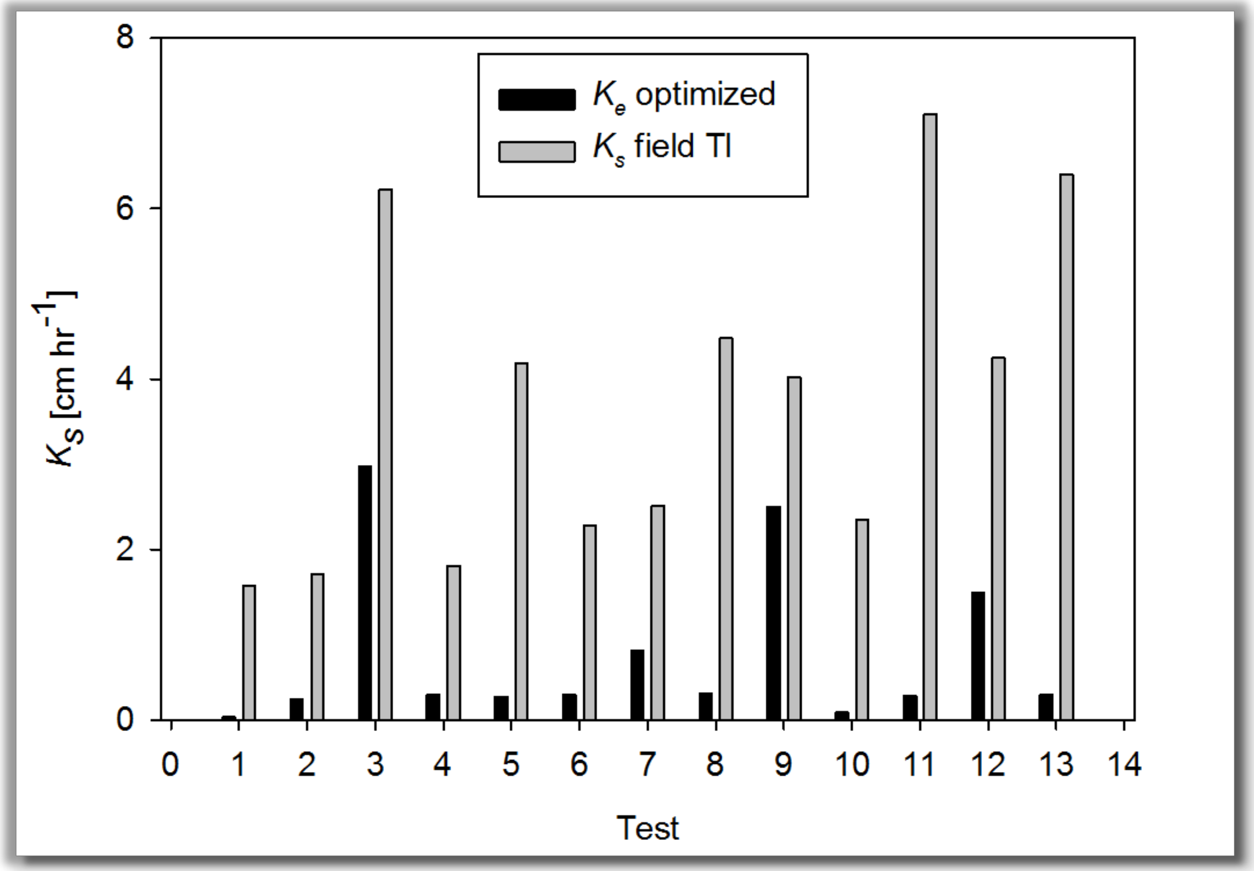
# Optimizing G-A Model Parameters

- **RFS water content converted to cumulative infiltration**
- **Optimization to derive G-A parameters of *Ke* and *S***
  - **Levenberg-Marquardt optimization approach**
- **Goal of optimization to ensure G-A model-predicted infiltration curves reflect field measured curves**



# Optimizing G-A Model Parameters

- **MDTI measured *Ks* compared to G-A model-predicted *Ke***
- **Optimized *Ke* not typically 0.5**Ks* proposed by Rawls *et al.* (1983)**



# DRI’s “Bunkerville” Approach: *Observations*

- **Rapid site characterization/scaling techniques**
- **Hydraulic properties can be expressed in several ways (CN, G-A model, etc.)**
- **Techniques have considerable flexibility and portability**
- **Site-specific data can improve the predictability of surface runoff (important for arid environments)**
- **Result for parameters more suitable for physically-based rainfall-runoff modeling study**

# Future Research Needs

- **Region-specific methods to estimate precipitation losses**
  - **Iowa cornfield hydrology differs from southwestern US semi- and arid land hydrology**

- **Curve Numbers: Ia = ???!!! · S**
- **G-A Model: If optimized *Ke* ≠ 0.5 *Ks ???!!!***

- **Efficient methods to make watershed-scale applications**

# Questions?

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