Lecture I

Hydrological modeling requirements for Water Resources Applications - Model Calibration and parameter Estimation Issues

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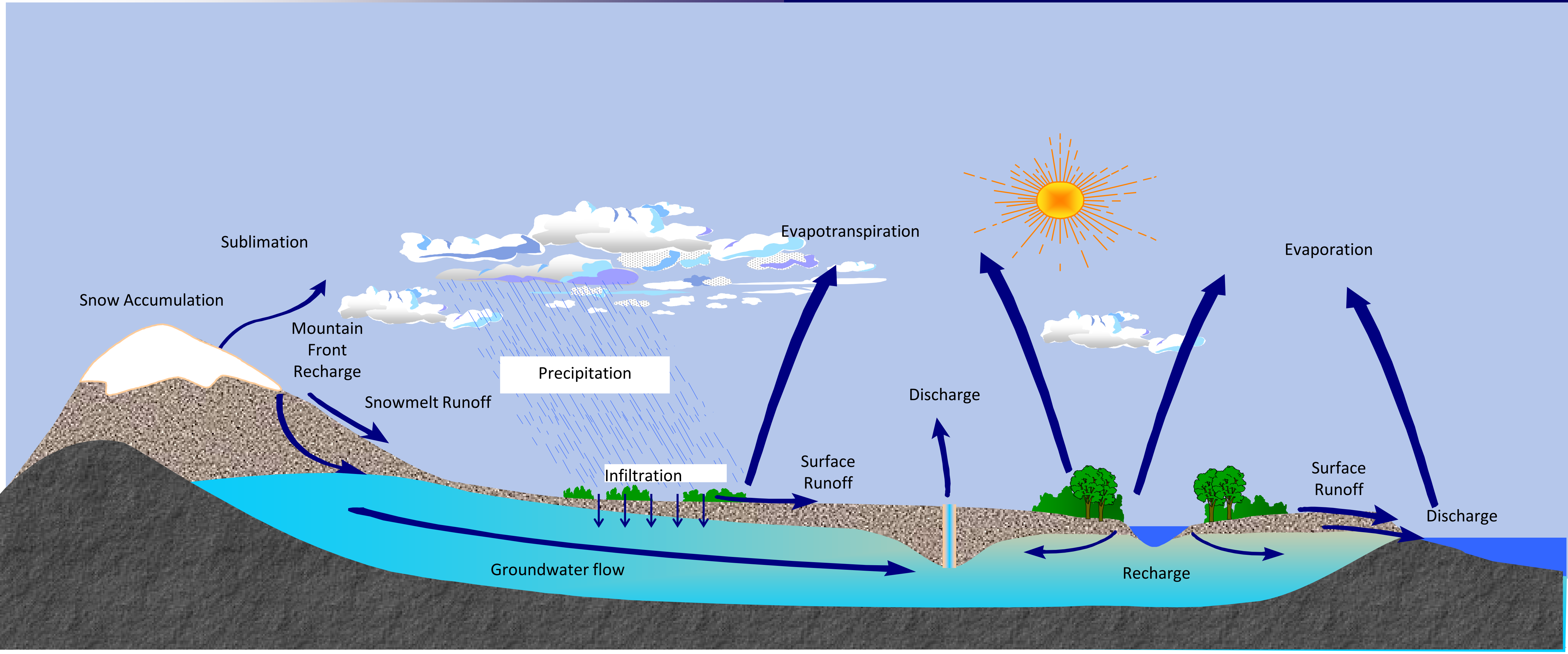
ICTP 6th Workshop on: Water Resources in Developing Countries: Hydroclimate Modeling and Analysis Tools

Trieste, Italy: May 20th – 31st 2024

University of California Irvine (UCI)

A View of The Earth

Studying the Hydrologic Cycle at Various Scales

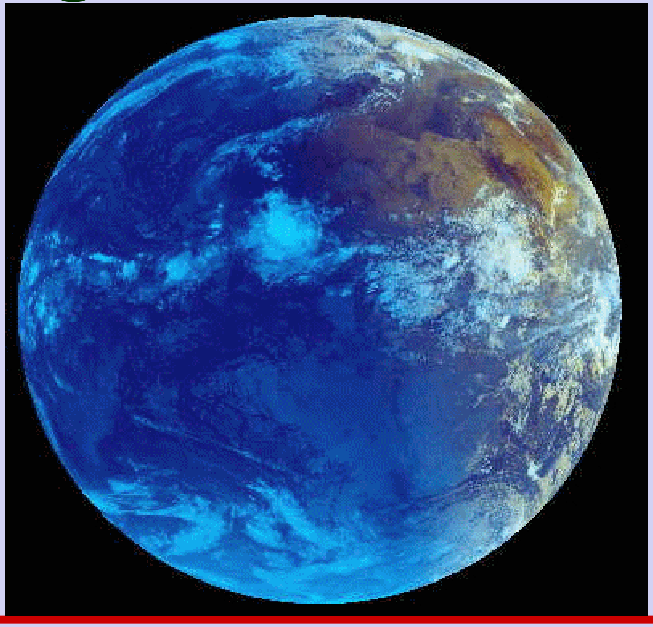


Globally: 86% of Evap. and 78% of Precip. occur over the oceans

Climate, Hydrology and Water Resources

- ***How will Climate change affect precipitation variability and water Availability?***

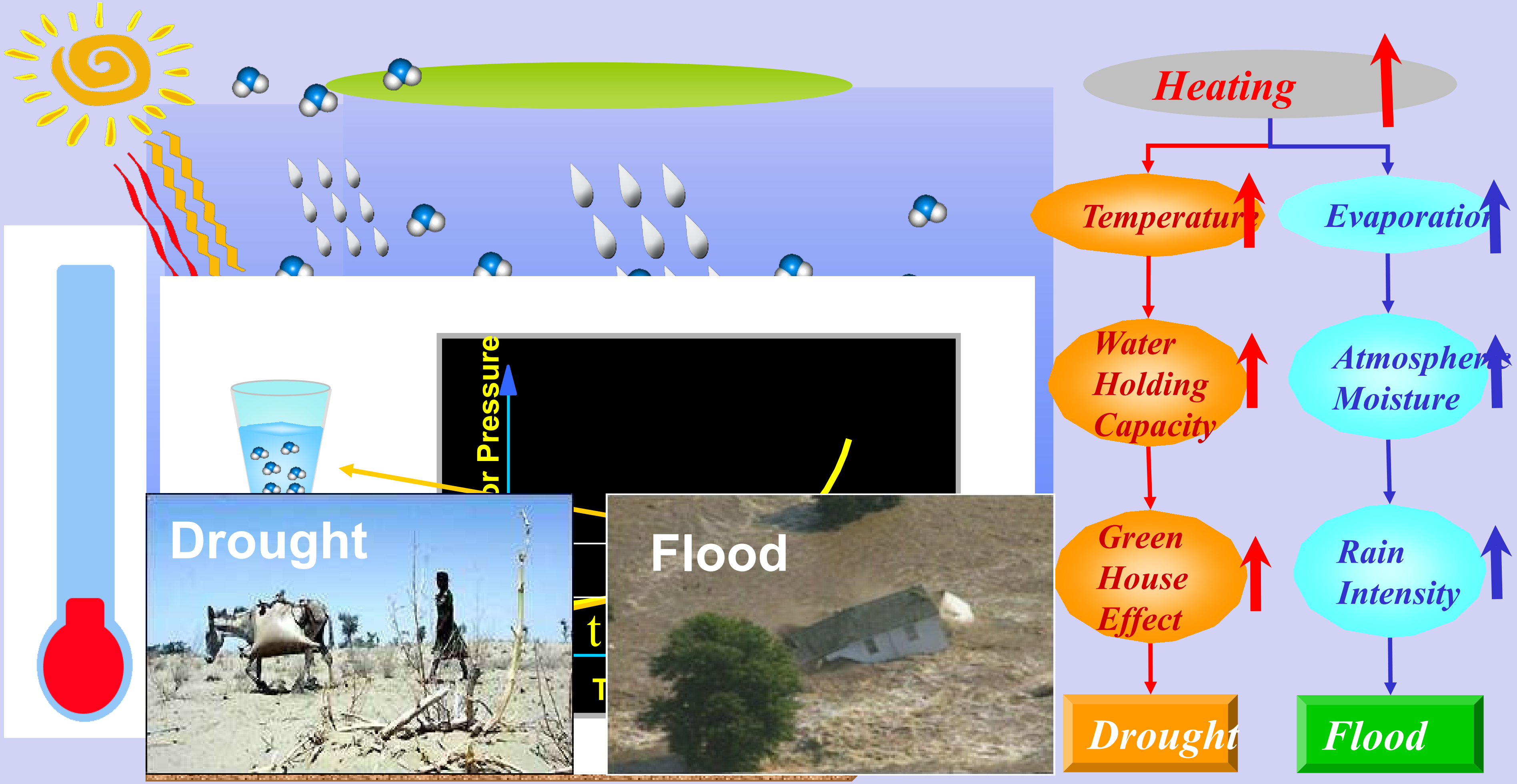
- ***Can we predict the future changes which are responsive to "user" needs?***



A Key Consideration:

The Link Between Climate and Hydrologic Cycle

Global Warming And Hydrologic Cycle Connection



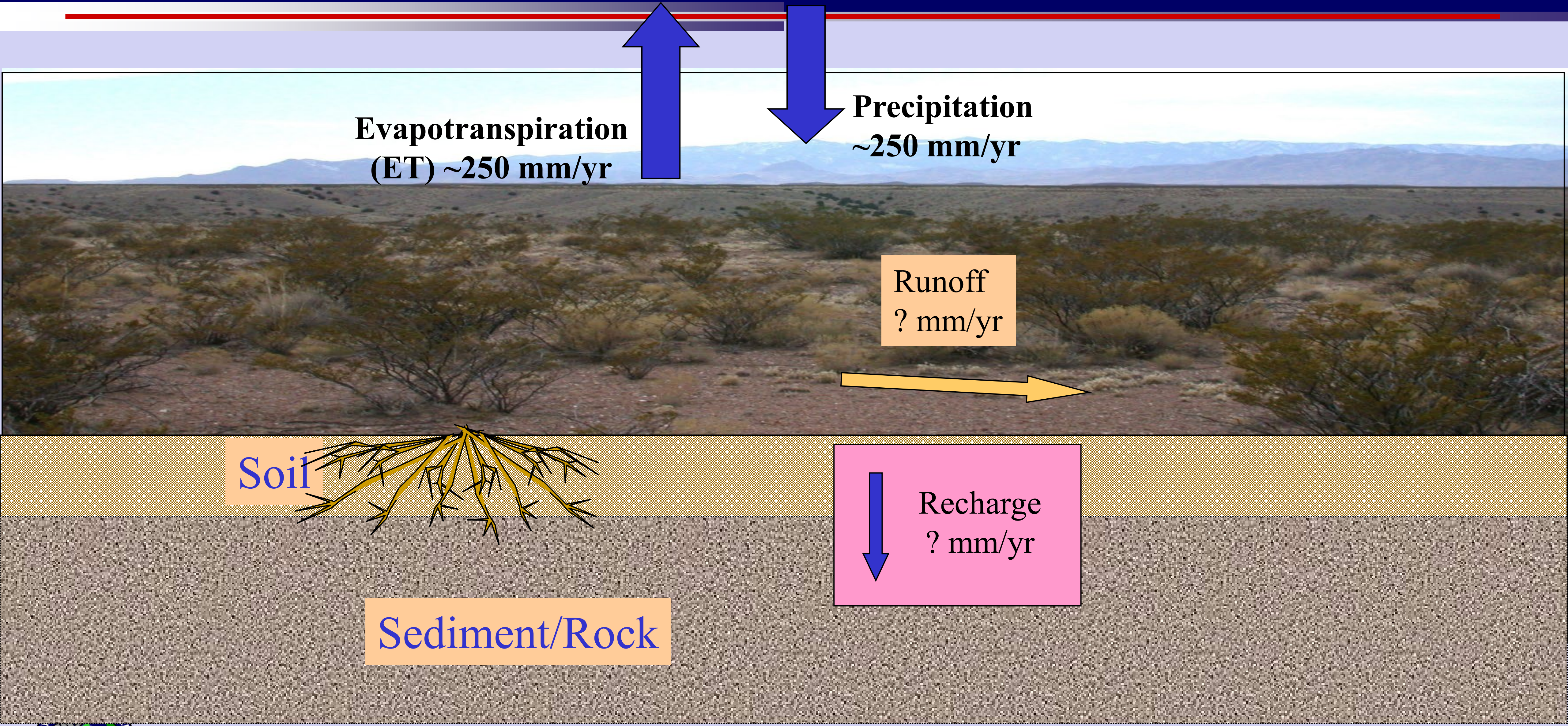
Created by: Gi-Hyeon Park

Some of the Issues facing the Arid & Semi-Arid Regions:

Implications of Hydrologic Variability

(Extremes)

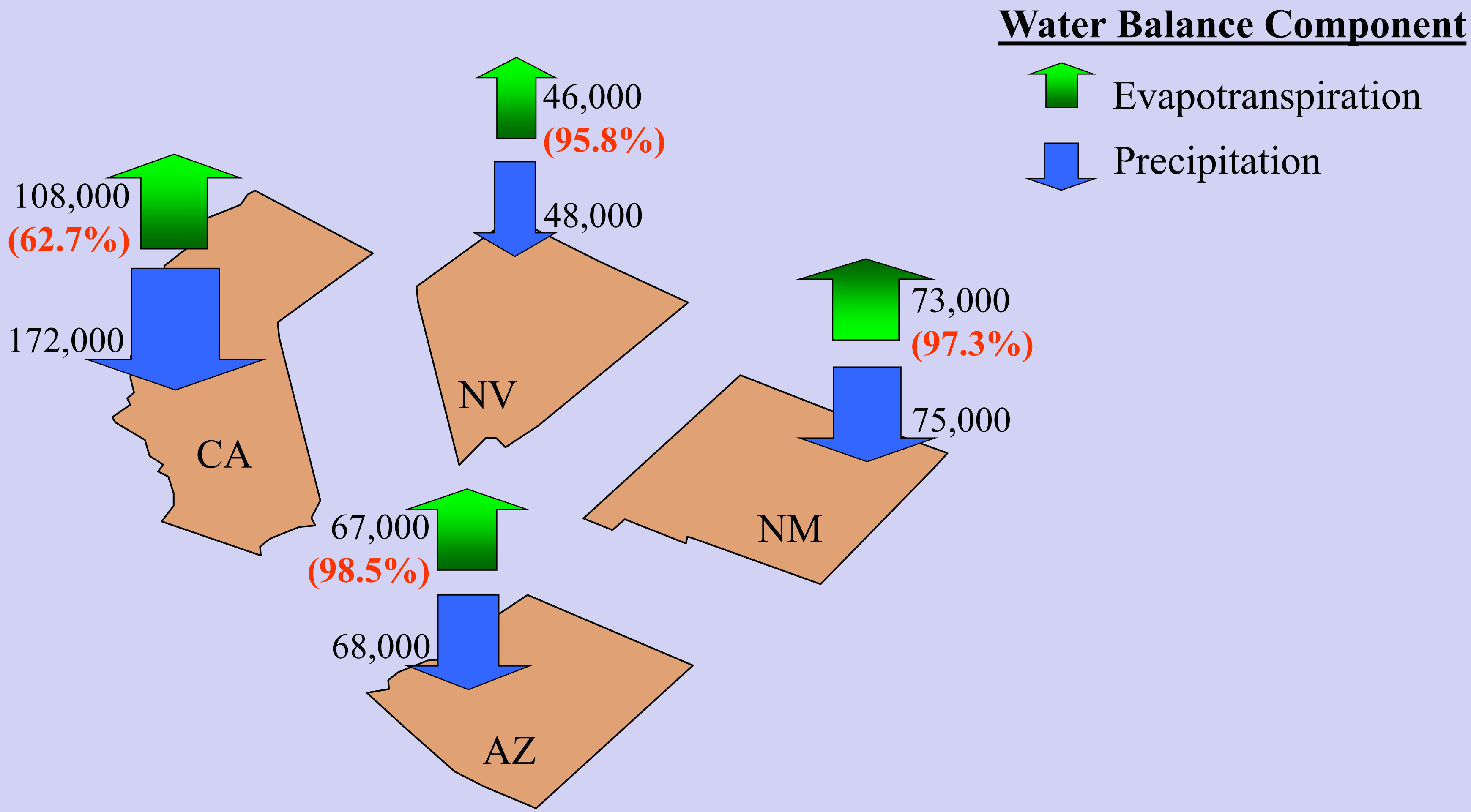
Water balance in Semi Arid Regions



Source: Eric Small, NMT now at CU Boulder

Water Balance in the Semi-Arid Southwest

Data in Million Gallon/Day. Source: USGS Water Use Report 1990



Vegetation change in the Southwestern US:

Semi-arid grasslands in
New Mexico and Arizona

are being replaced
by deep rooted shrubs.

Interspaces are sources of runoff, Canopies are sinks for runoff

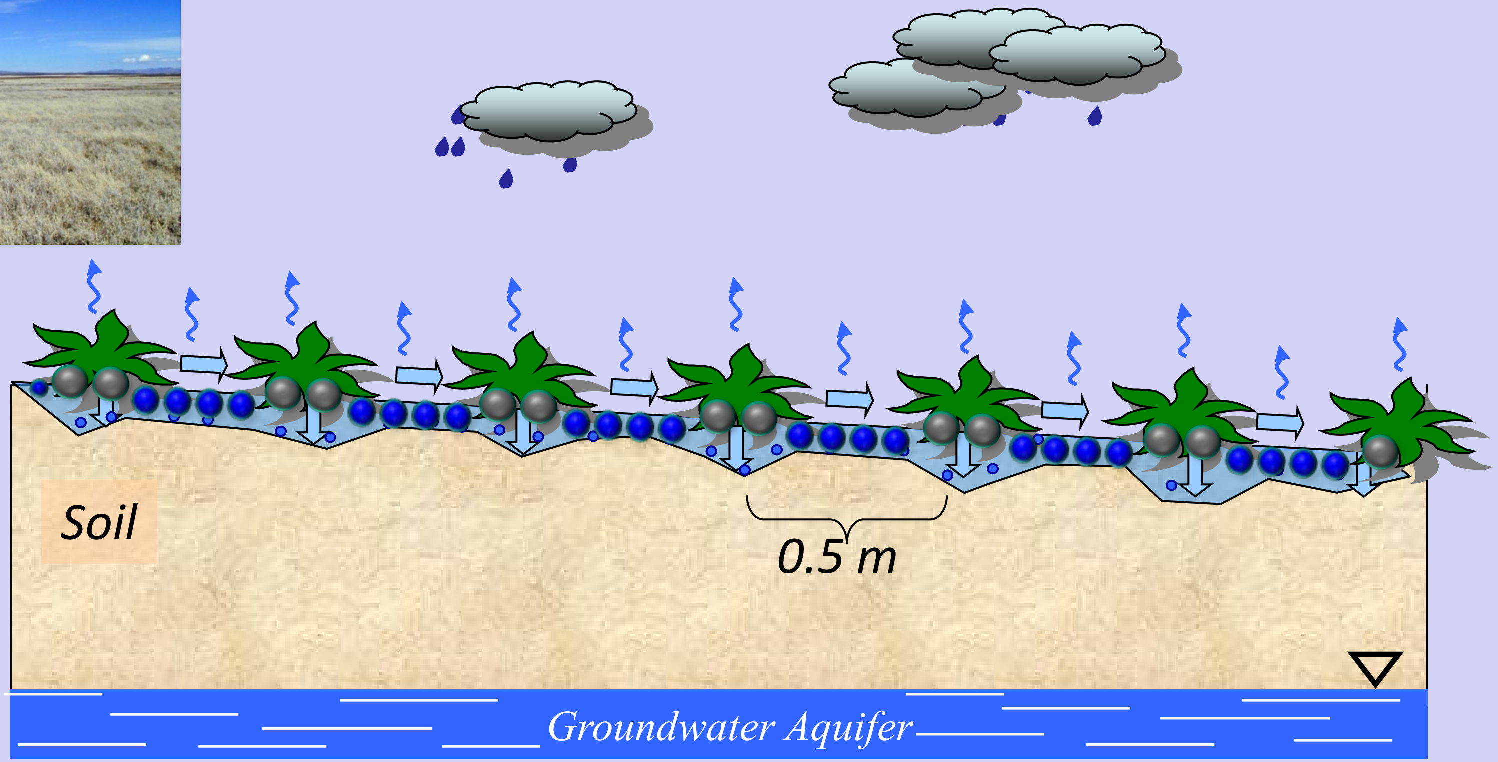
grasslands

deep rooted shrubs.

Source: Eric Small, NMT now at CU Boulder

Impact of Vegetation Cover Change on Infiltration

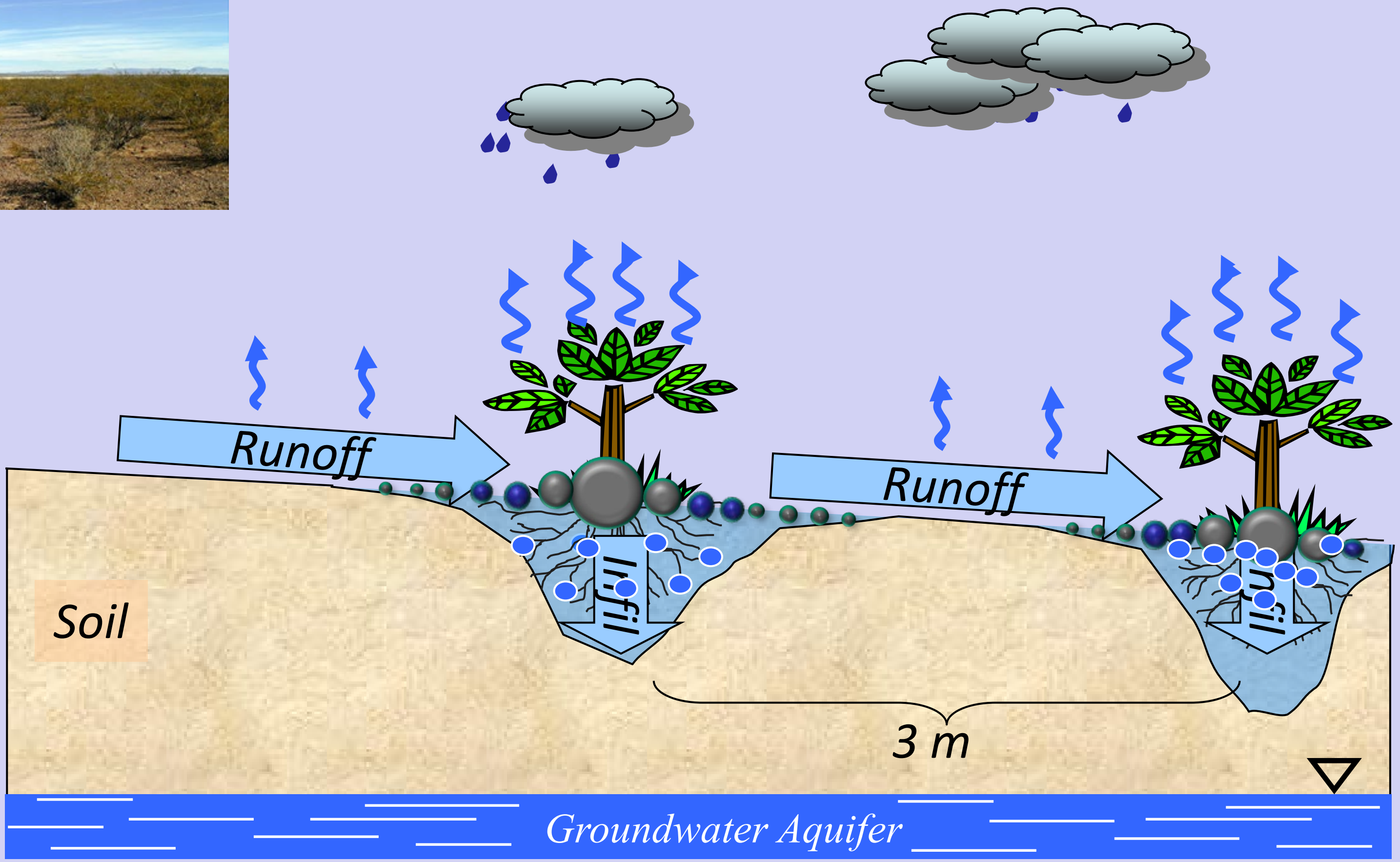
grasslands



GRASSLAND

Impact of Vegetation Cover Change on Infiltration

deep rooted shrubs.



SHRUBLAND

*Animation Assisted by: **Wei Chu and Gi-H. Park***

Study By: Eric Small, NMT now at CU Boulder

Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Two Primary Water Resources/Hydrology Challenges:

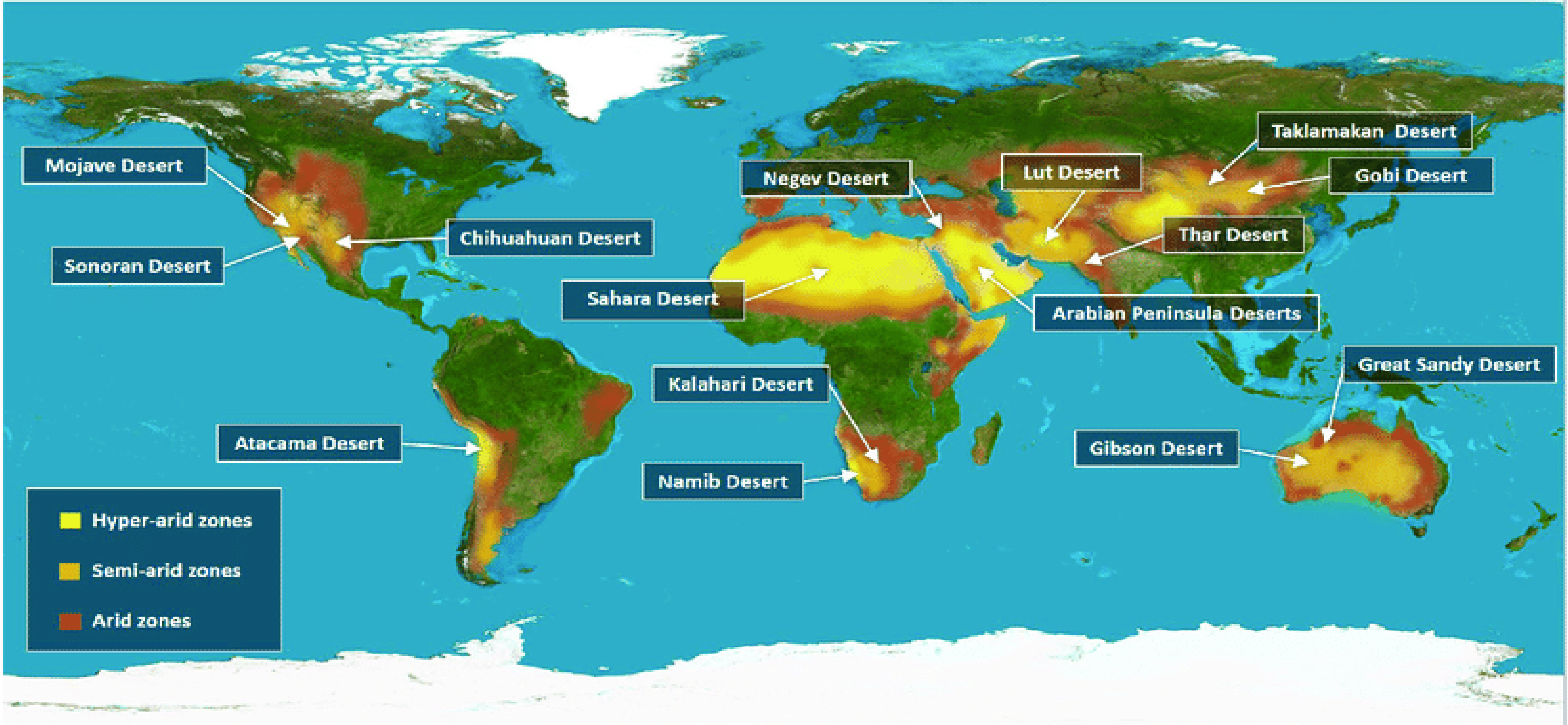
- ***Hydrologic Hazards (Floods and Droughts)***

- ***Water Supply Requirements (Quantity and Quality)***

Major Deserts of the World

Major Deserts of the World			
Name	**Type of Desert**	**Surface Area**	**Location**
Antarctic	Polar	5.5 million mi^2	Antarctica
Arctic	Polar	5.4 million mi^2	Alaska, Canada, Greenland, Iceland, Norway, Sweden, Finland, Russia
Sahara	Subtropical	3.5 million mi^2	Northern Africa
Arabian	Subtropical	1 million mi^2	Arabian Peninsula
Gobi	Cold Winter	500,000 mi^2	China and Mongolia
Patagonian	Cold Winter	260,000 mi^2	Argentina
Great Victoria	Subtropical	250,000 mi^2	Australia
Kalahari	Subtropical	220,000 mi^2	South Africa, Botswana, Namibia
Great Basin	Cold Winter	190,000 mi^2	United States
Syrian	Subtropical	190,000 mi^2	Syria, Iraq, Jordan, Saudi Arabia
Chihuahuan	Subtropical	175,000 mi^2	Mexico
Great Sandy	Subtropical	150,000 mi^2	Australia
Kara-Kum	Cold Winter	135,000 mi^2	Uzbekistan, Turkmenistan
Colorado Plateau	Cold Winter	130,000 mi^2	United States
Gibson	Subtropical	120,000 mi^2	Australia
Sonoran	Subtropical	120,000 mi^2	United States, Mexico
Kyzyl-Kum	Cold Winter	115,000 mi^2	Uzbekistan, Turkmenistan, Kazakhstan
Taklamakan	Cold Winter	105,000 mi^2	China
Iranian	Cold Winter	100,000 mi^2	Iran
Thar	Subtropical	75,000 mi^2	India, Pakistan
Simpson	Subtropical	56,000 mi^2	Australia
Mojave	Subtropical	54,000 mi^2	United States
Atacama	Cool Coastal	54,000 mi^2	Chile
Namib	Cool Coastal	13,000 mi^2	Angola, Namibia, South Africa

Global Distribution of Desert Areas and their



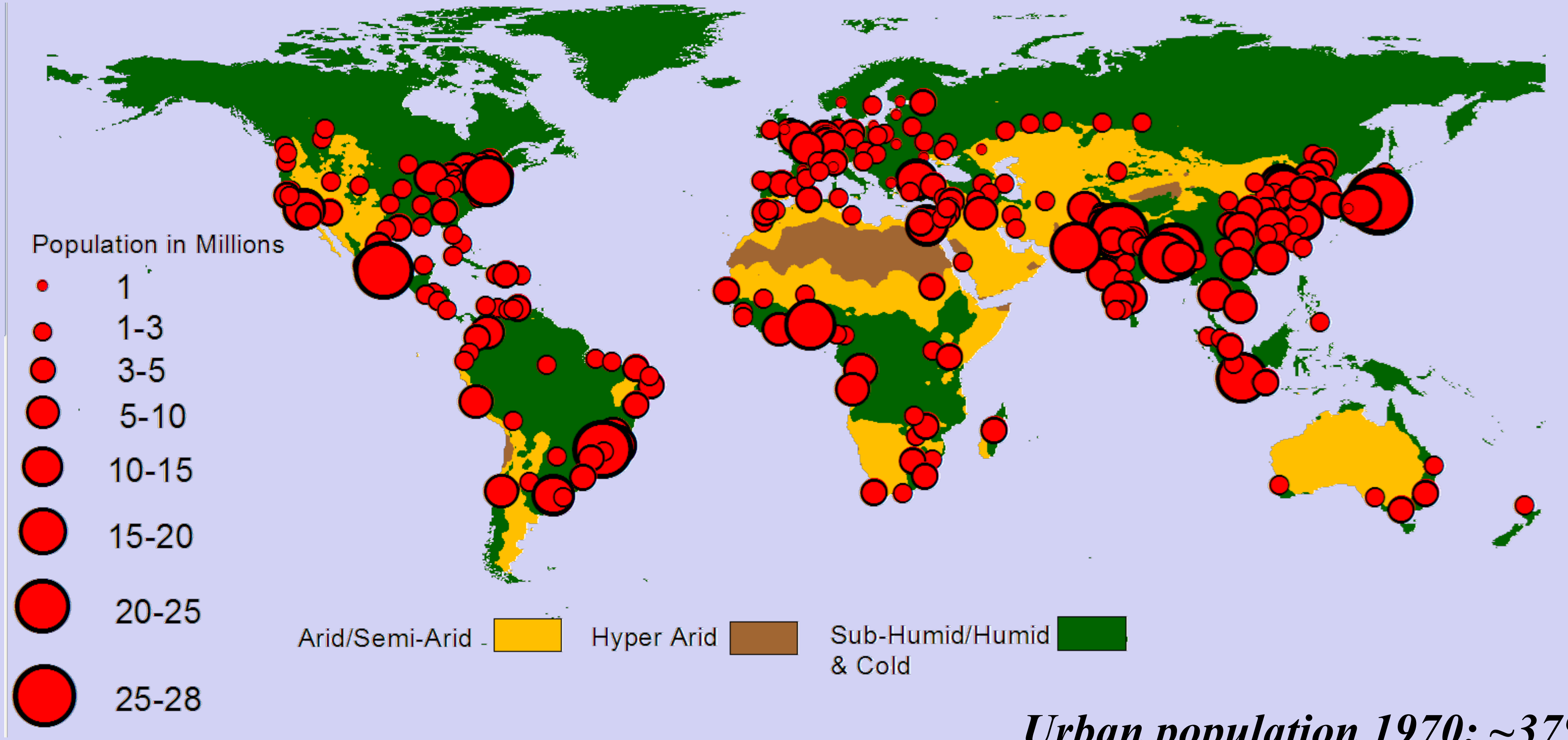
Source: Adapted from World Atlas of Desertification (Cherlet et al., 2018)

Stresses On Water Resources and Related Ecosystems:

- ***Population Impact*** *(More Predictable!)*
- ***Climate Impact*** *(Less Predictable!)*

Increasing Population: Number of Mega Cities

Projected Global Population: 8.3 Billion by 2025



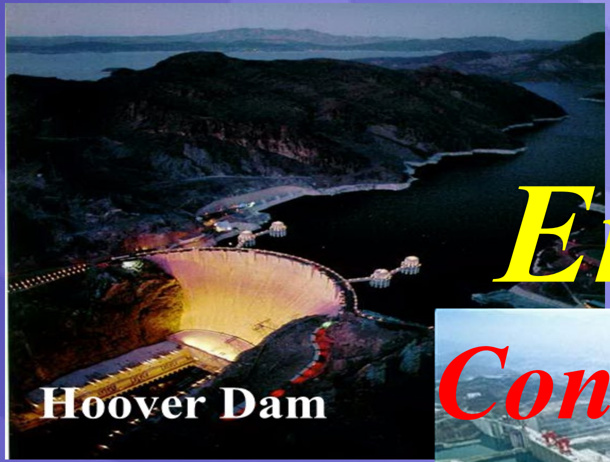
Urban population 1970: ~37%
2010: ~53%

Took 200,000 years of human history for world's population to reach 1 billion; and only 200 years more to reach 7 billion plus.

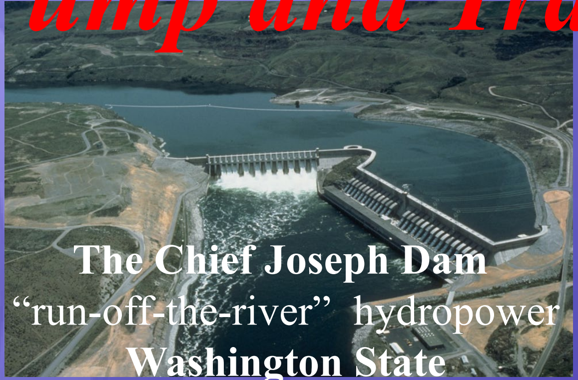
Primary Solution To Satisfy Water Resources Needs and Address Hydrologic Extremes

Engineering Approach:

Control, Store, Pump and Transfer


Hoover Dam


Three Gorges Dam


The Chief Joseph Dam
"run-off-the-river" hydropower
Washington State


Central Arizona
Project Aqueduct

Capturing and regulating Stream flow: Reservoirs

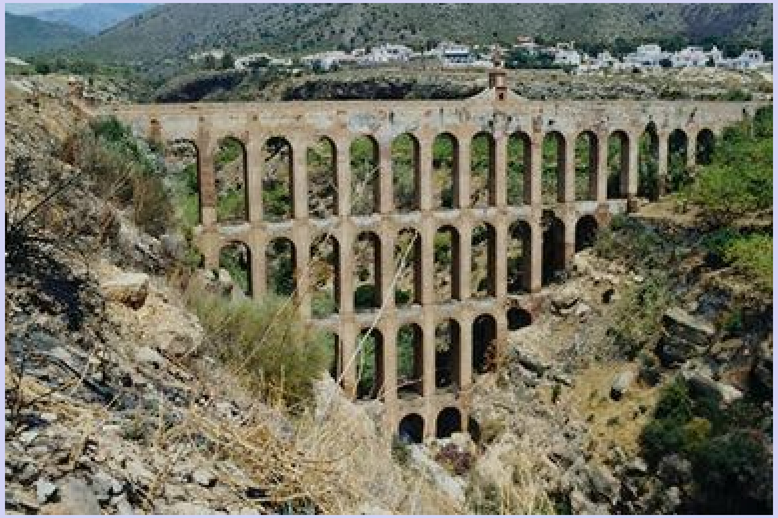
The old:

(500-800 yr old Dam: Southern Iran)

And the new

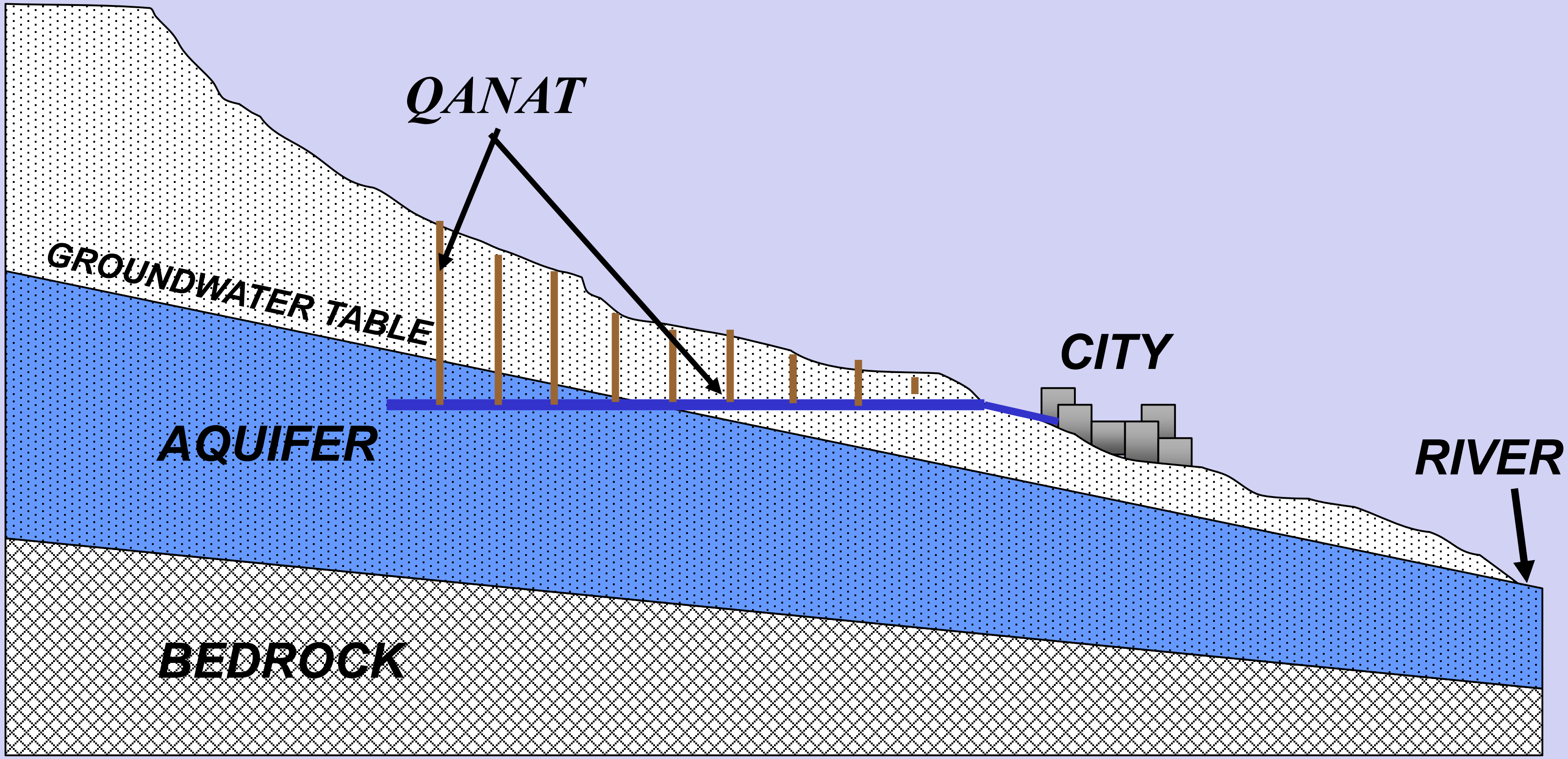
Roman Aqueducts Raised Water Works to Functional Art

Gravity flows of imported surface water sustained ancient Roman cities.



Today's Large Aqueducts are transforming many regions

A Qanat is a horizontal well!



Qanat is not the shortest distance from the surface to the groundwater

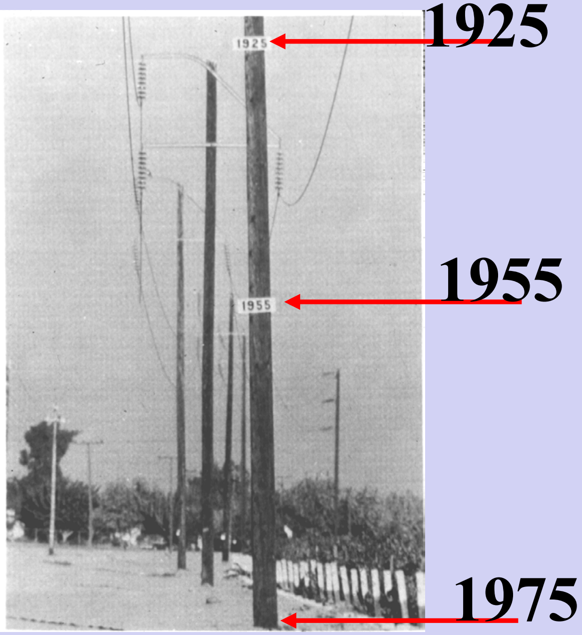
Source: Prof Majid Hassanizadeh

Ground Water Extraction

The way it is now

Mechanical Pumps: Ground Water Over Pumping

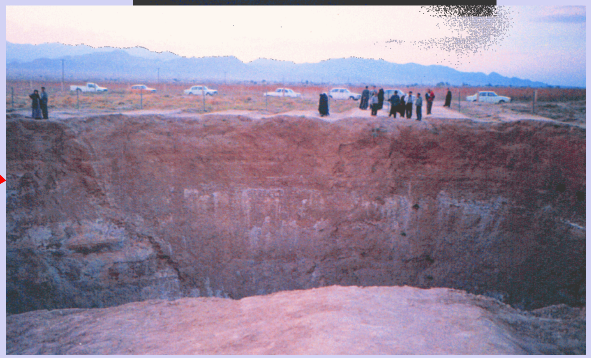
Groundwater Overdraft, land subsidence and sinkholes



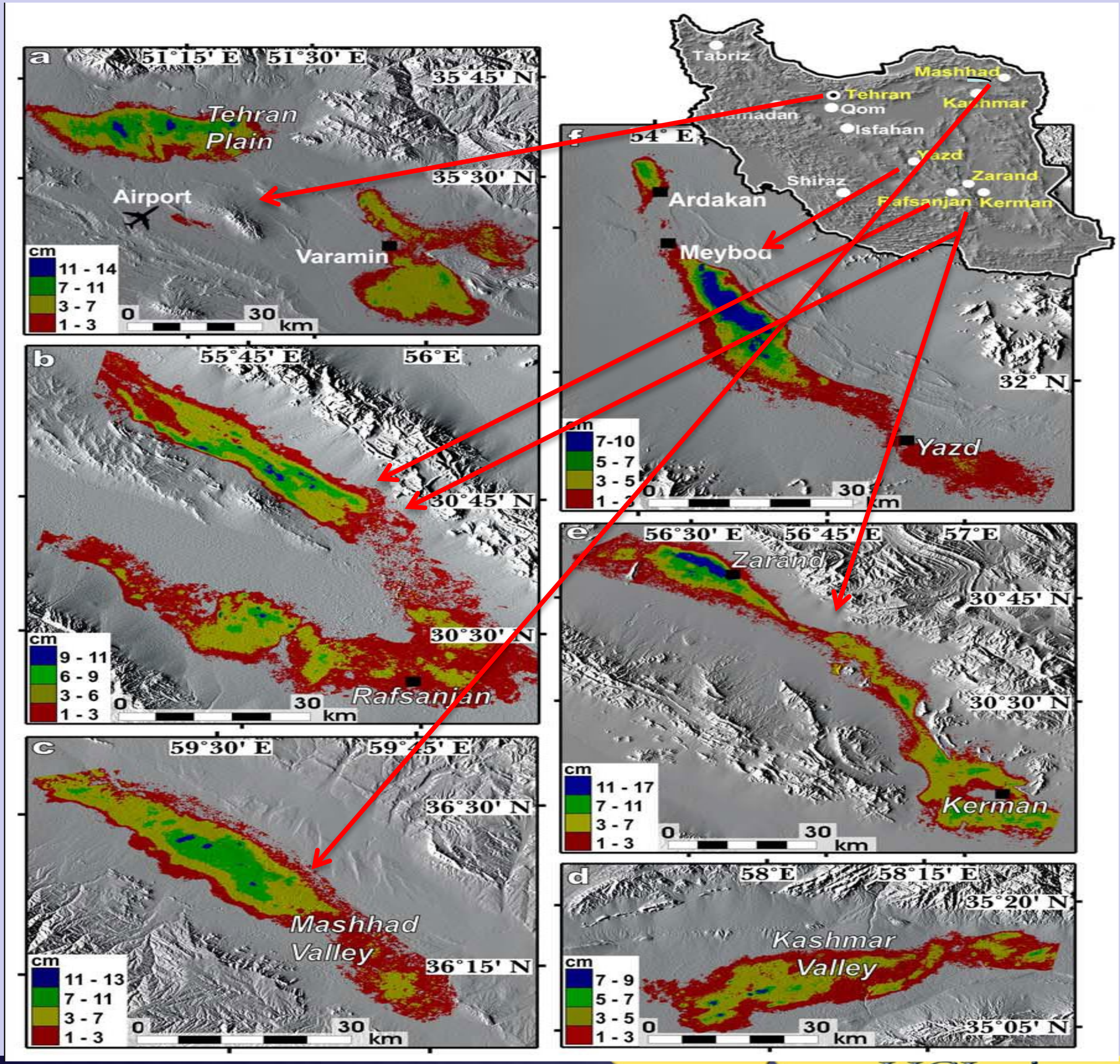
San Joaquin Valley, CA

In the US

Near Kerman, Iran



Land Subsidence Due to Ground water Pumping : Iran



Motagh M, TL Walter and M Sharifi

GRL (2008) - (DOI:10.1029/2008GL033814)

Expectations:

Provide useful, Relevant and "Reliable" Information for operational, planning and Design of water Resources systems

Information Relevant to Water Resources Planning

- Observations (Learning from Data: Statistical and extrapolation techniques)

- Models (Future Predictions)

Information Relevant to Water Resources Planning

- Models Projections
- Observations

Required Hydrometeorologic Predictions

Short Range -> Long Range

hours ------> days ------> weeks ------> months ---> seasons ---> years ---------> decades

- Flash Flood Warning
- Flash Flood Guidance
- Headwater Guidance
- Flood Forecast Guidance
- Reservoir Inflow Forecasts
- Spring Snow Melt Forecasts
- Water Supply Volume

Short-range | *Mid-range* | *Long-range*

Forecast Requirements

Required Hydrometeorological Predictions

Short Range – · – · – · – · – · – · – · – · – · – · – · – · – · – · – · Long Range

hours ----> days -----> weeks ---> months --> seasons --> years ------> decades

Flash Flood Warning

Flash Flood Guidance

Headwater Guidance

Flood Forecast Guidance

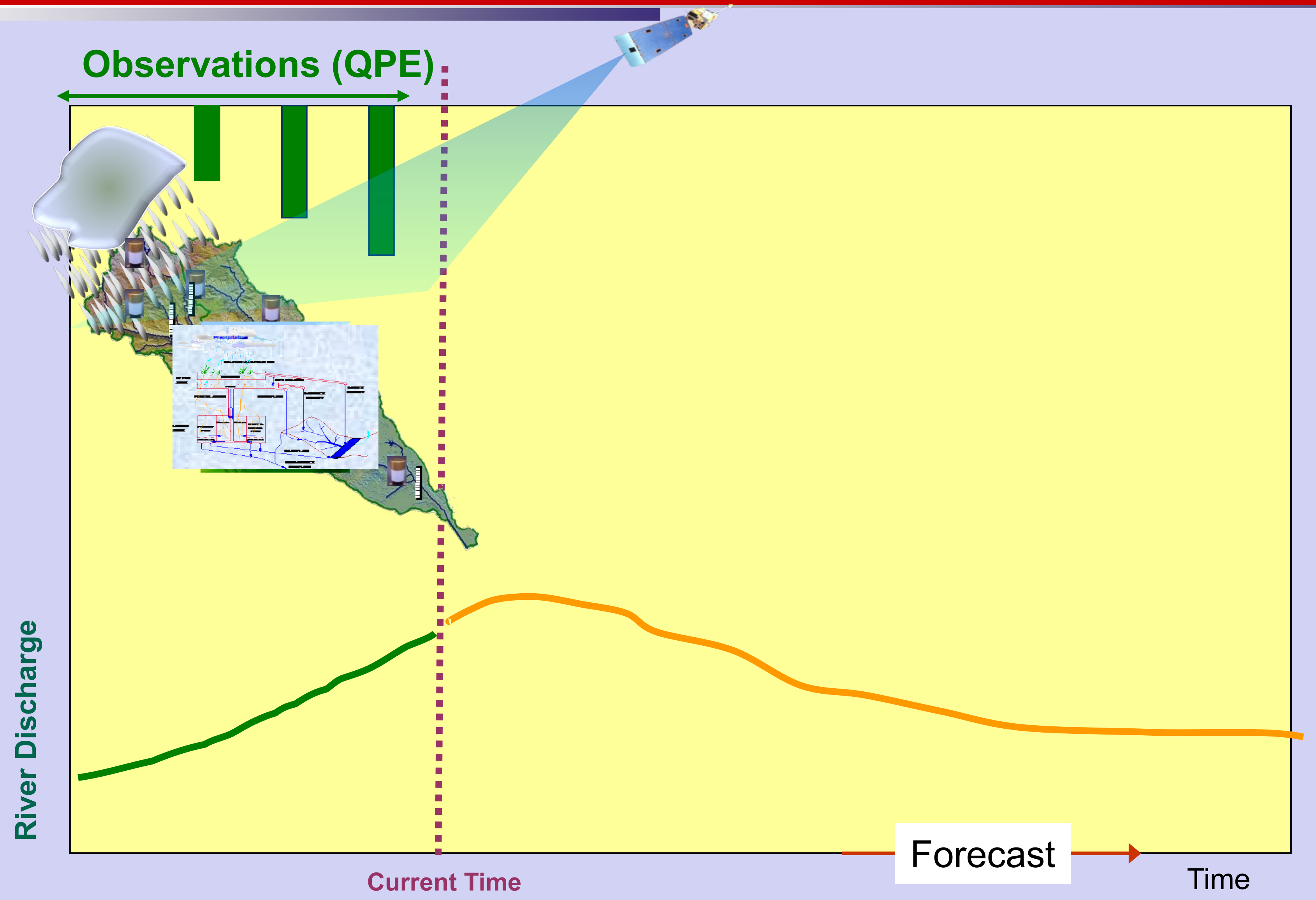
Reservoir Inflow Forecasts

Water Supply Volume

Short-range

- ***Weather Scale:***
  - ***flood and River flow forecasting***

Common practice in Flood and River Flow Forecasting



Animation Assisted by: Q. Xia & Gi-H. Park

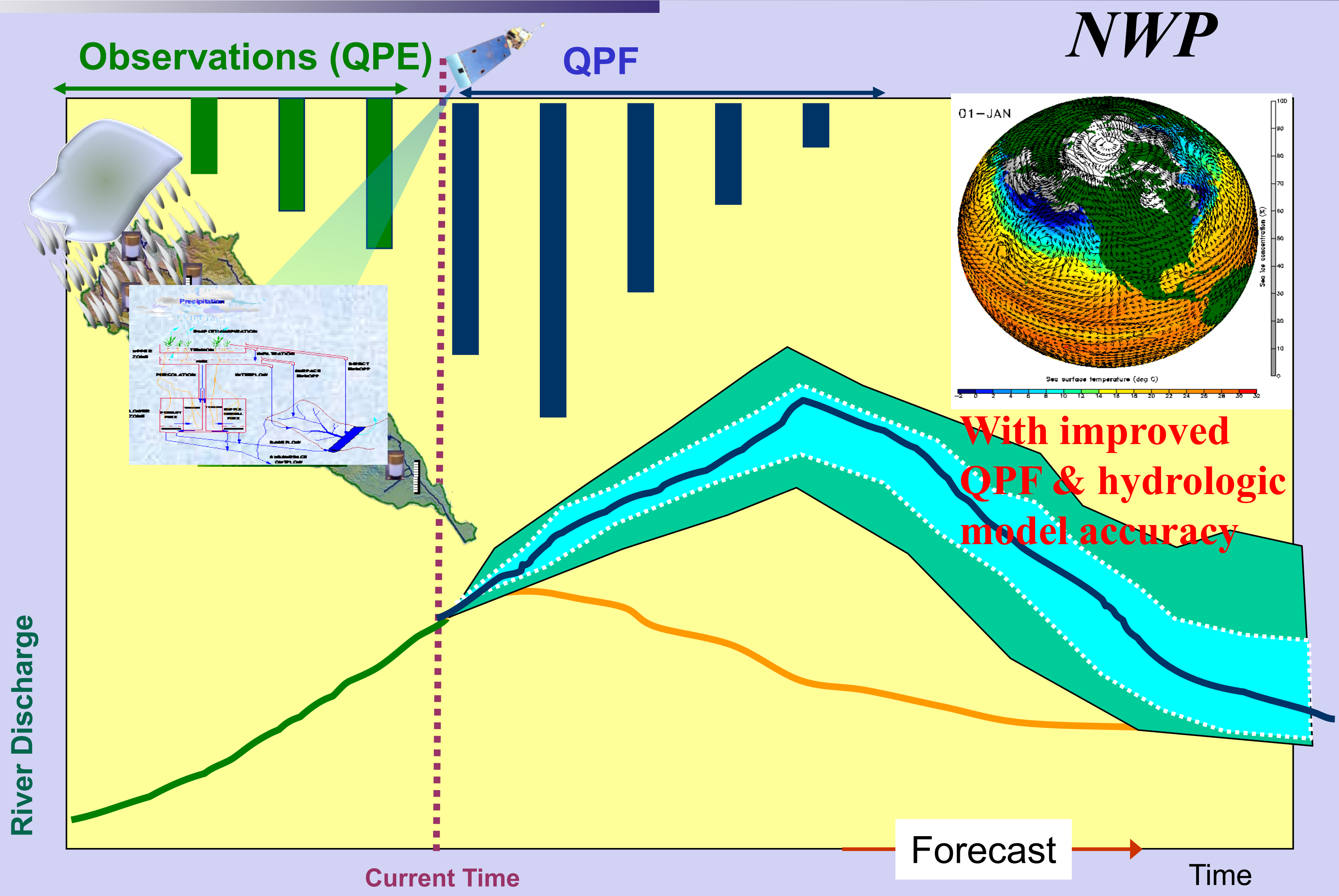
Extending the Short-term flood Forecasts

Estimating Future "Short-Term" Rainfall:

1- Models: (NWP - QPF)

2- Extrapolation-based Nowcasting

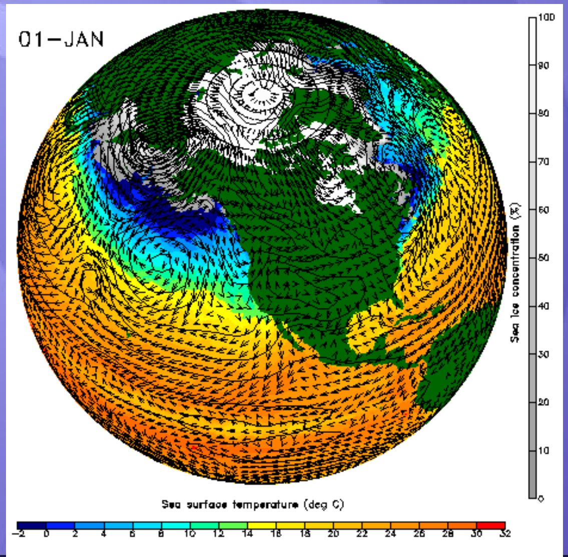
Efforts in Extending the Forecast Lead Time



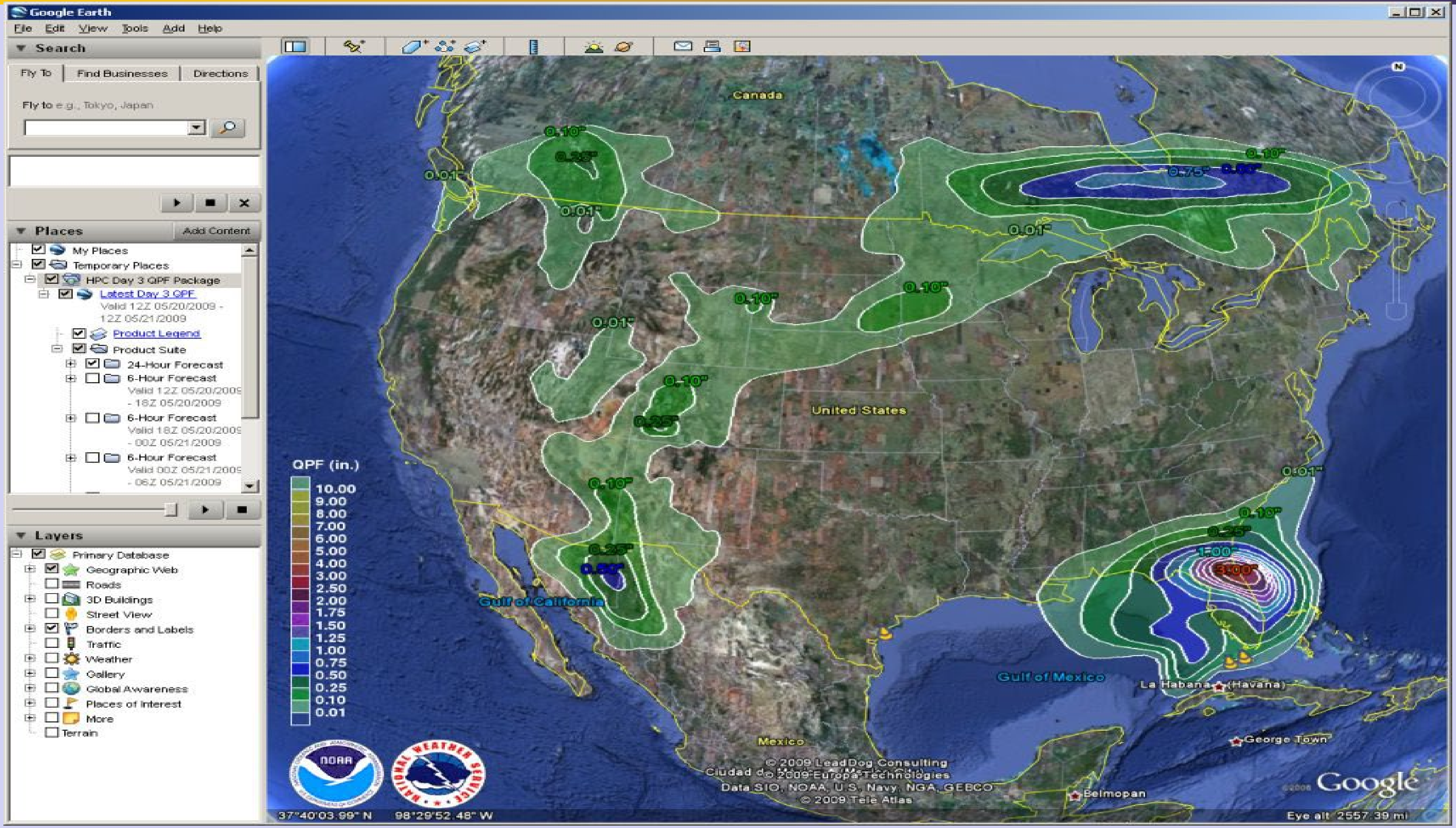
Animation Assisted by: Q. Xia, Gi-H. Park & L. Bastidas

Progress in QPF to extend the lead time of hydrologic forecasts

NWP

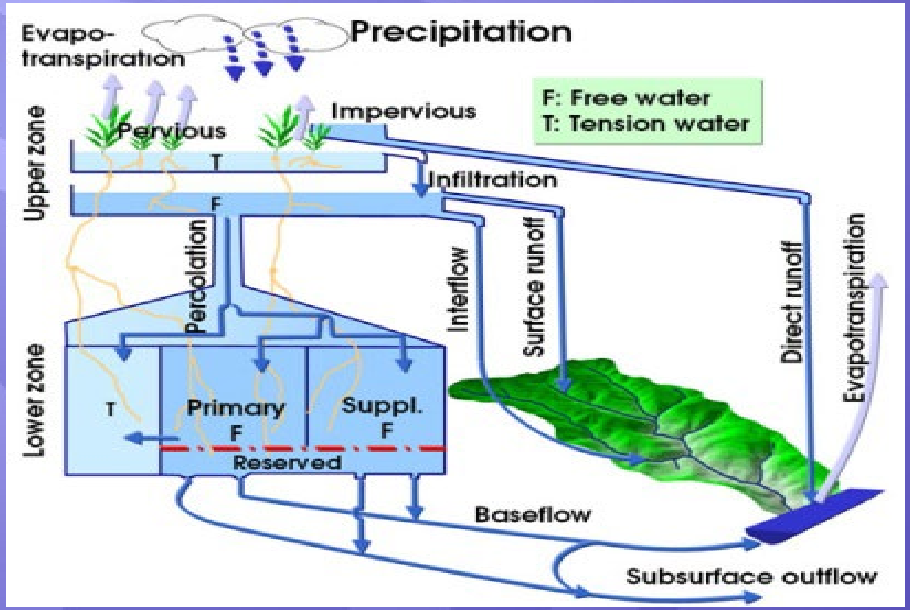


Quantitative Precipitation Forecast (QPF)

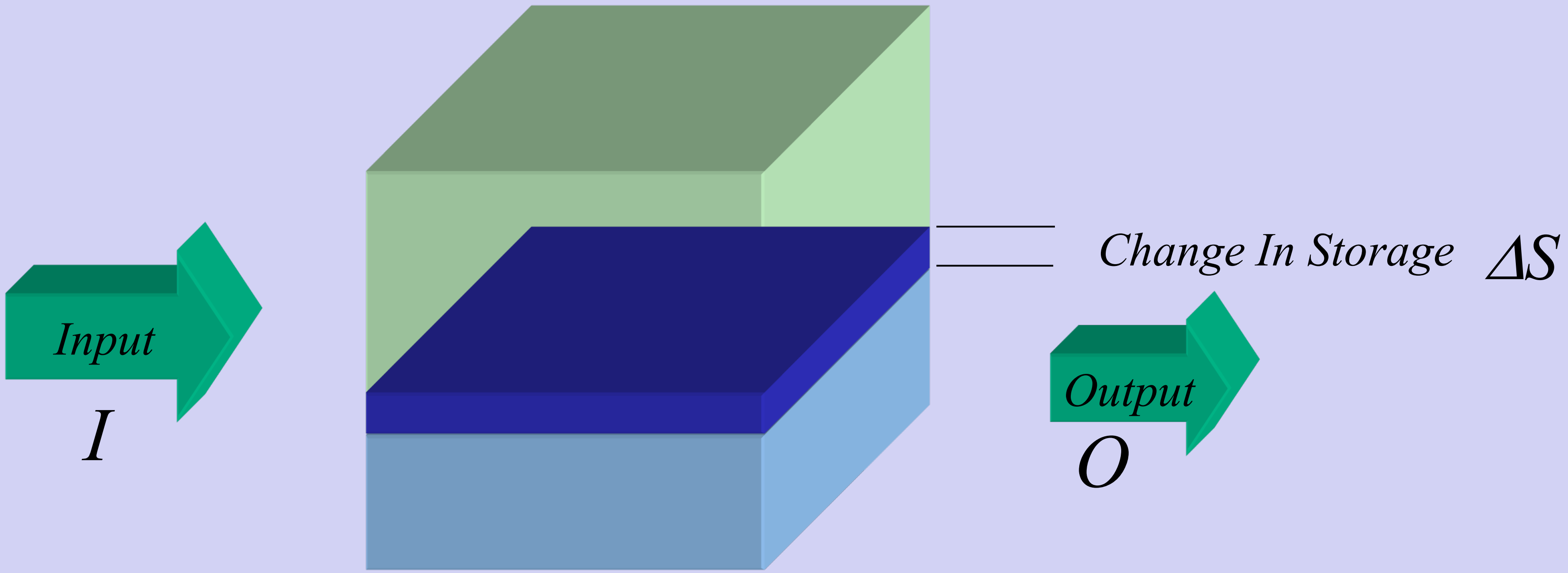


Source: NWS-WPC website

Progress in hydrologic modeling

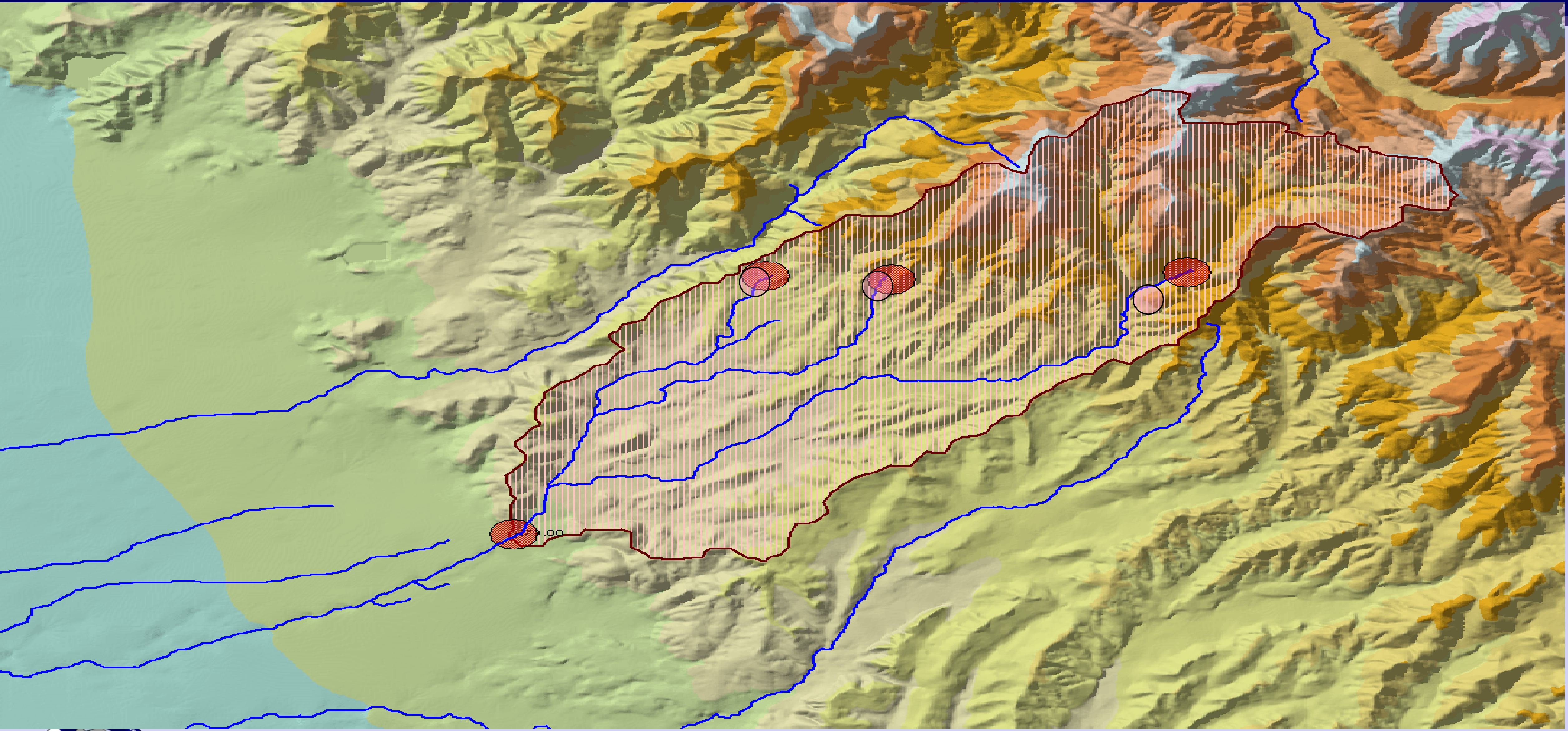


Fundamental Law

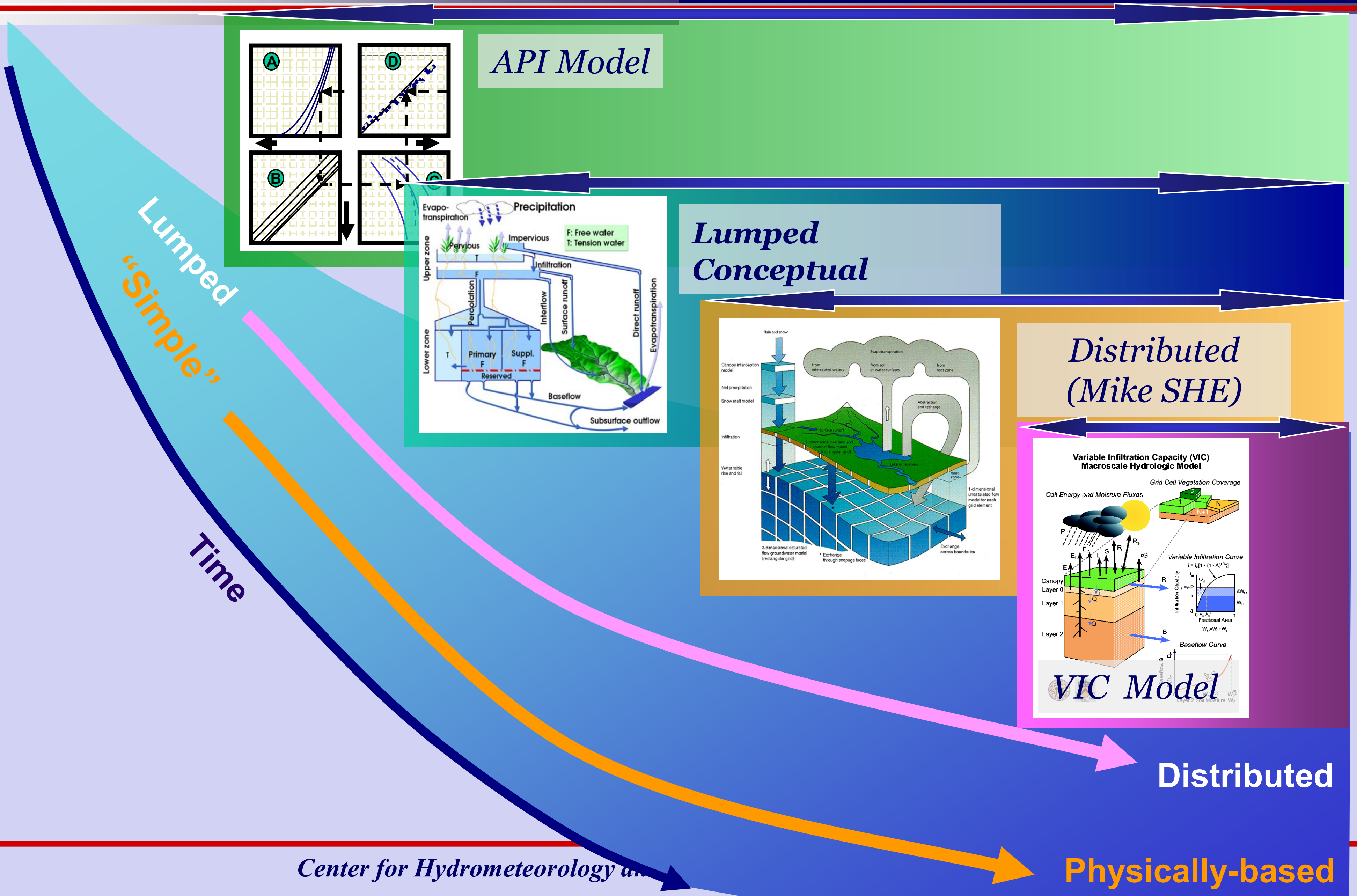


$$I - O = \Delta S$$

Trace The Water Drop

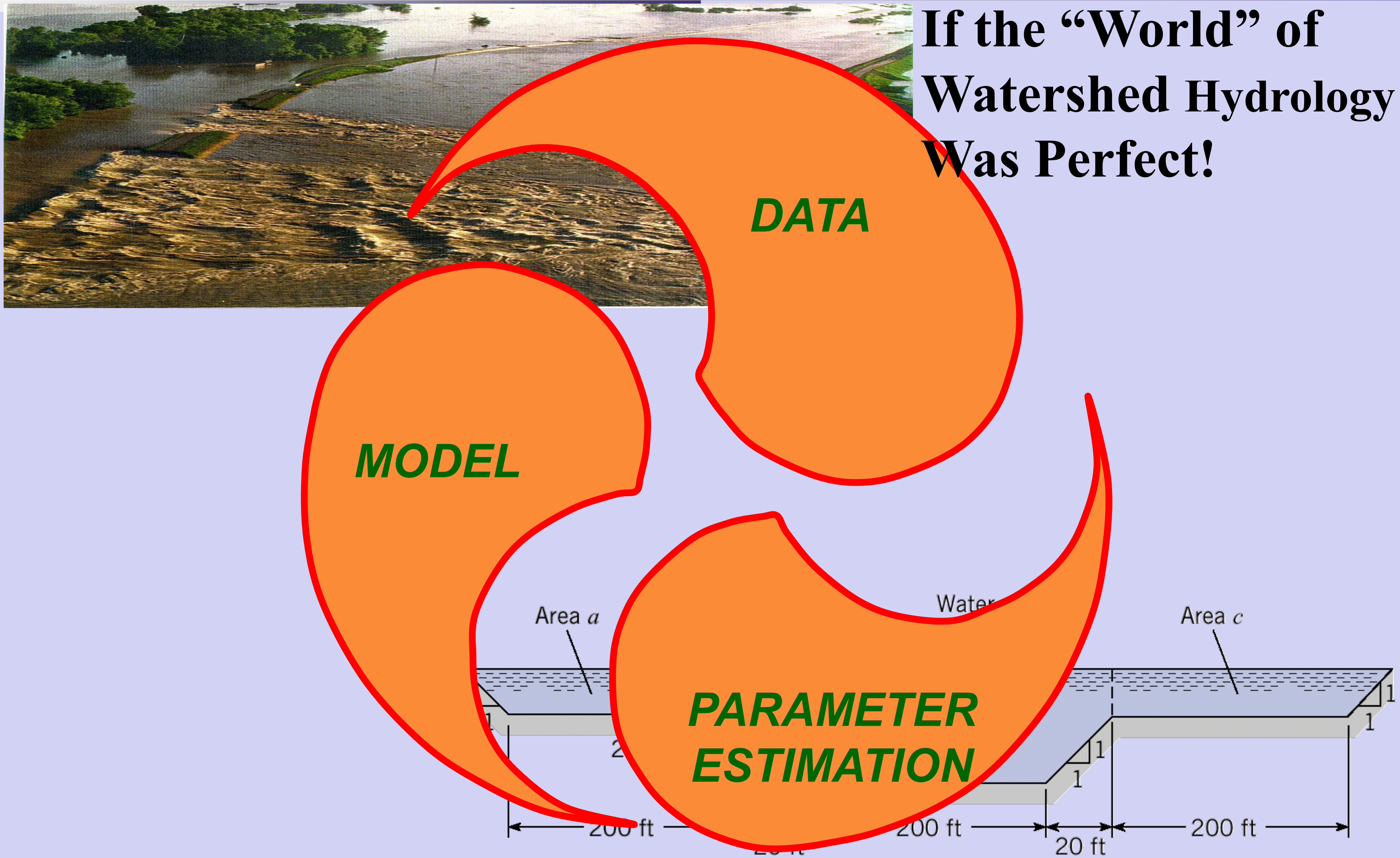


Evolution of Hydrologic R-R Models



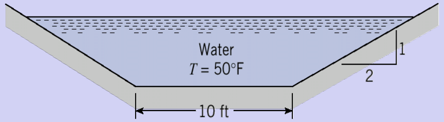
Hydrologic Modeling: 3 Elements!

If the "World" of Watershed Hydrology Was Perfect!

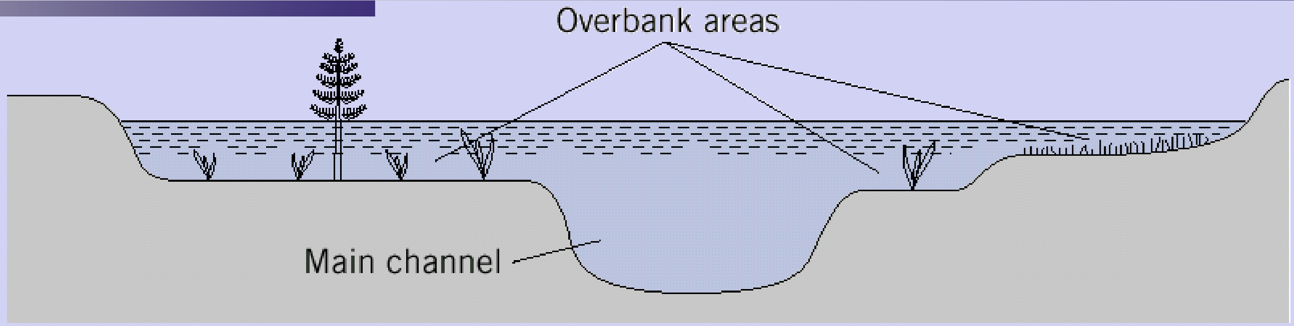


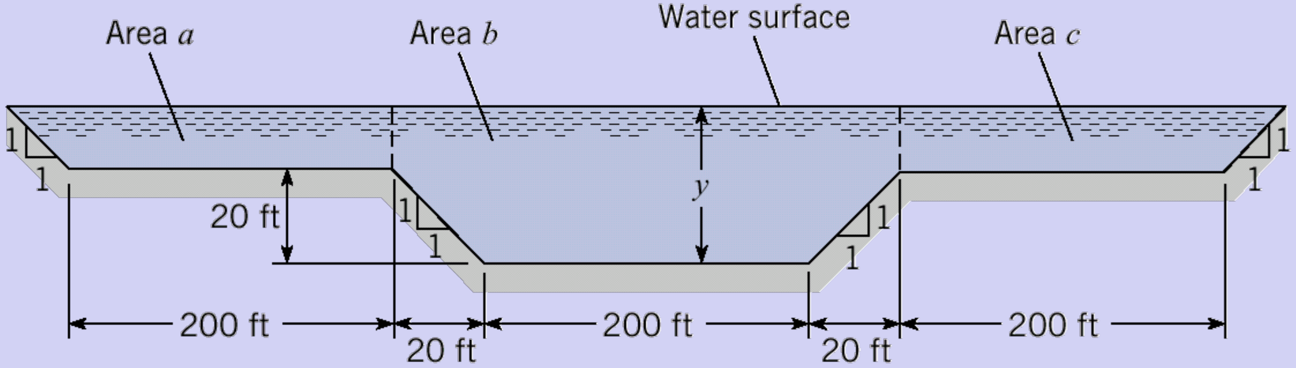
Flow in Channels: How far can we go simplifying?

$V = n^{-1} R^{2/3} S^{1/2}$

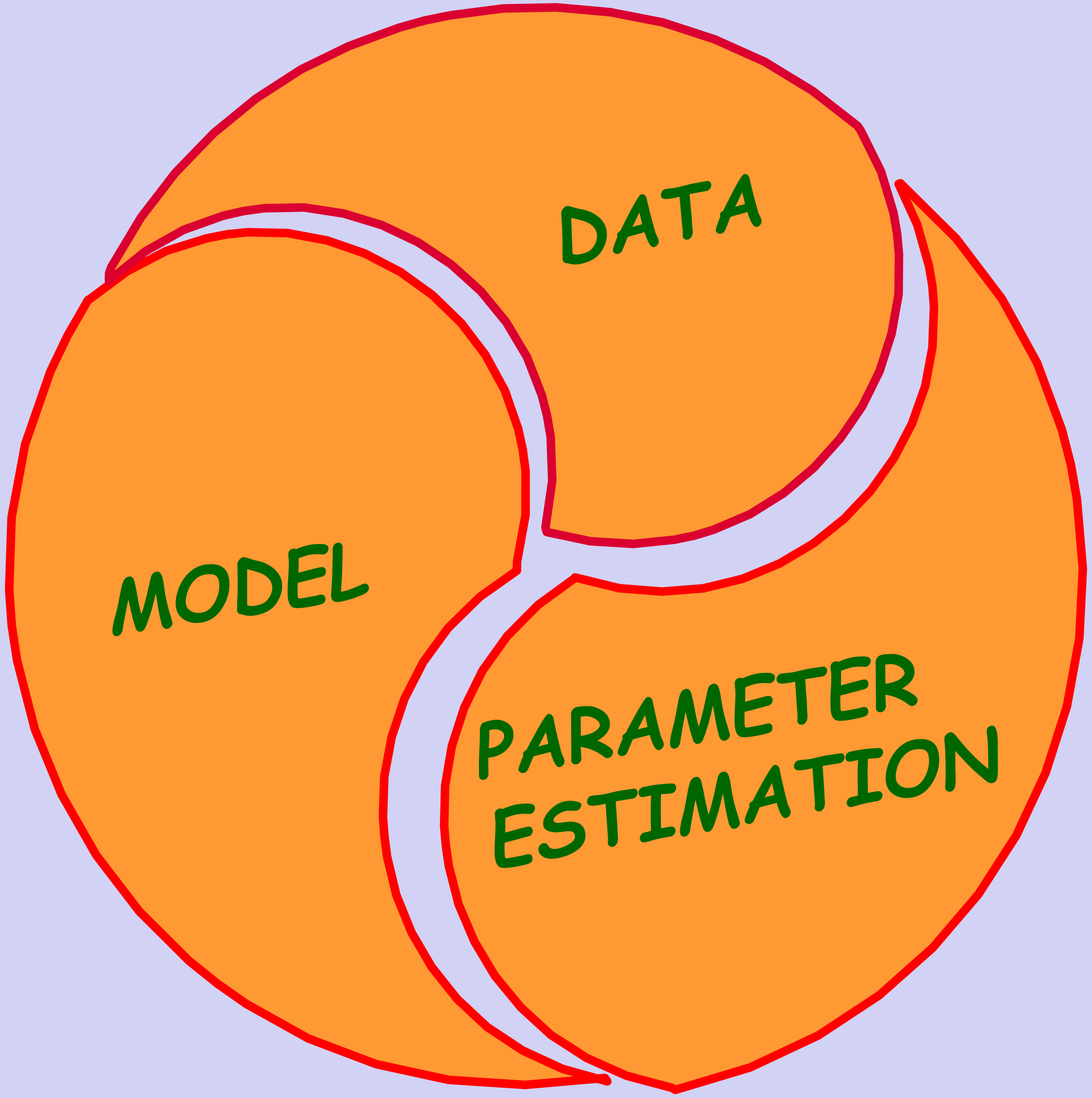


n – Manning Coefficient
R – Hydraulic Radius
S – Energy Slope

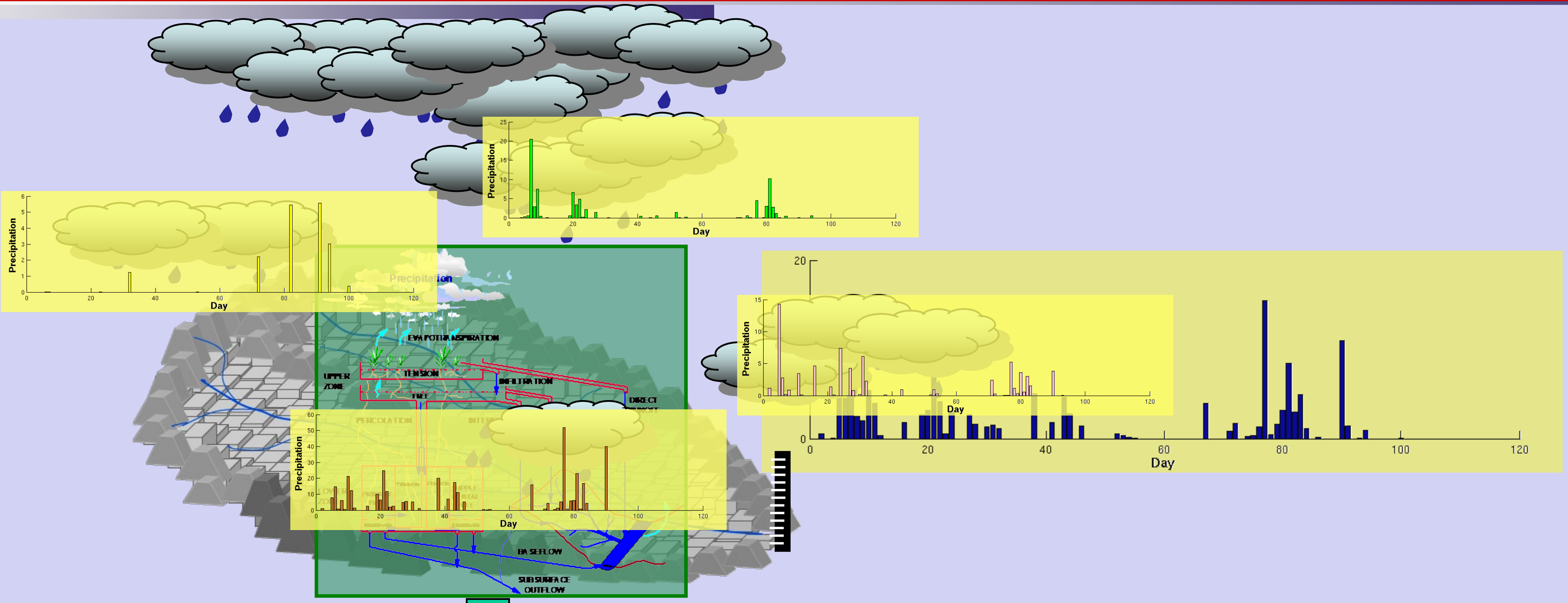


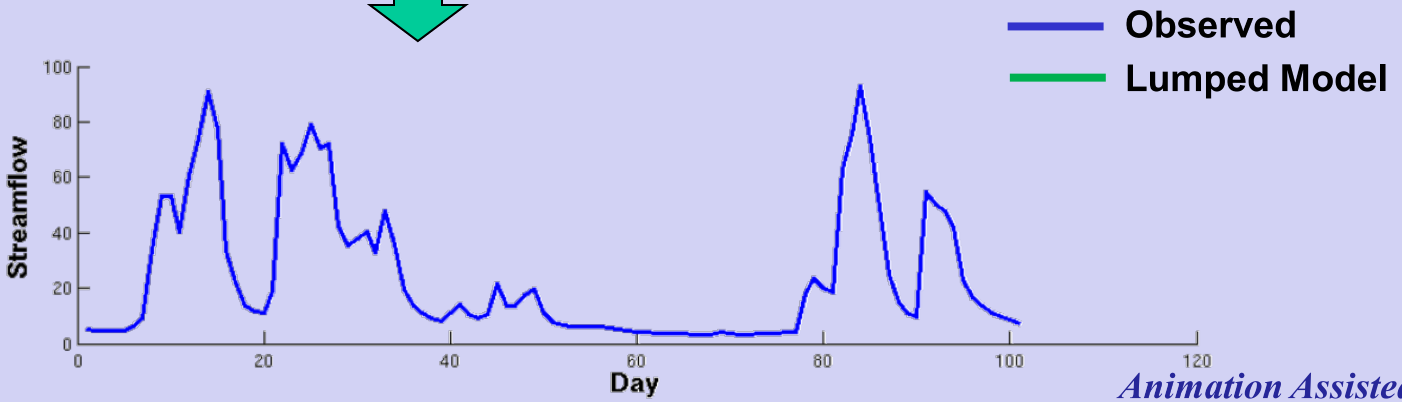


Hydrologic Modeling



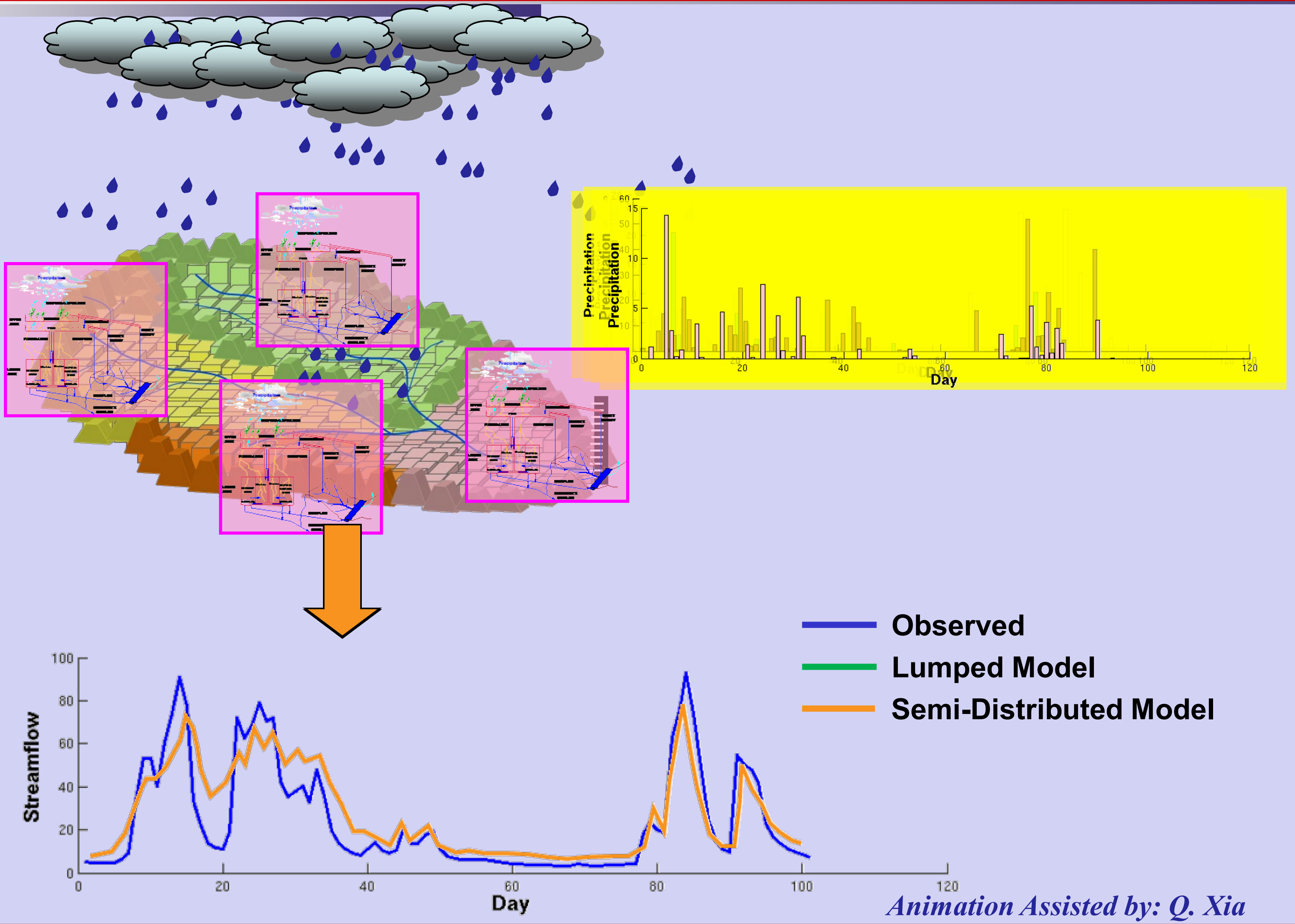
Hydrologic Modeling: "Lumped"





Animation Assisted by: Q. Xia

"Semi-distributed" Hydrologic Models



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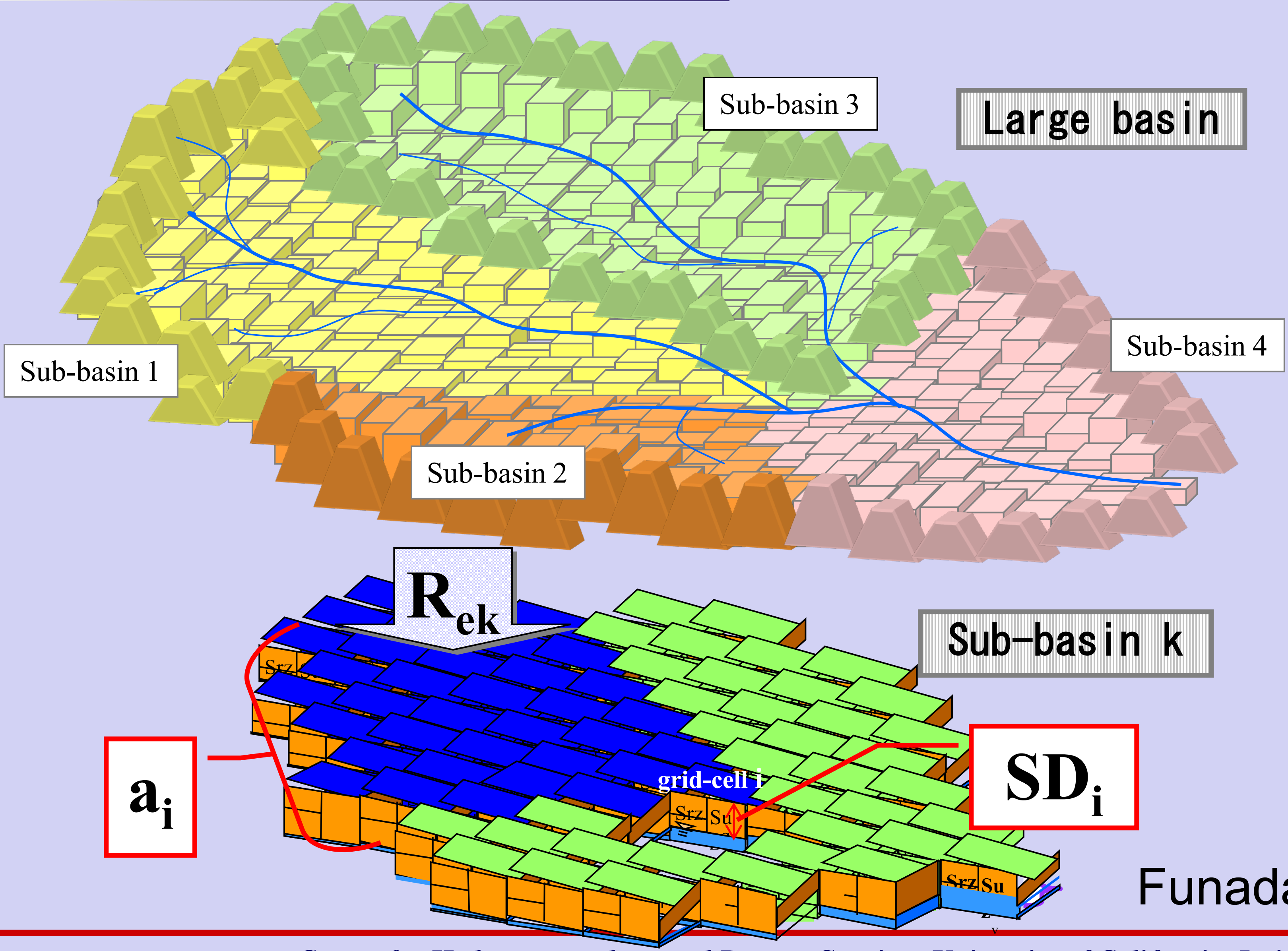
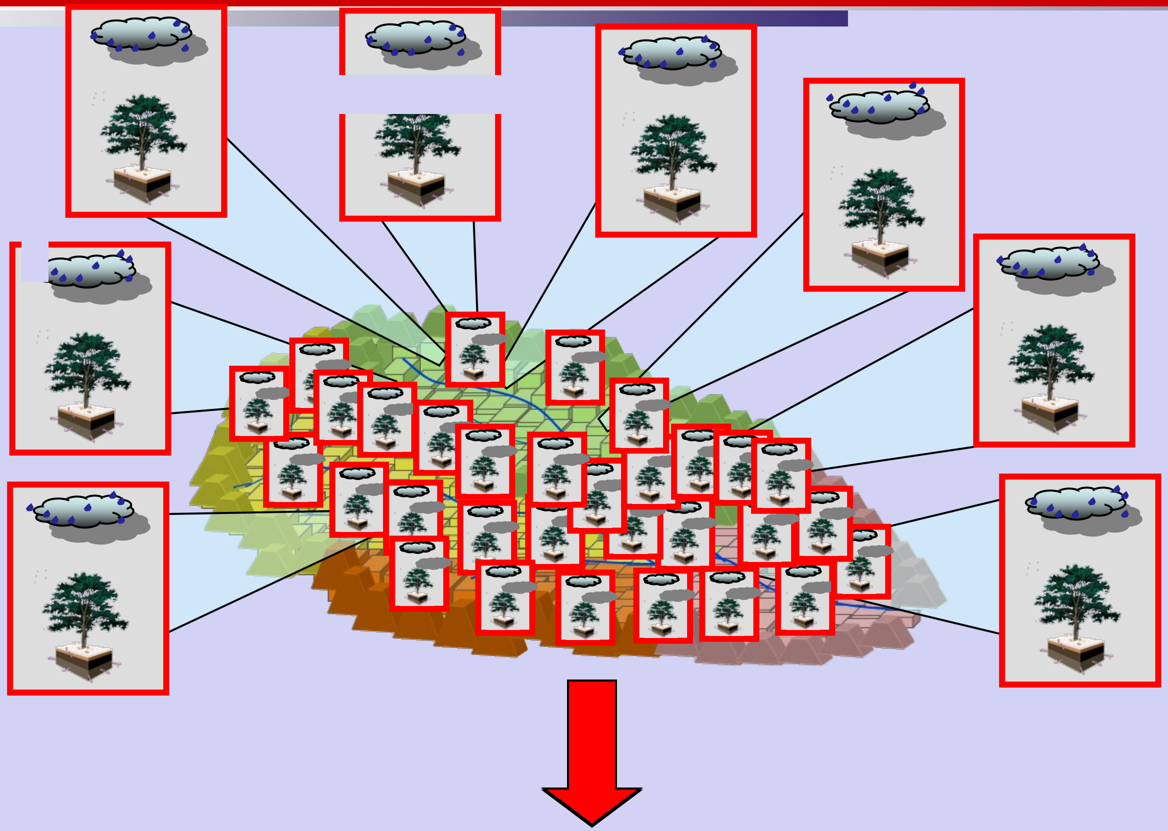
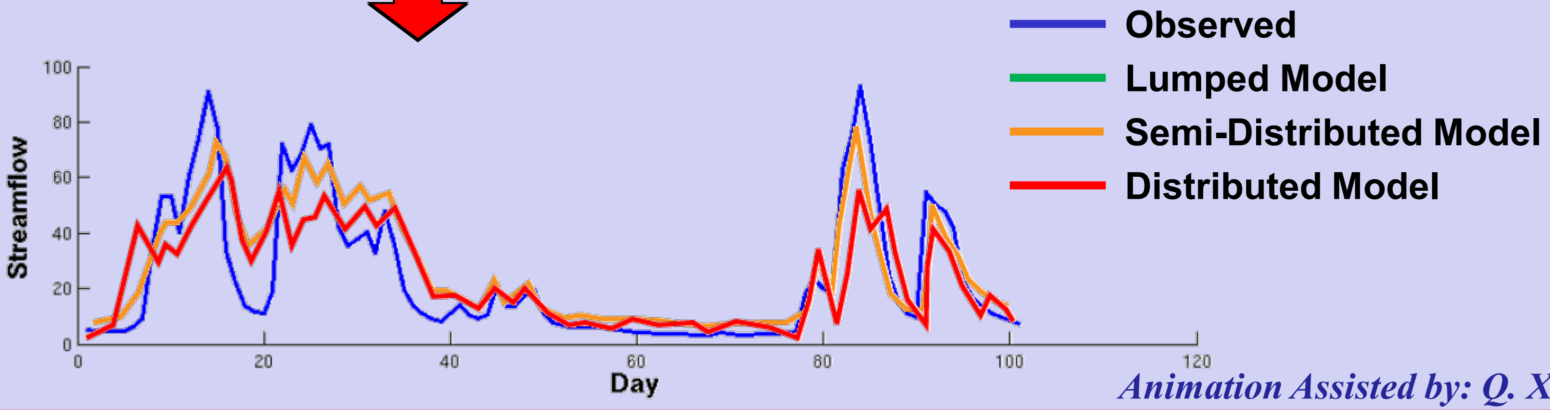
Example of Distributed Model Appl. in large Basins



Funada, 2004

Example of Distributed Model





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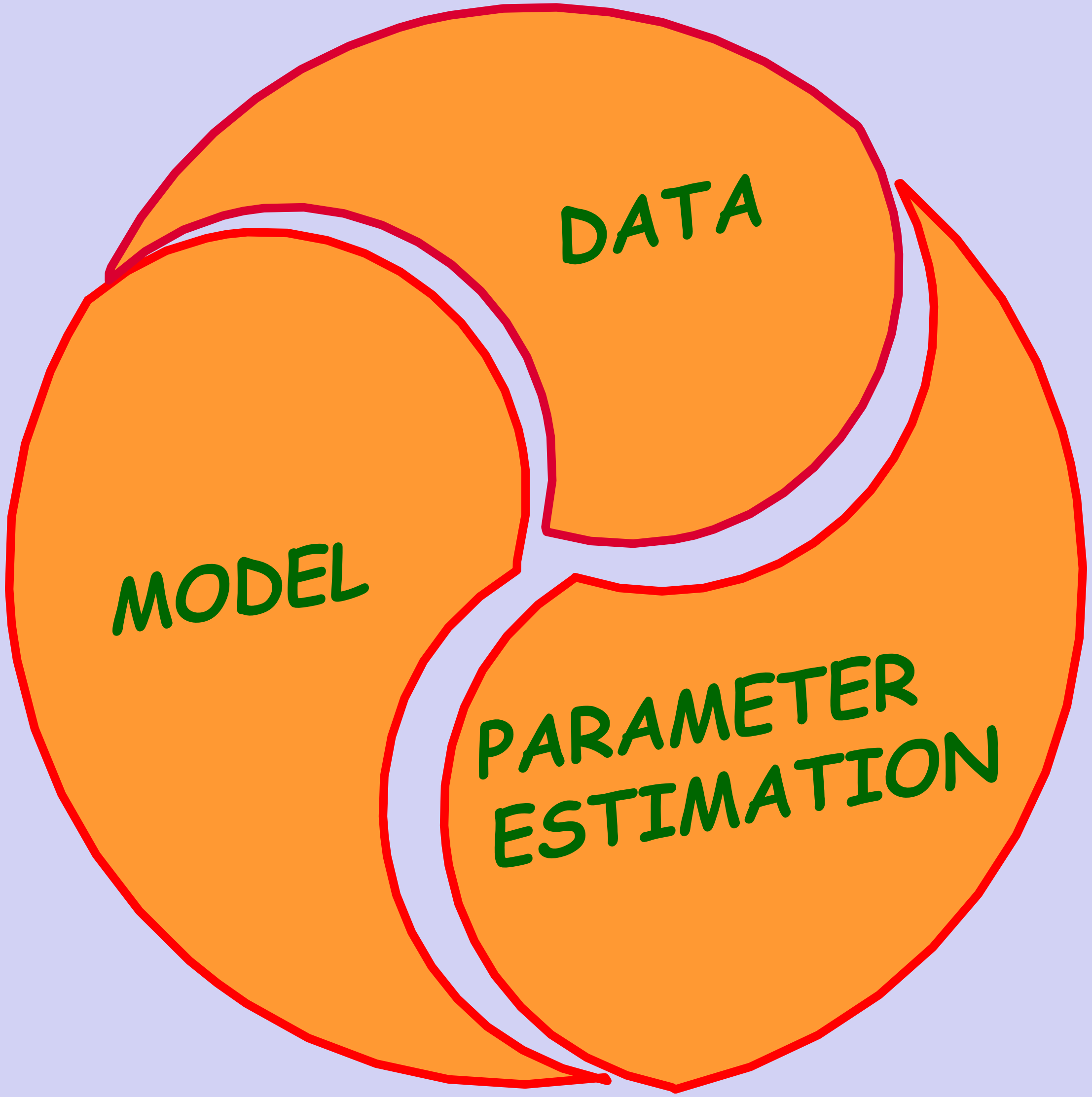
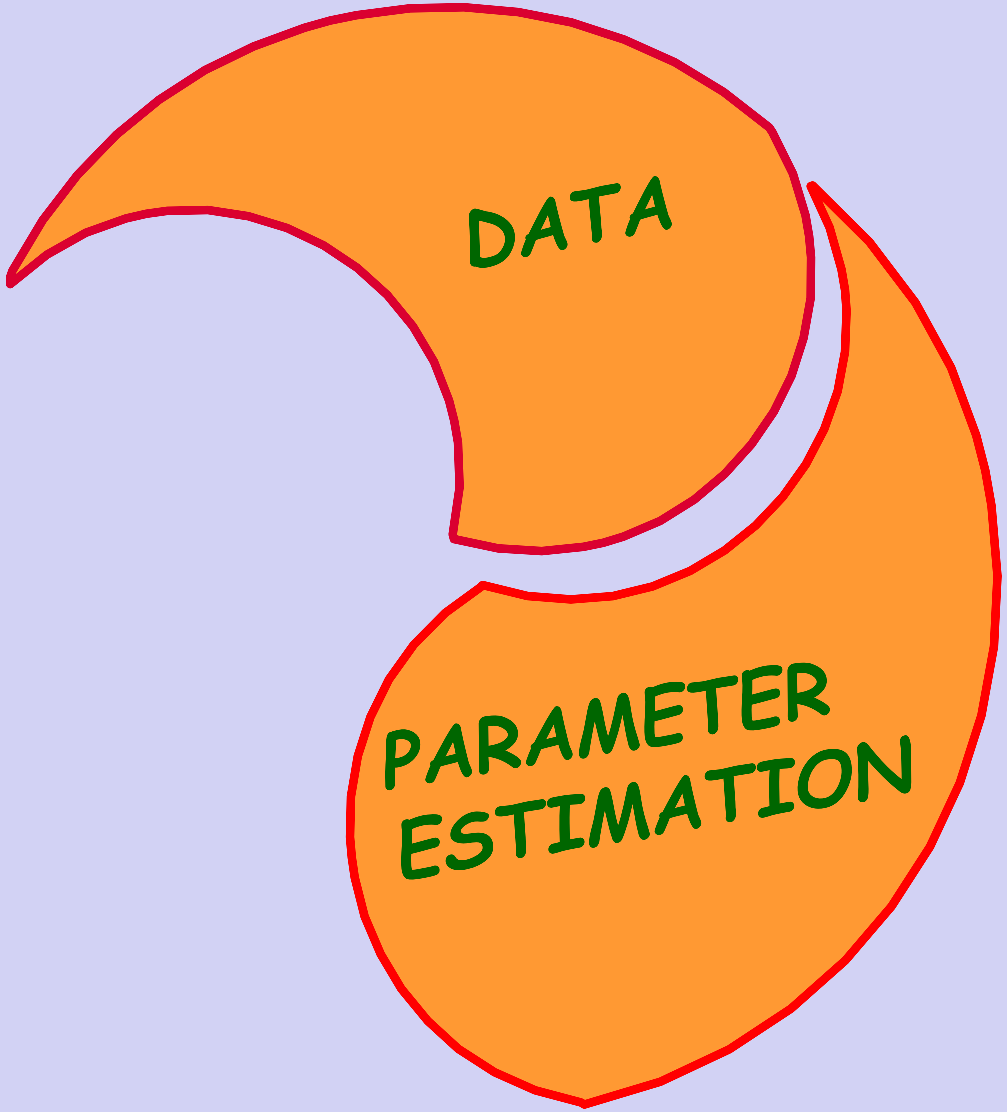
Hydrologic Modeling

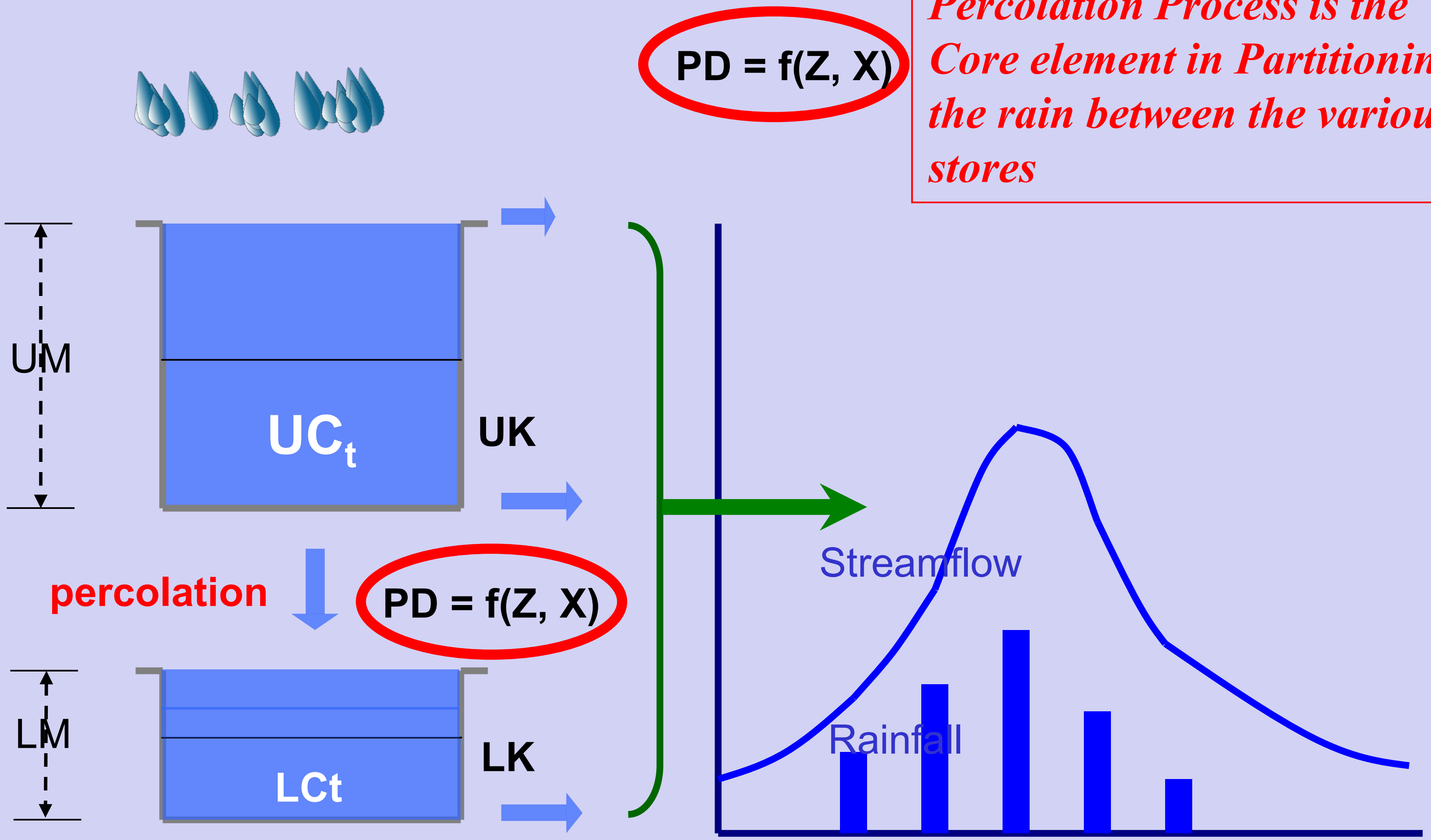


Model Calibration



A look into the "heart" of R-R Models

Percolation Process is the Core element in Partitioning the rain between the various stores



The Automatic Calibration Approach

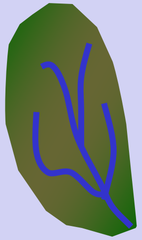
The Identification Problem

1. **Select a model structure** (Input-State-Output equations)

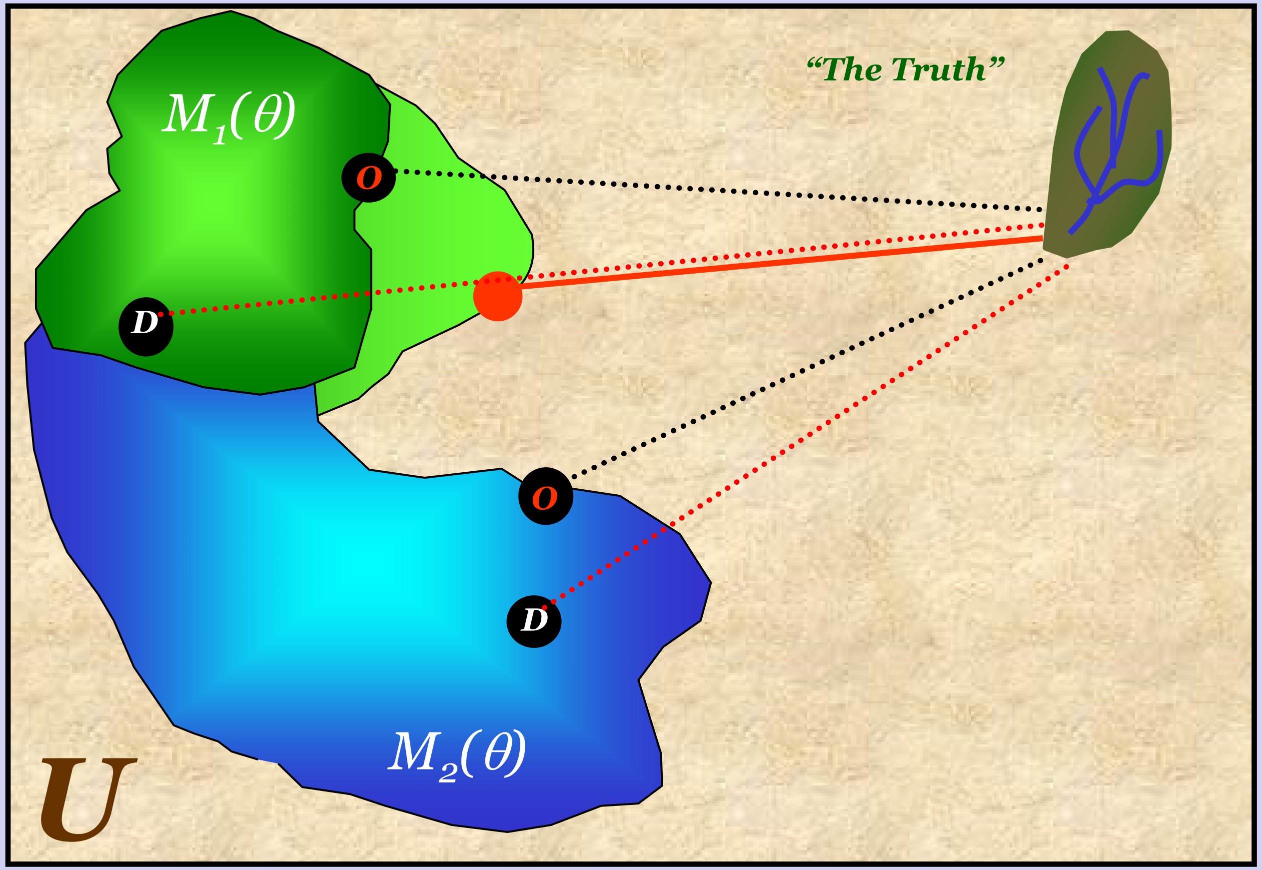
2. **Estimate values for the parameters**

U – Universal Set

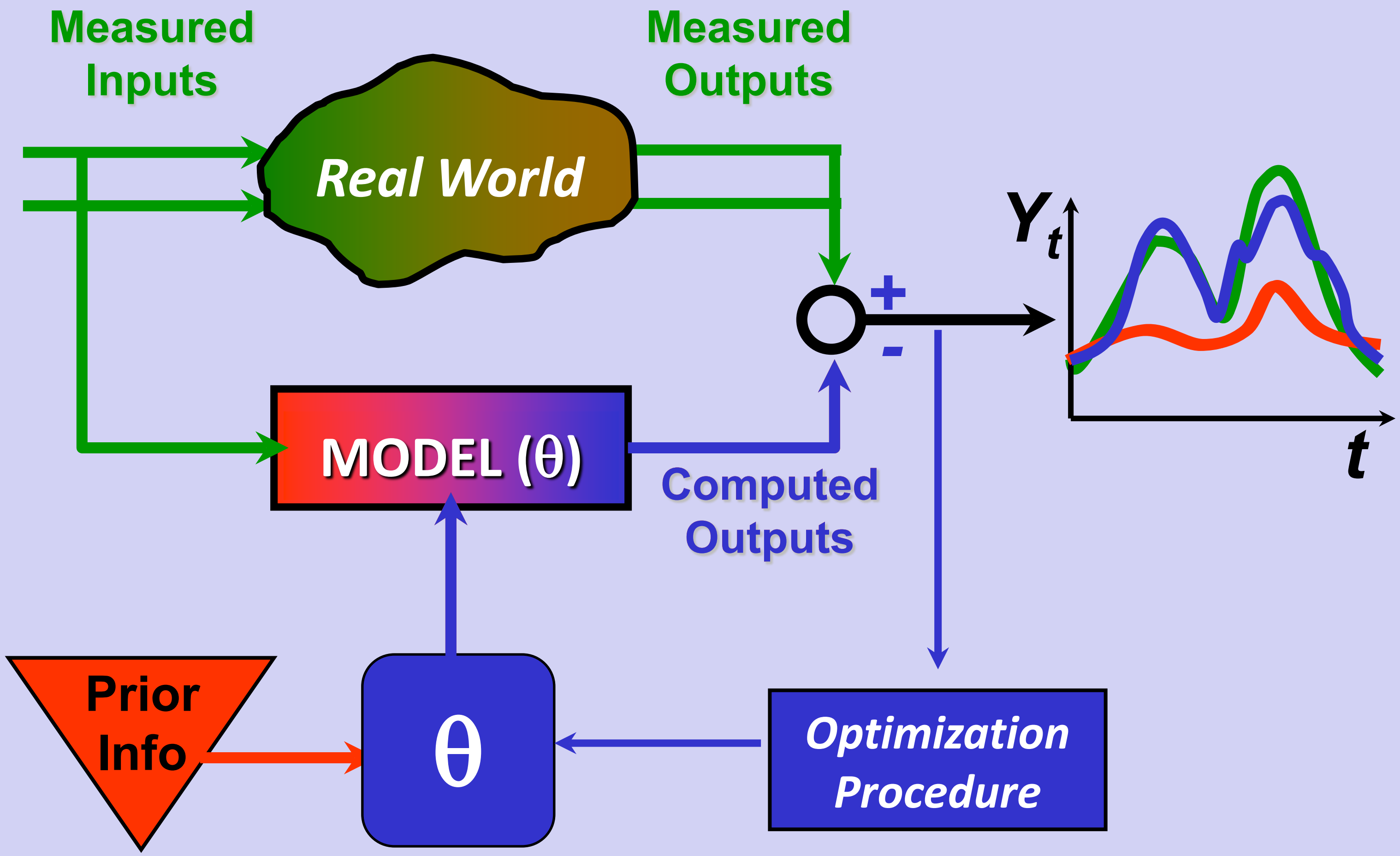
B - Basin



$M_i(\theta)$ – Selected Model Structure



The Concept of Model Calibration



"Calibration: constraining the model to be consistent with observations"

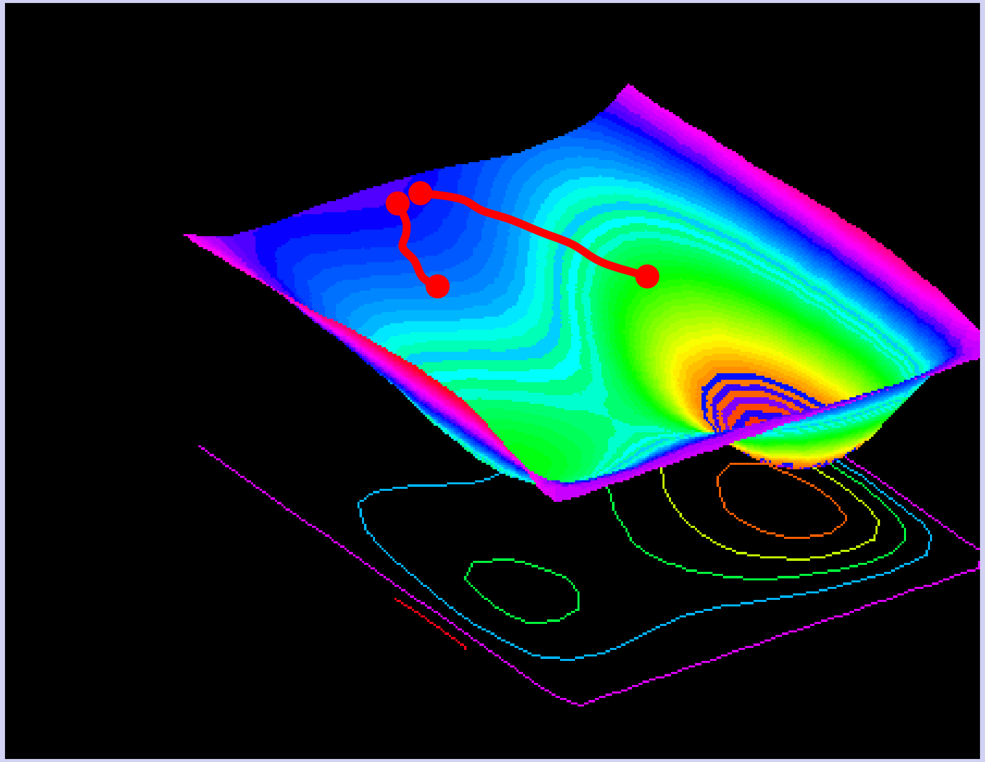
The Automatic Calibration Approach

Calibration components

Objective Function

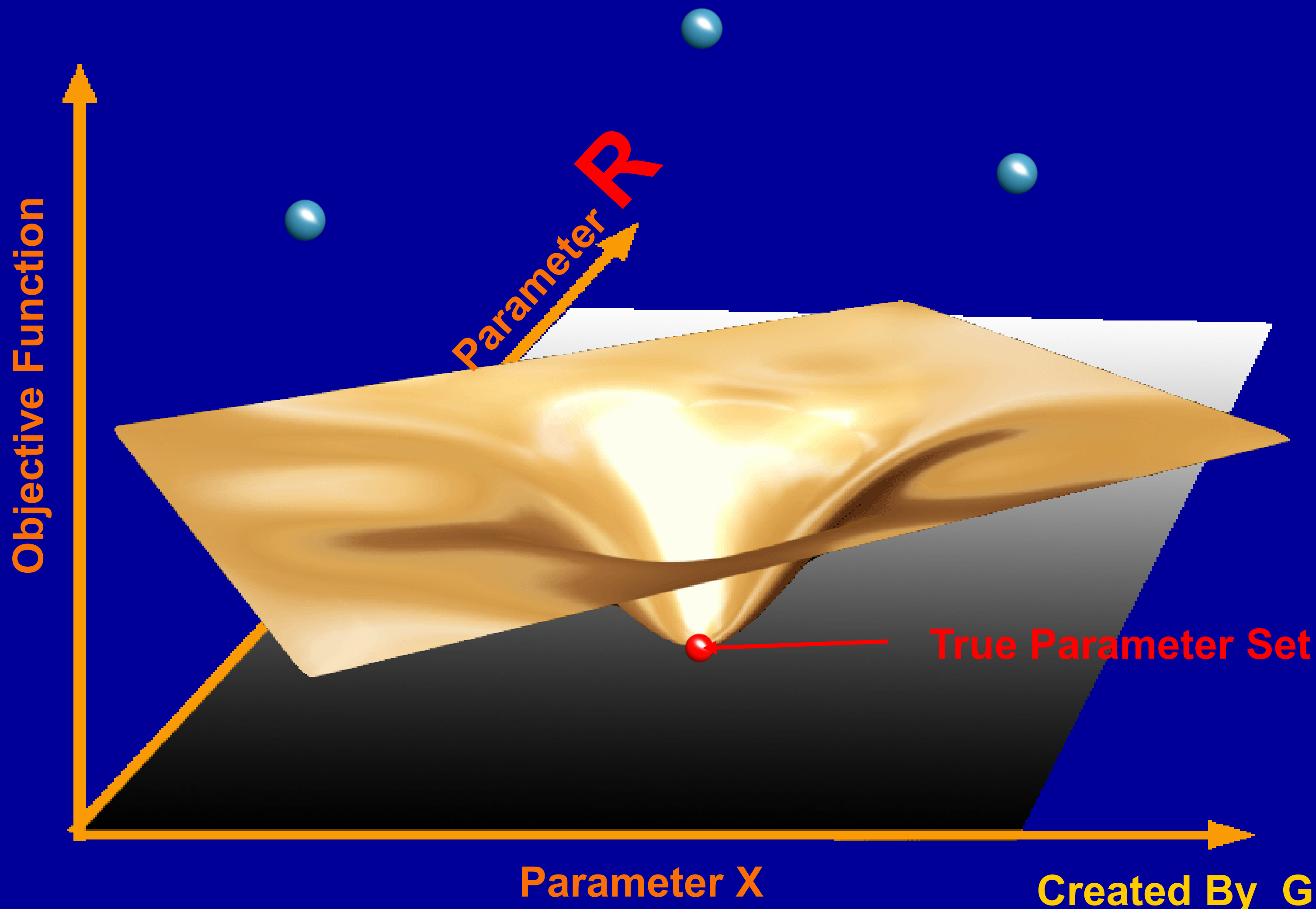
Search Algorithm

Sensitivity Analysis



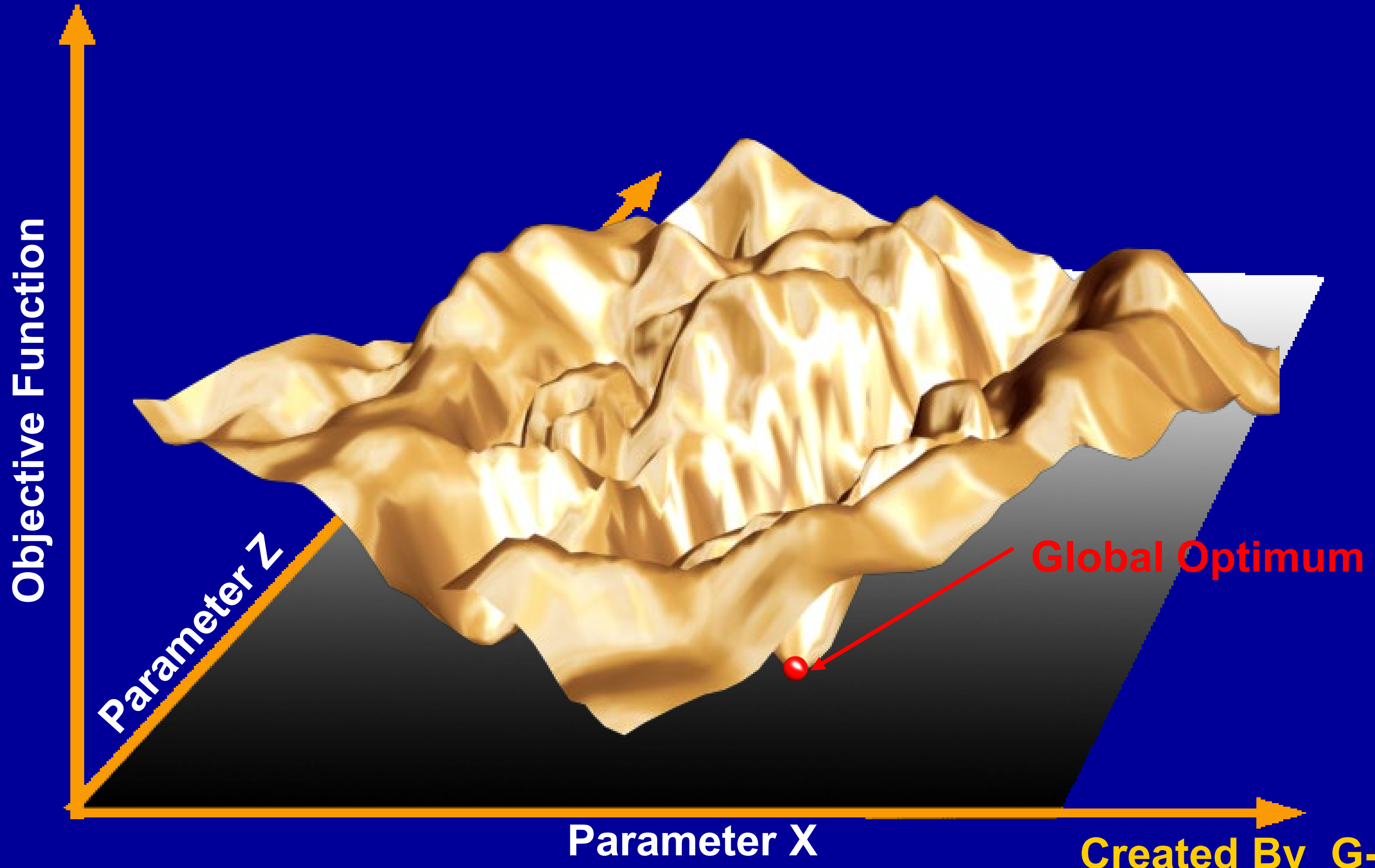
Problems with identifiability

The Ideal case: Convex Optimization



Created By G-H Park

Parameter Estimation (non-convex, multi-optima)



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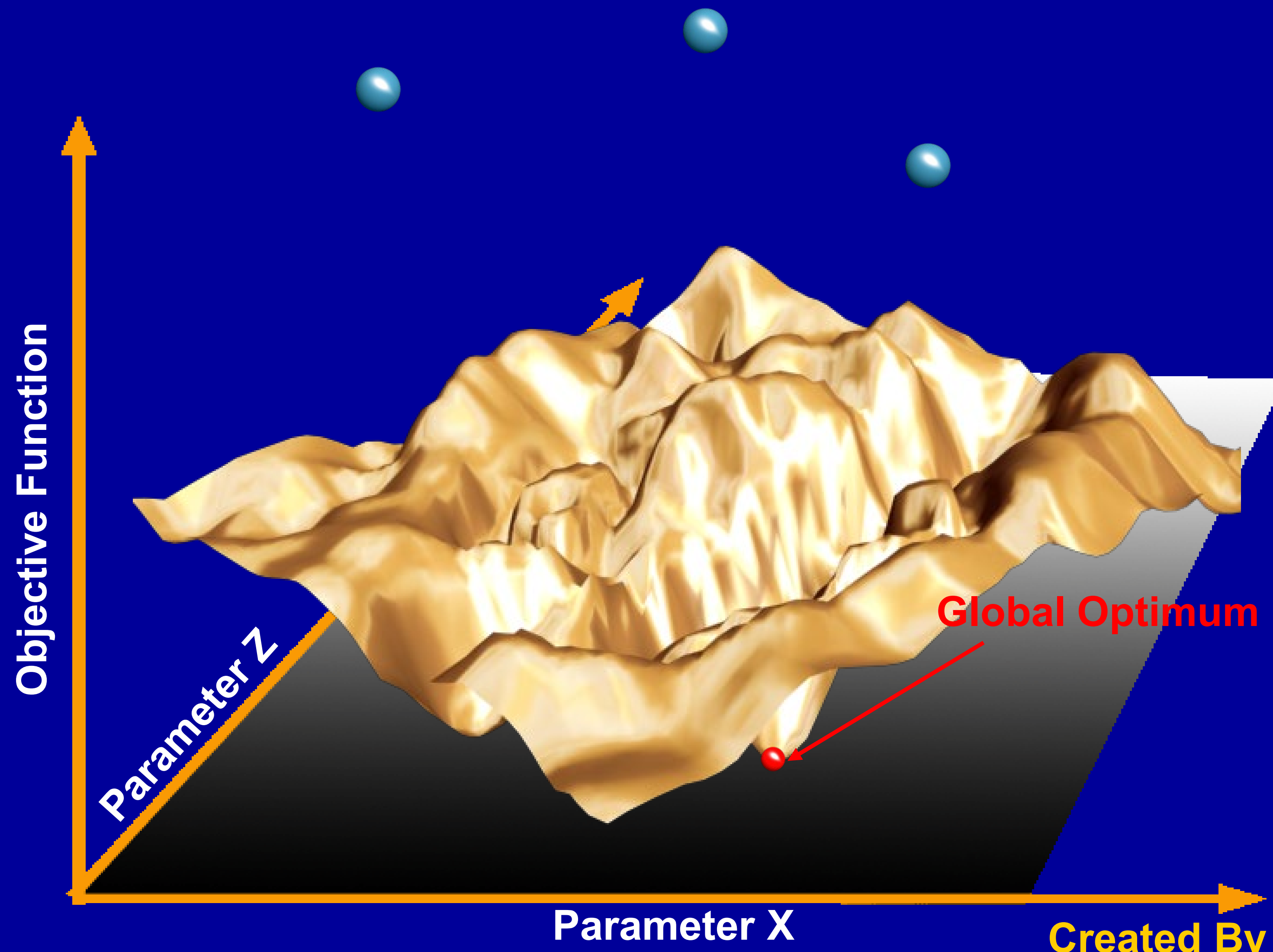
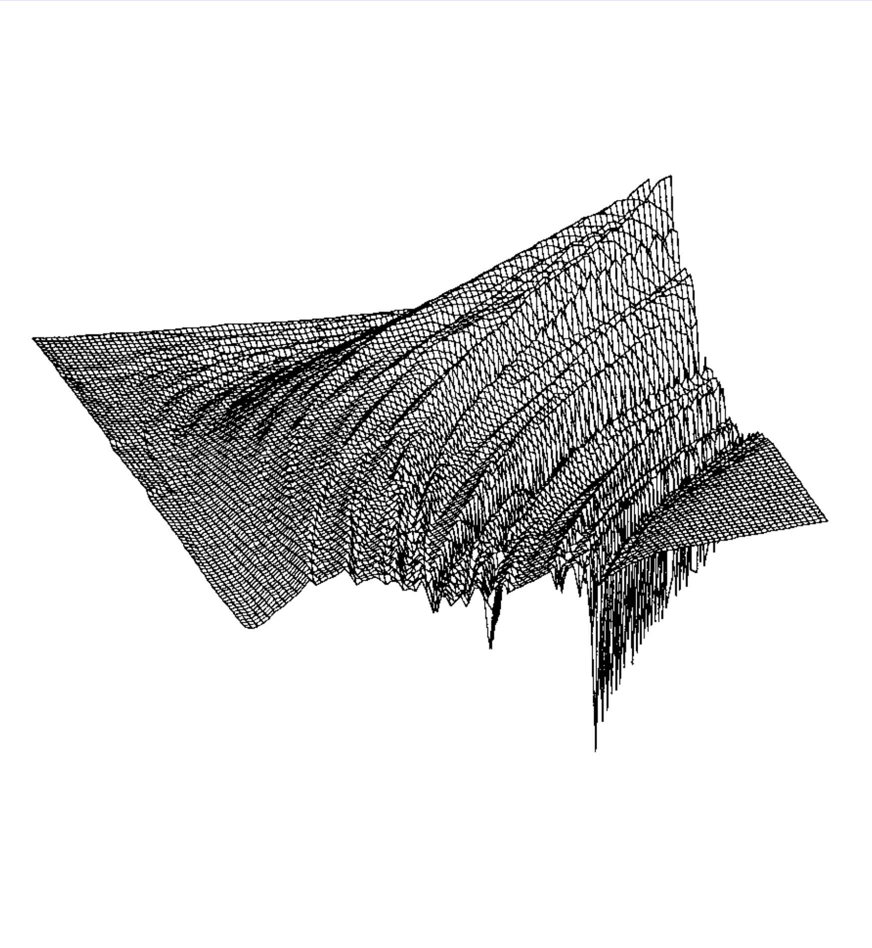
Parameter Estimation (non-convex, multi-optima)



Created By G-H Park

Difficulties in Optimization

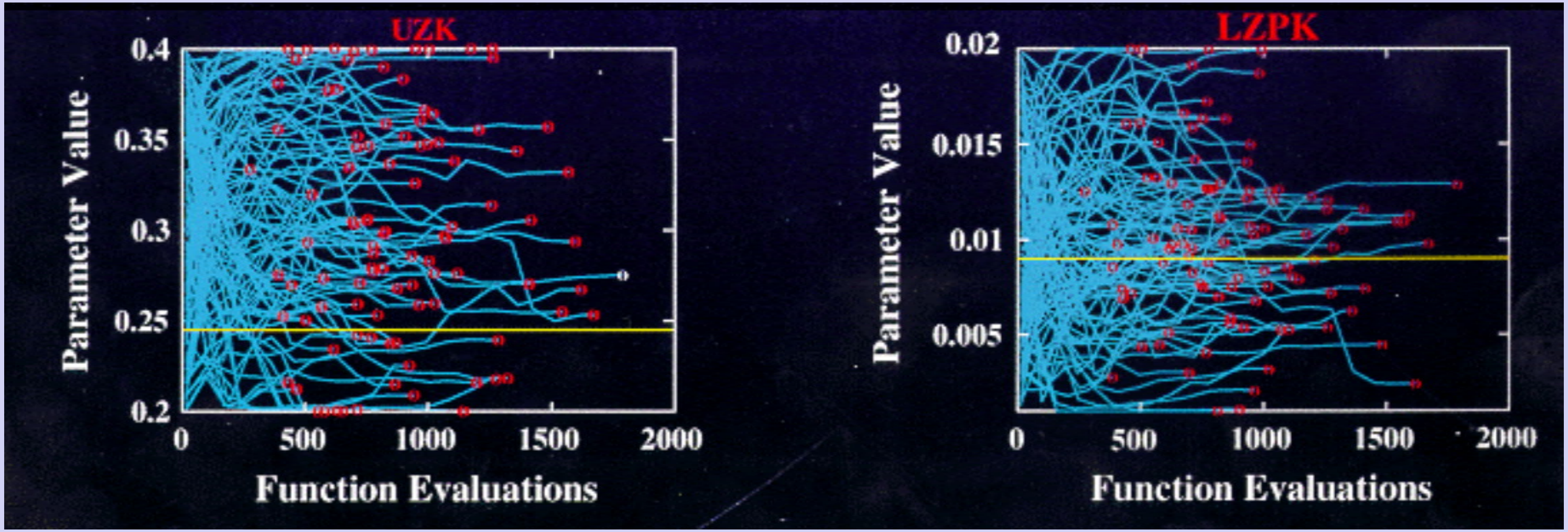
1.- Regions of Attraction	*More than one main convergence region*
2.- Local Optima	*Many small "pits" in each region*
3.- Roughness	*Rough surface with discontinuous derivatives*



Duan, Gupta, and Sorooshian, 1992, WRR

Optimization Strategy – Local Direct Search

Calibration of the Sacramento Model
Downhill Simplex Method, *Nelder & Mead, 1965*

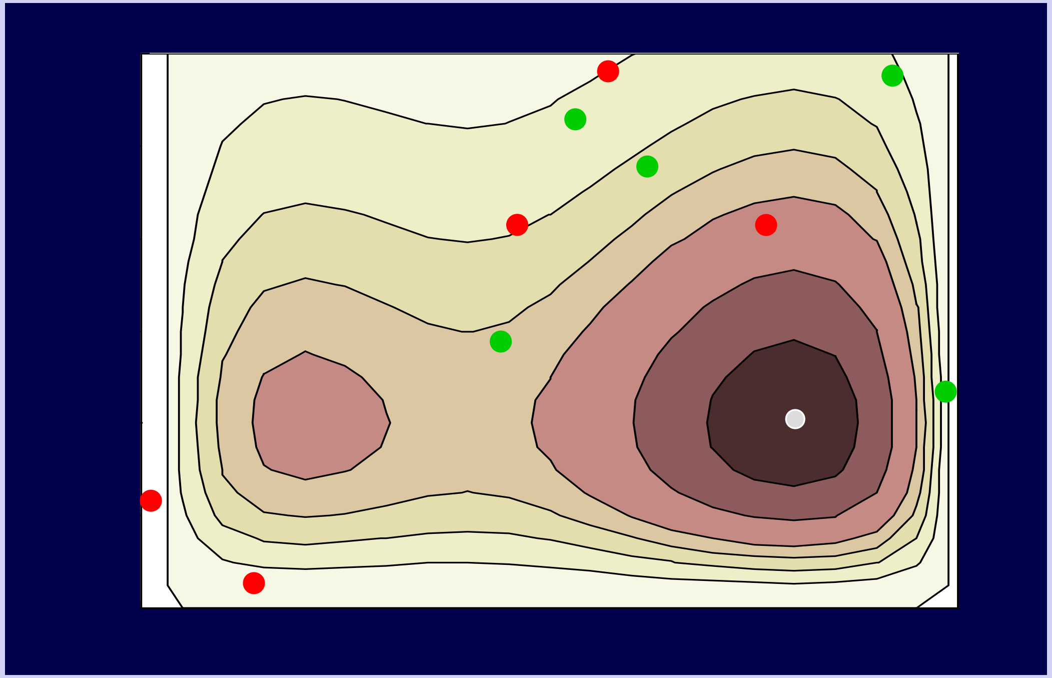


Duan, Gupta, and Sorooshian, 1992, WRR

The SCE-UA *Algorithm …* *(1992)*

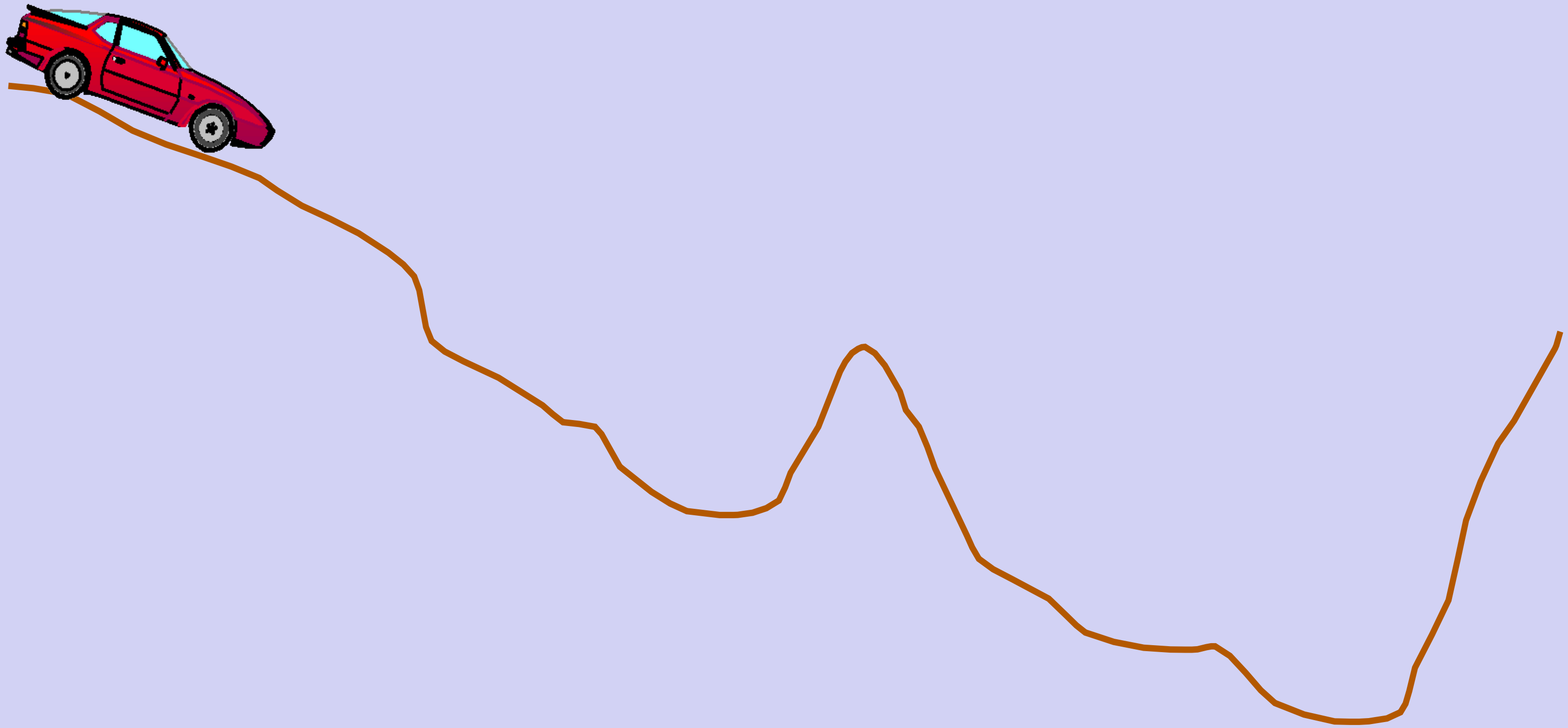
Duan, Gupta, and Sorooshian, 1992, WRR

The SCE-UA *Algorithm* …

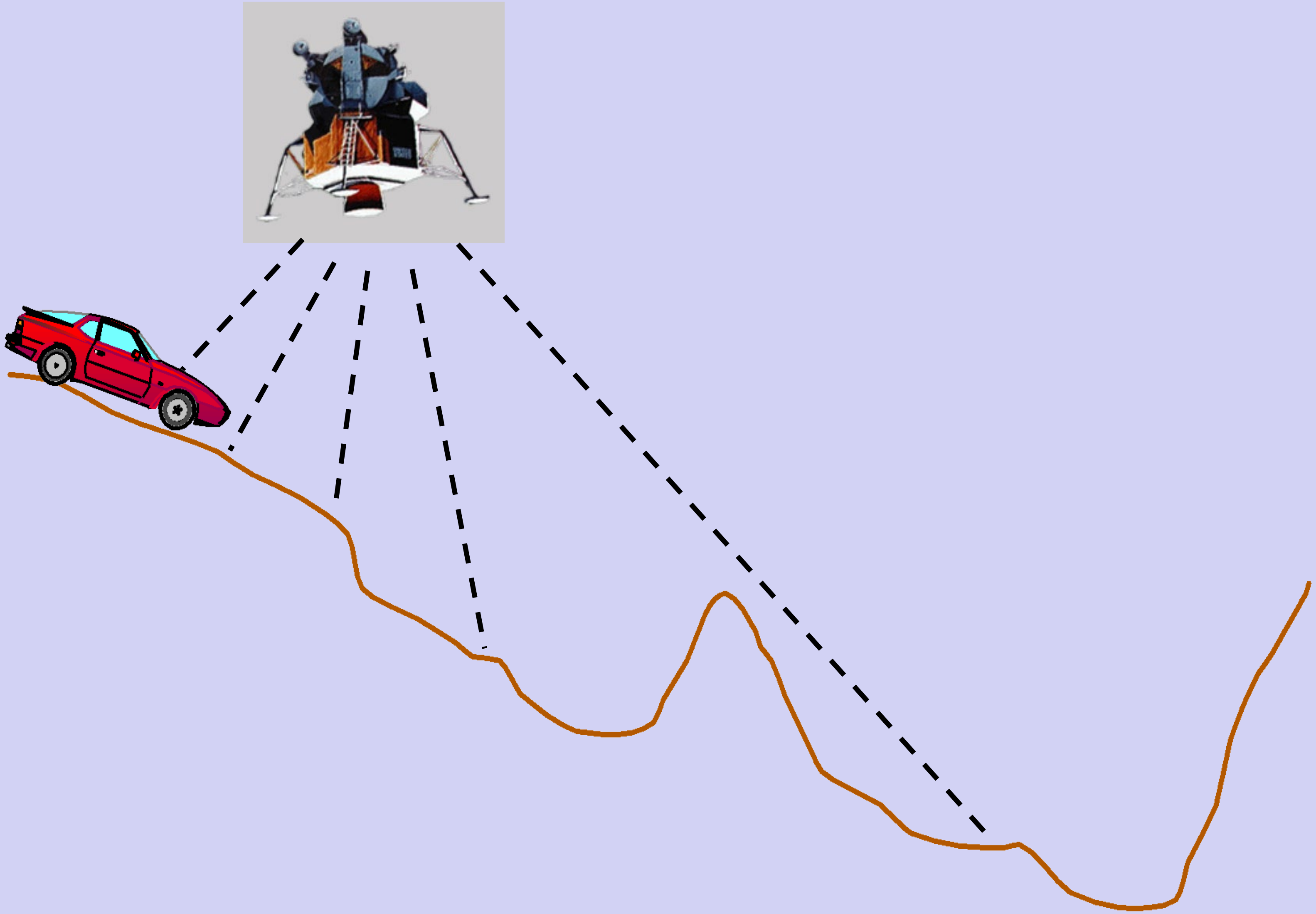


Duan, Sorooshian, and Gupta 1992, WRR

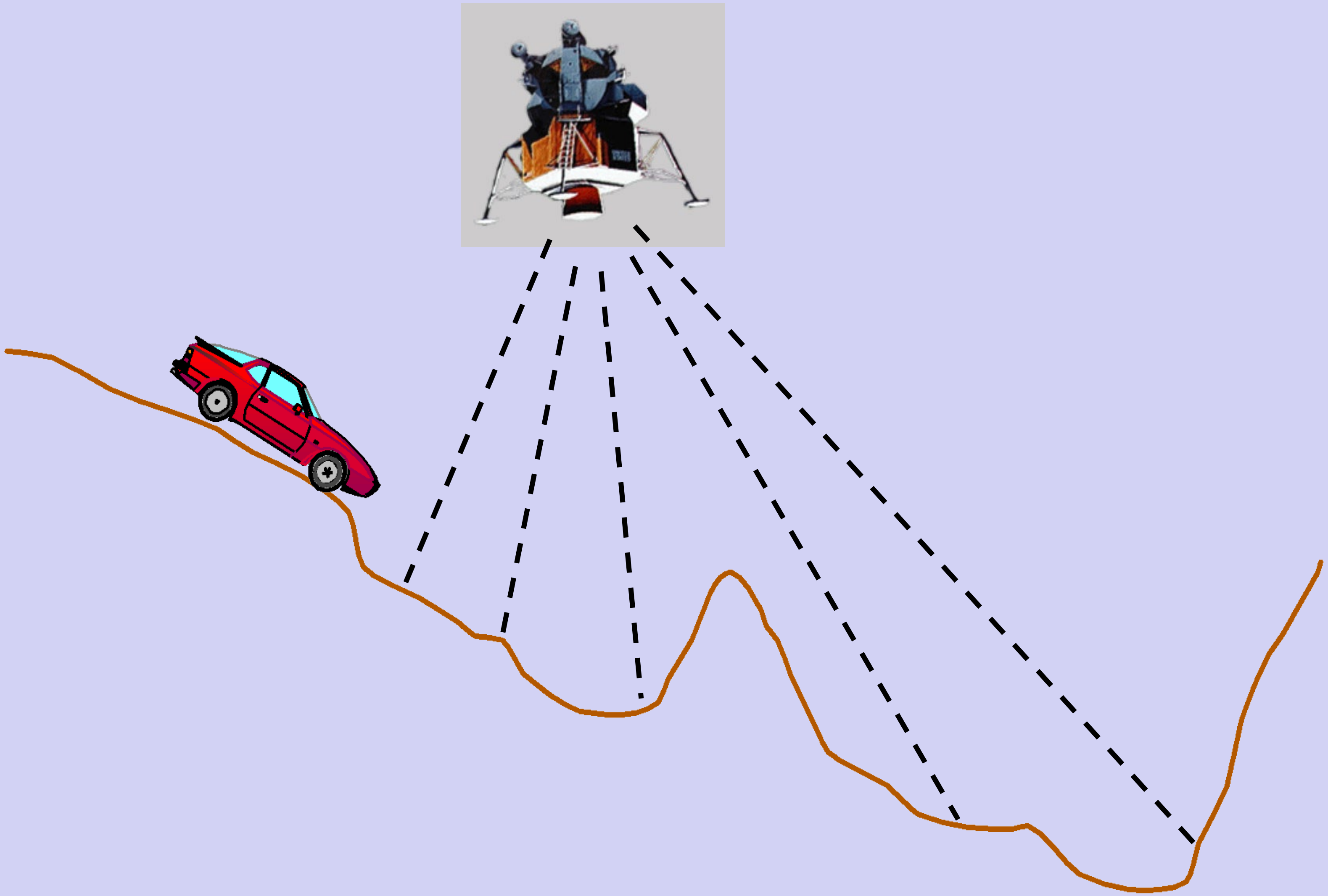
The Concept Behind SCE Method



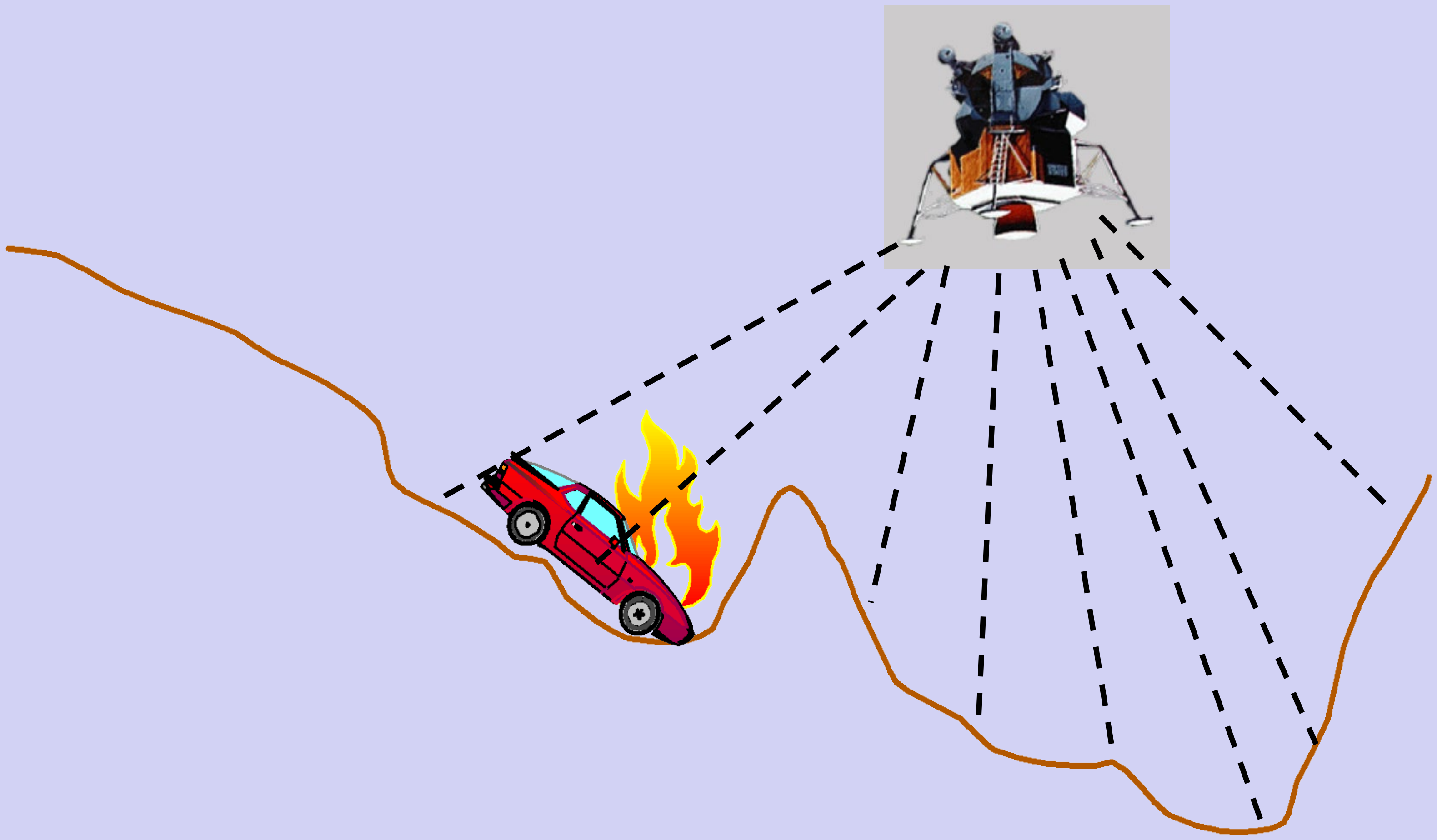
The Concept Behind SCE Method



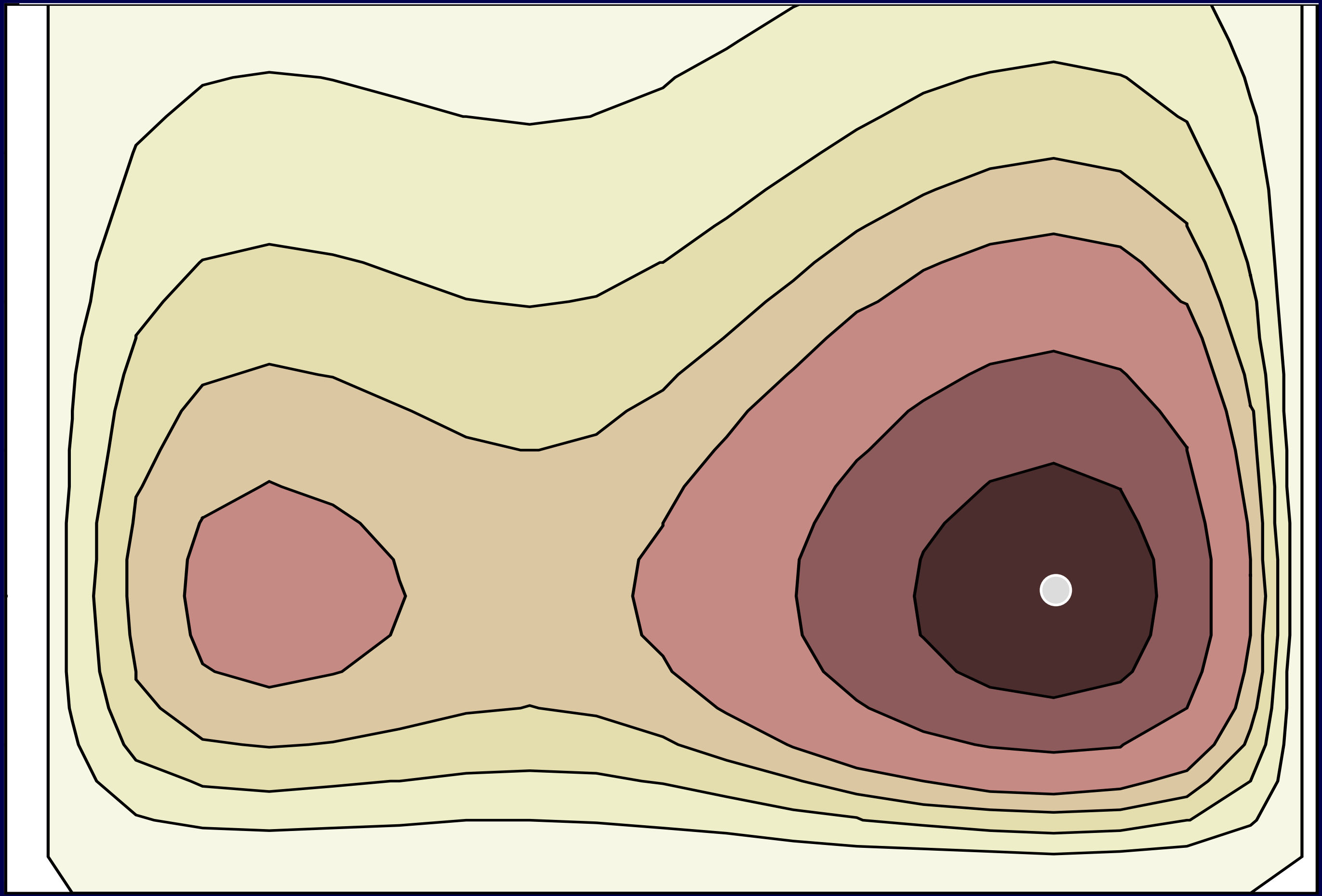
The Concept Behind SCE Method



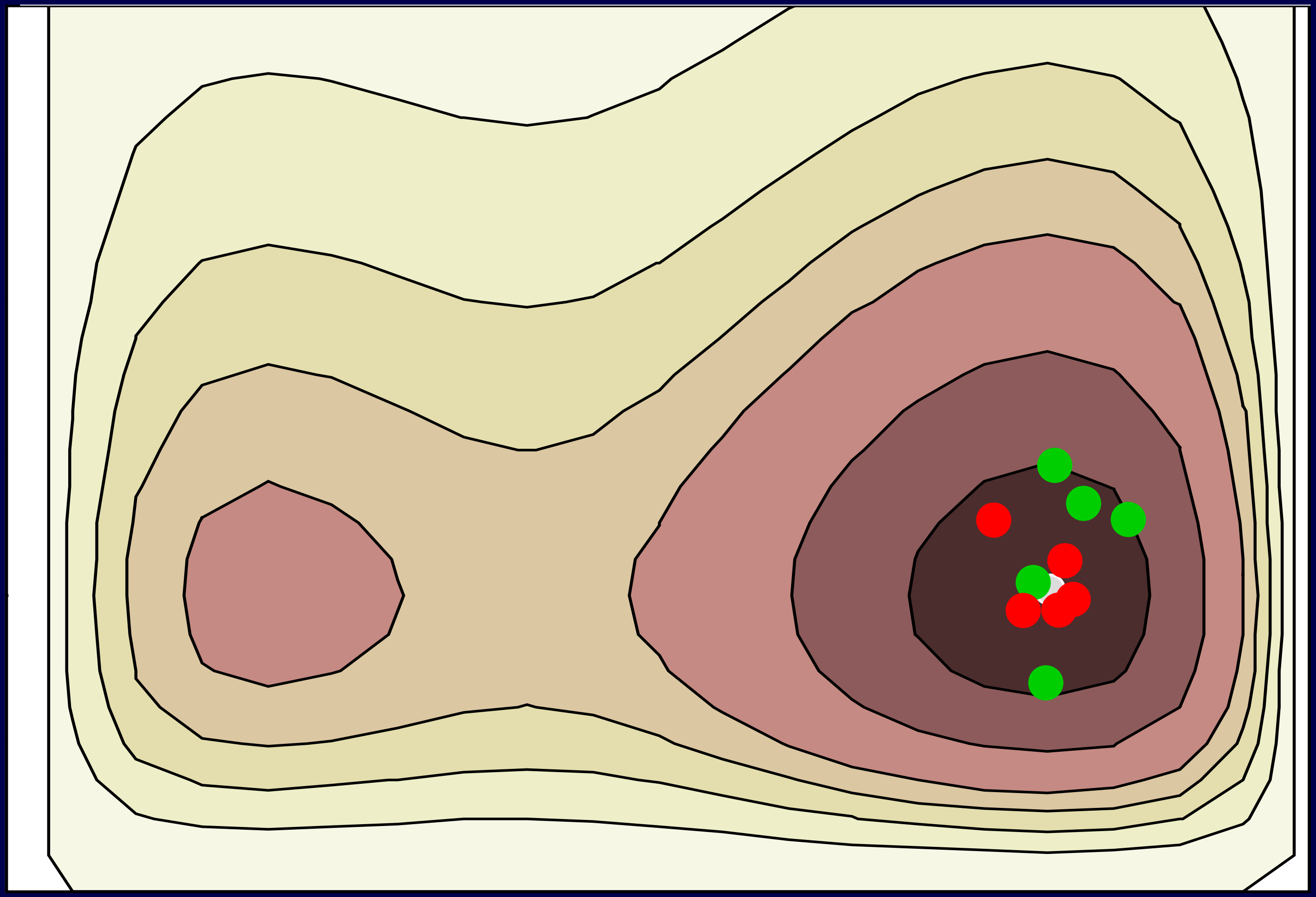
The Concept Behind SCE Method



SCE Method – How it works …



Shuffled Complex Evolution (SCE-UA)

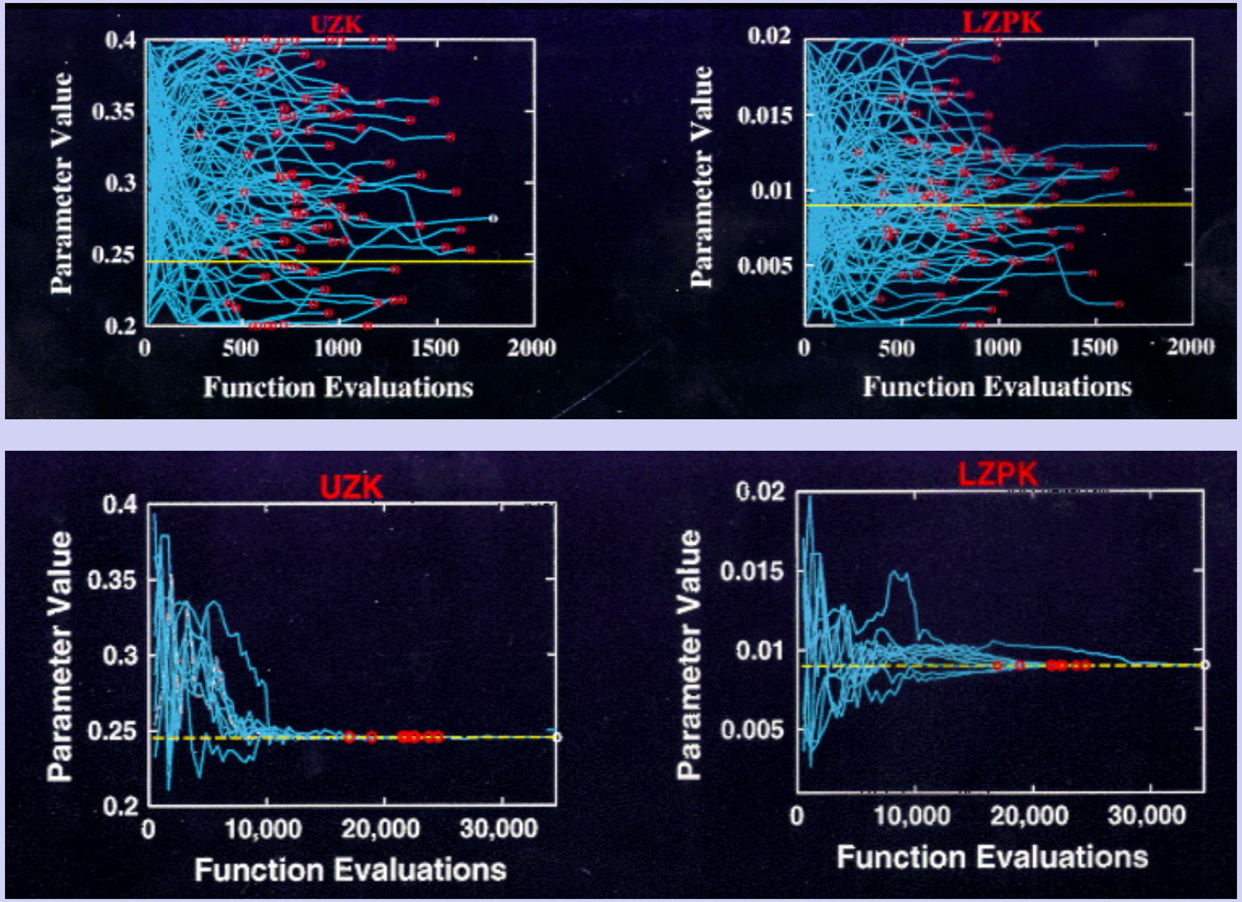


Global Optimization – The SCE-UA Algorithm

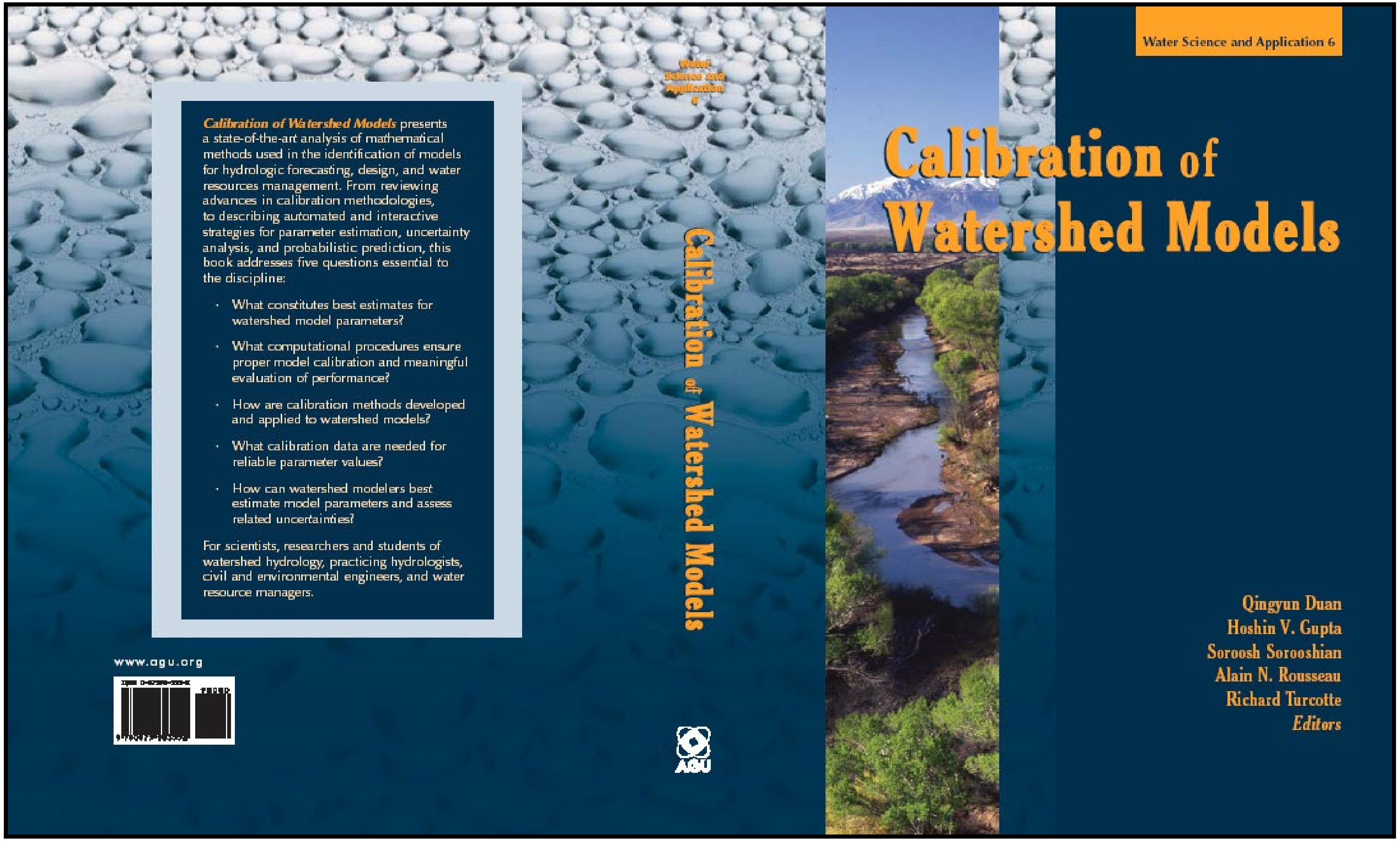
Duan, Gupta & Sorooshian, 1992, WRR

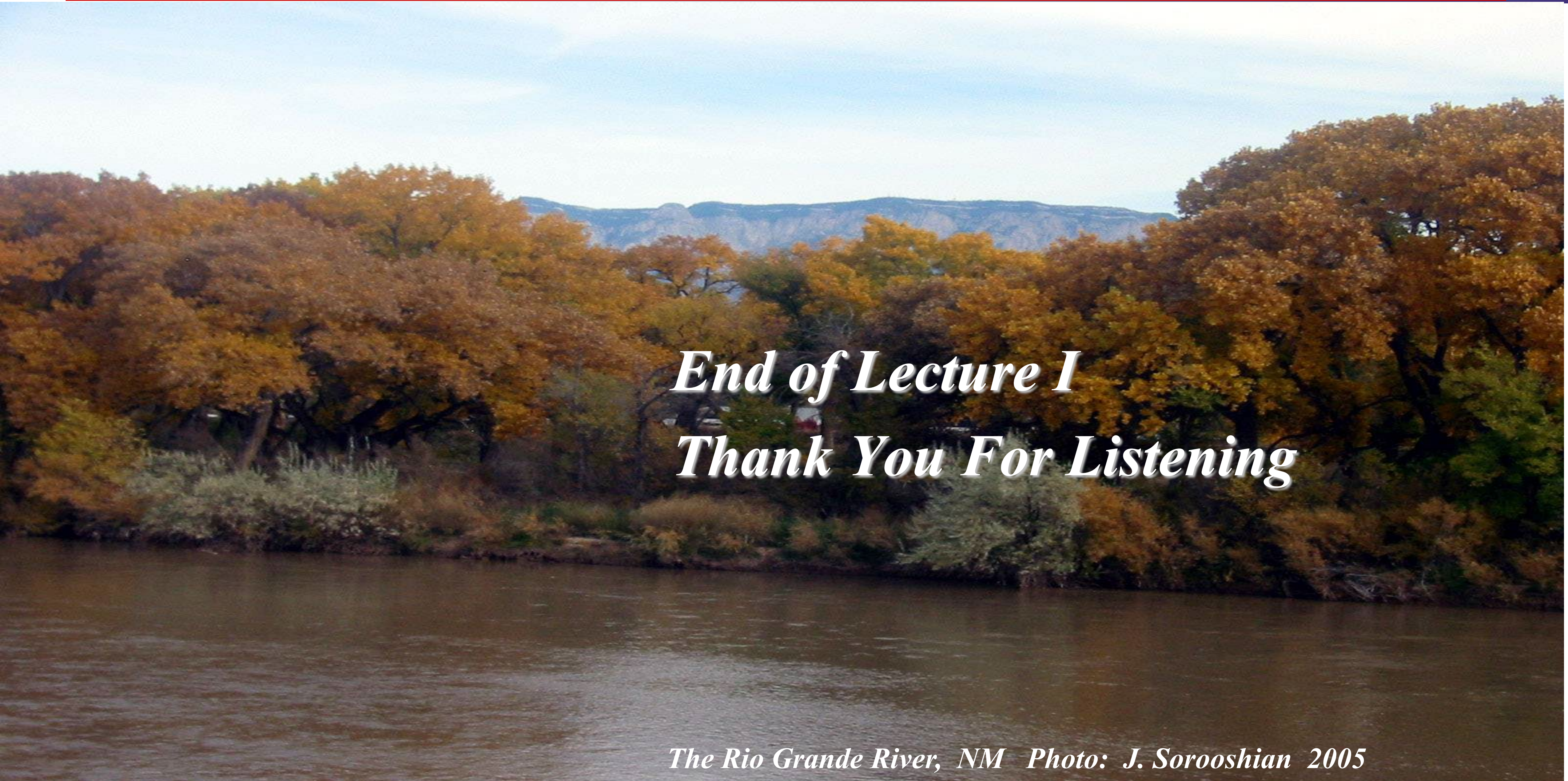
Simplex Method

Shuffled Complex Evolution (SCE-UA)



AGU Monograph – Now Available





End of Lecture I

Thank You For Listening

The Rio Grande River, NM   Photo: J. Sorooshian 2005