地理信息系统与遥感应用

# 第十六讲 GIS/RS综合应用

南方科技大学 · 环境科学与工程学院

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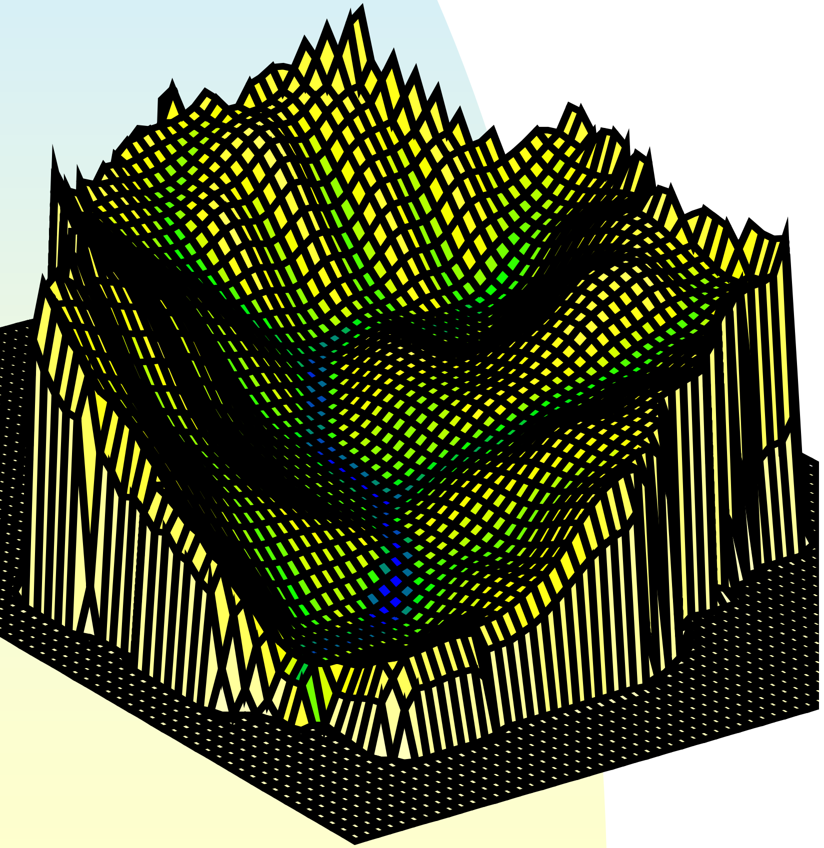
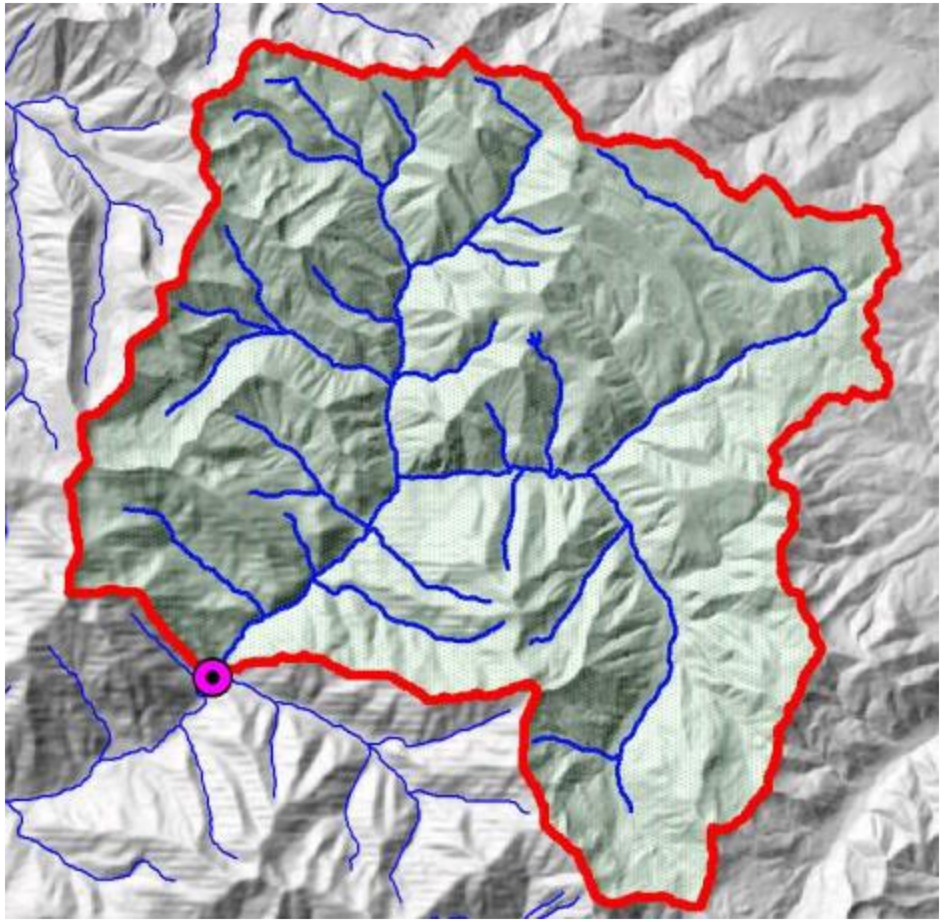
2018年12月19日

# Digital Elevation Model Based Watershed and Stream Network Delineation



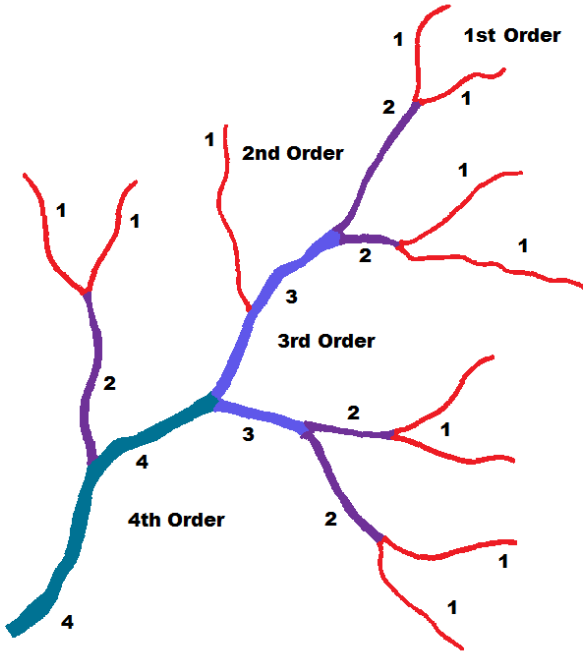
- Conceptual Basis
- Eight direction pour point model (D8)
- Flow accumulation
- Pit removal
- Stream network delineation

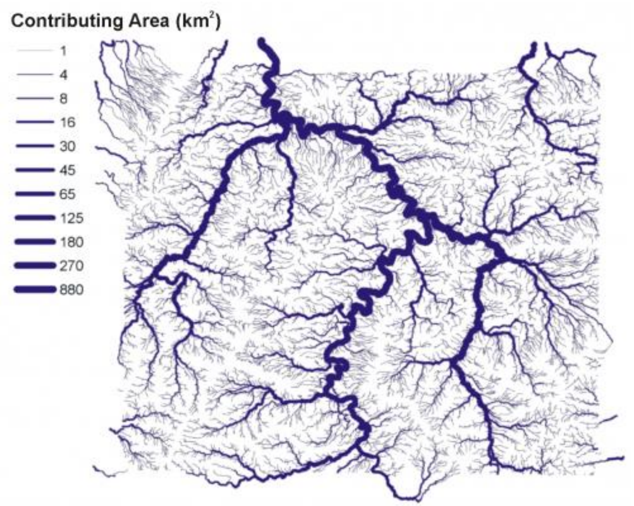
# Introduction to Delineation



- Creating a boundary that represents the contributing area for a particular control point or outlet
- Used to define boundaries of the study area, and/or to divide the study area into sub-areas

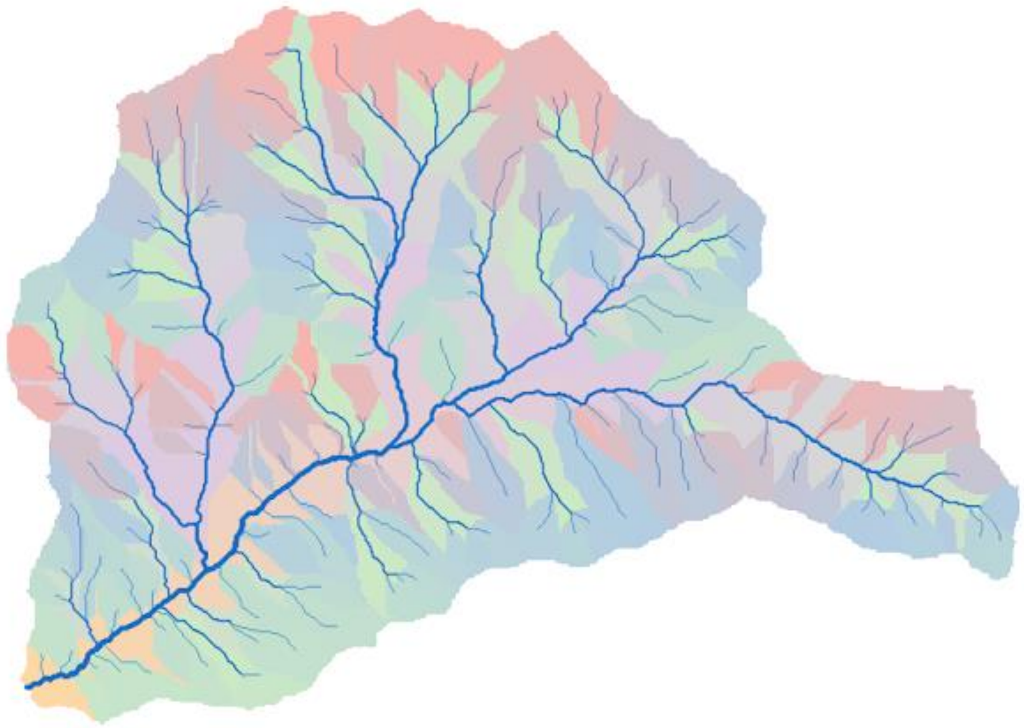
# Why Delineate



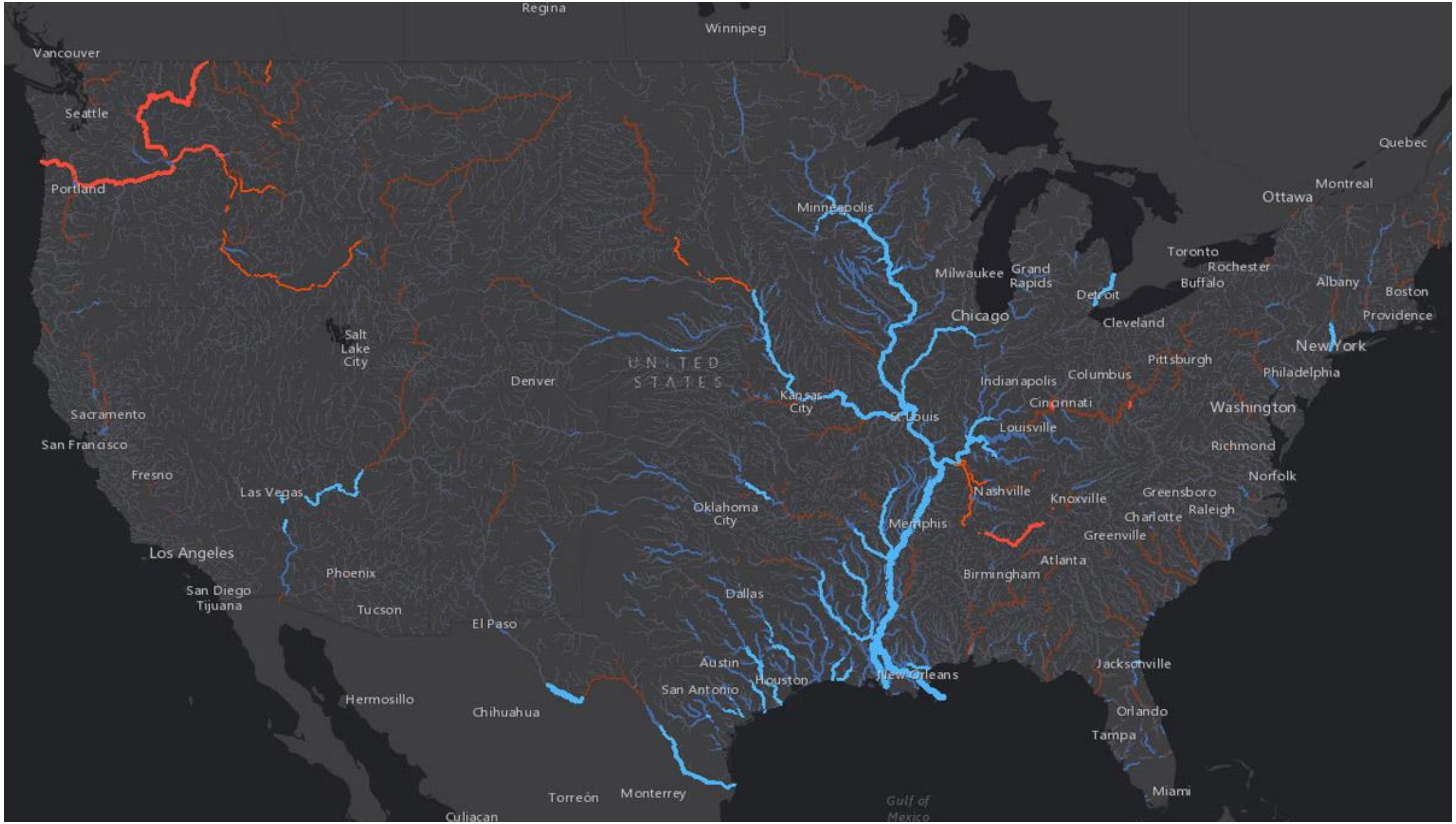

- Delineated watersheds and stream networks are required for most of hydrological modeling
- We can characterize and investigate what is going on in one portion of the study area versus another
- Dividing the watershed into discrete land and channel segments enables us to analyze watershed behavior

# How to Delineate



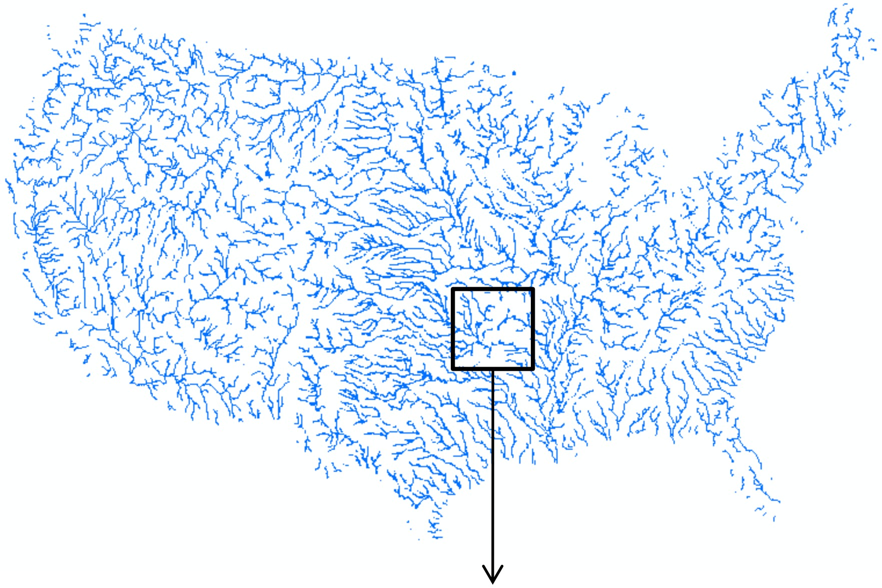
- Automatic (DEM based) delineation
    - DEM grids
- Manual delineation
    - From existing watershed boundaries and stream layers

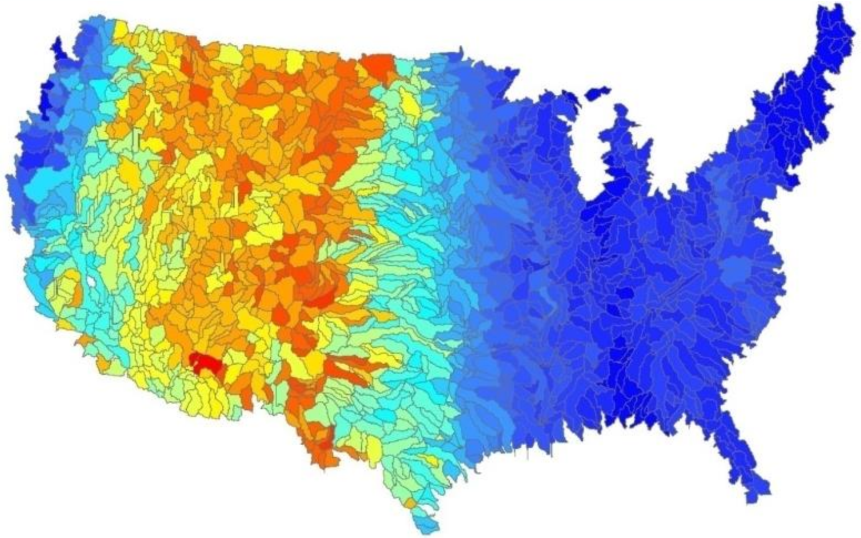
# Why Automatic Delineation Required



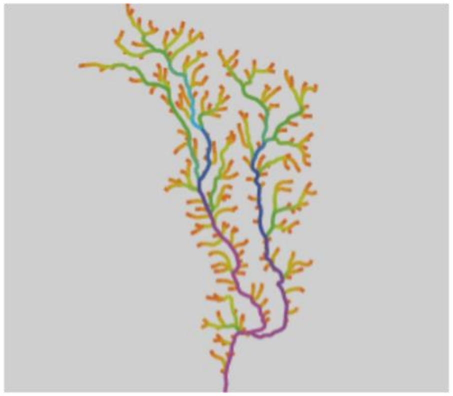

- 运行于UIUC的国家超算中心，实时预测全美270万条河段内的流量变化
- 从此水文系统能够像天气系统一样，实现从局部到全国的实时预测

# National Water Model



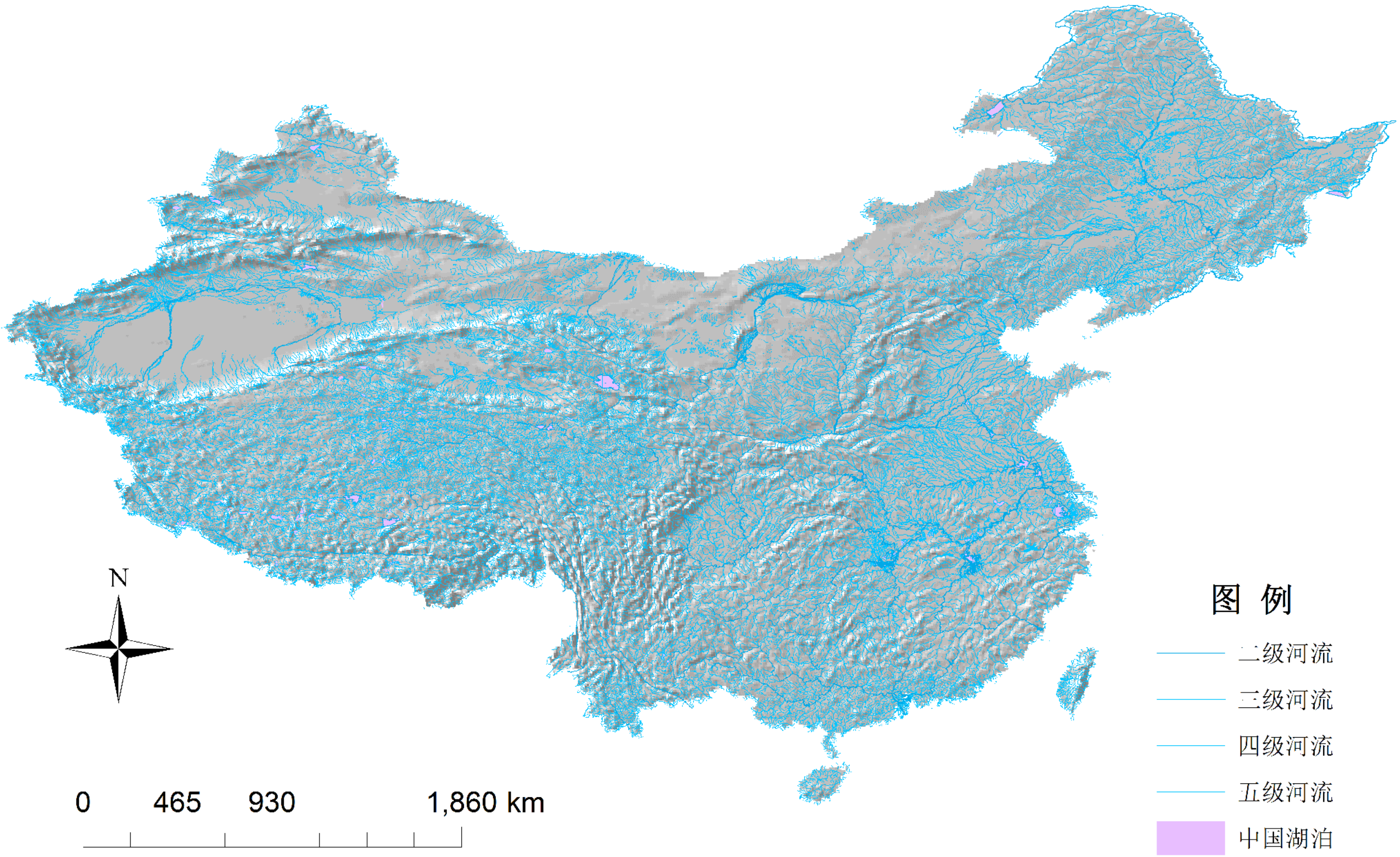


simulated inundation extent



http://water.noaa.gov

# China Water Model

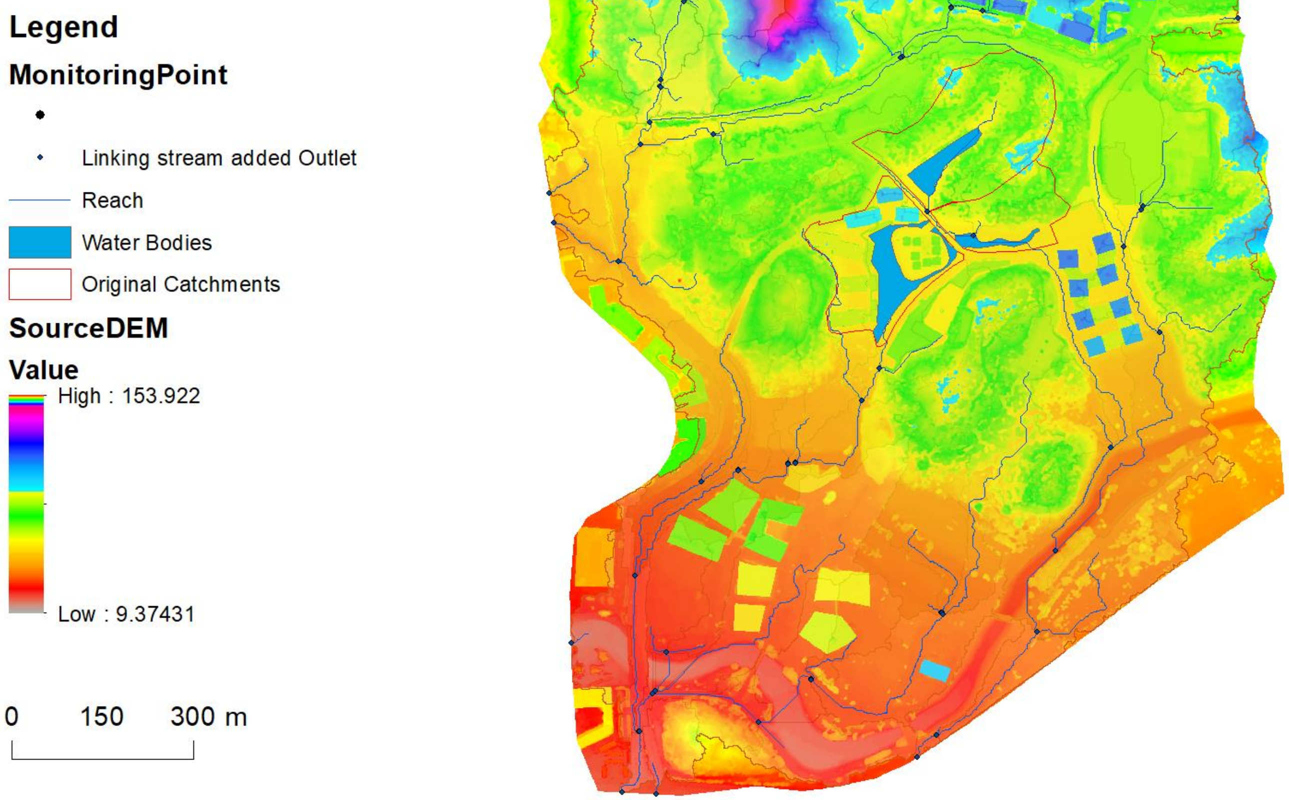



Proposed by Prof. Zheng Chunmiao in 2009

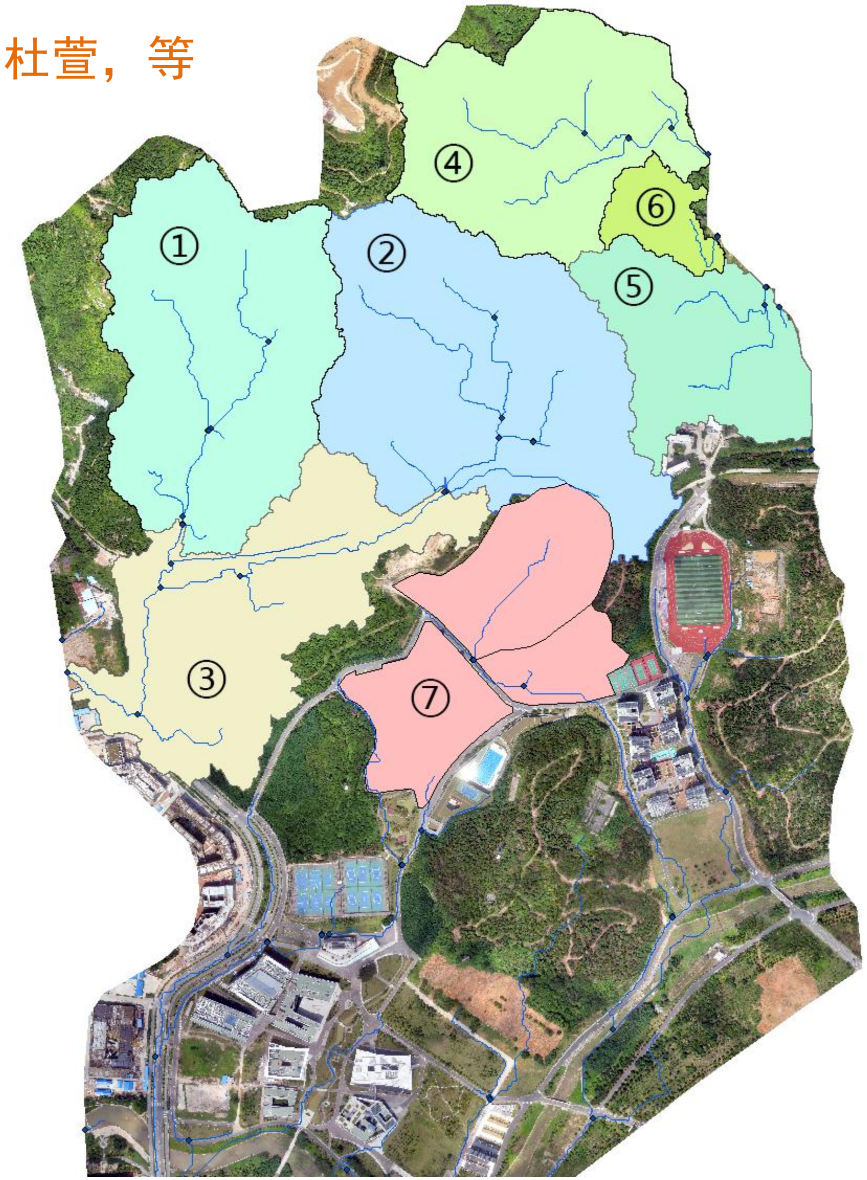
# SUSTech Water Model

俞启星，等

南科大高程图

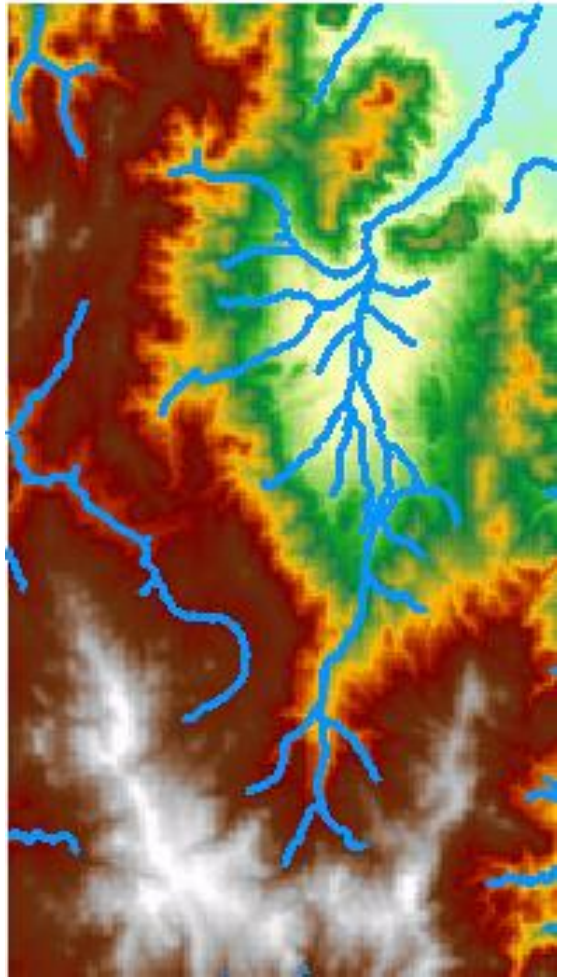



杜萱，等

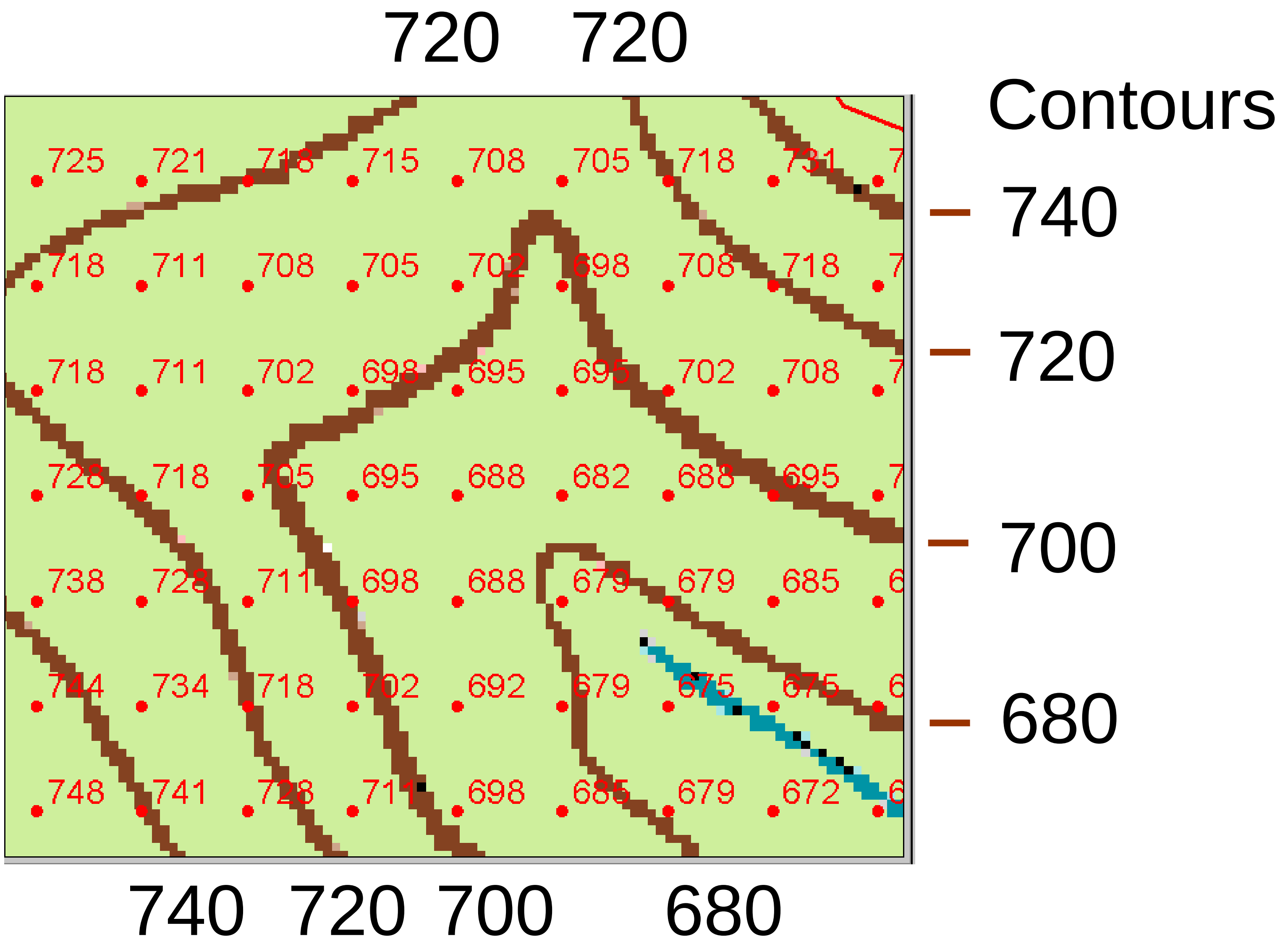


# Duality between Terrain and Drainage Network

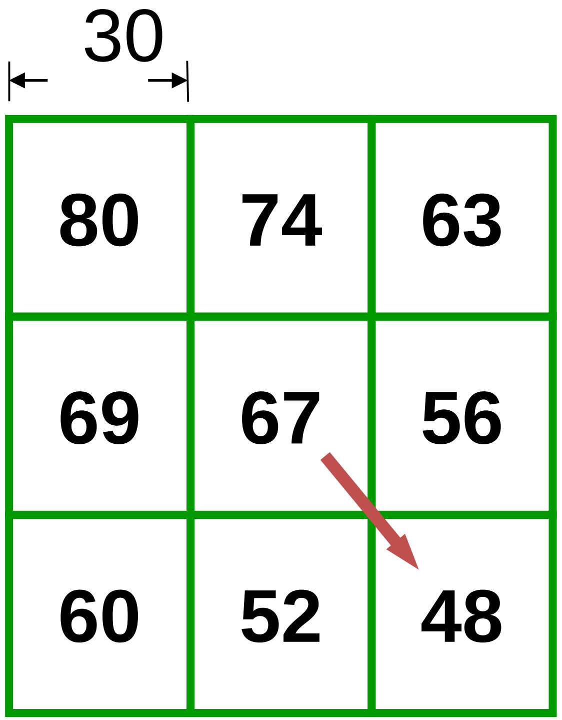
- Flowing water erodes landscape and carries away sediment sculpting the topography
- Topography defines drainage direction on the landscape and resultant runoff and streamflow accumulation processes

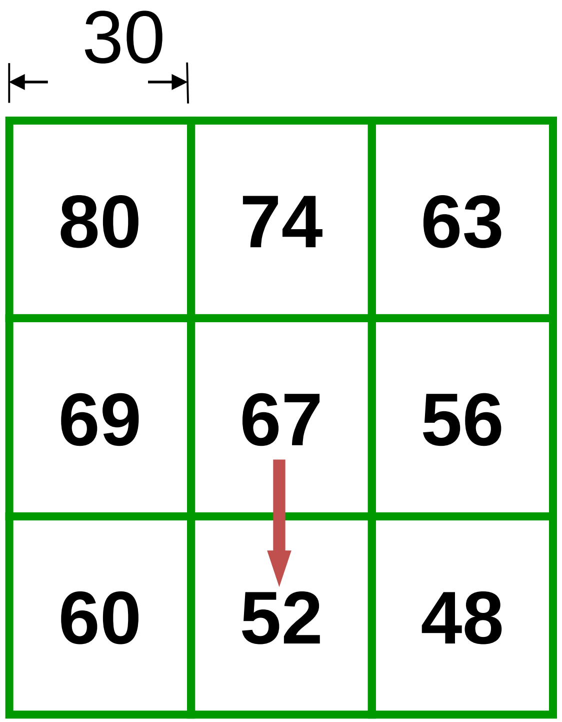


# DEM Elevations



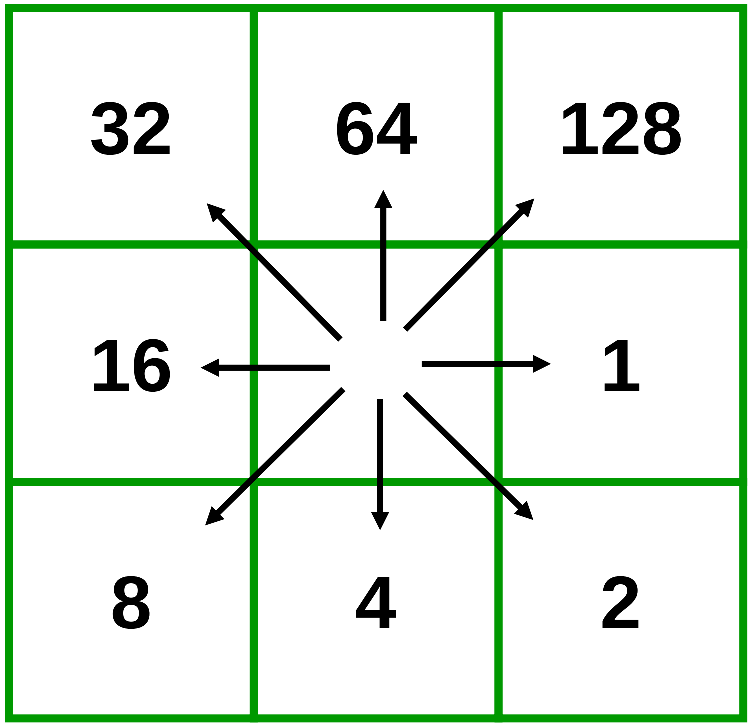
# Hydrologic Slope - Direction of Steepest Descent



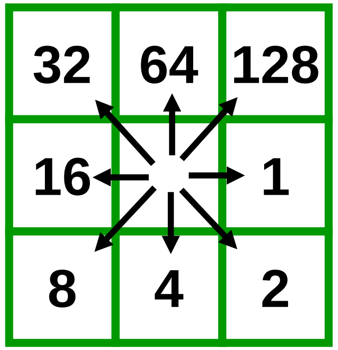

Slope: $\frac{67-48}{30\sqrt{2}} = 0.45$ $\frac{67-52}{30} = 0.50$

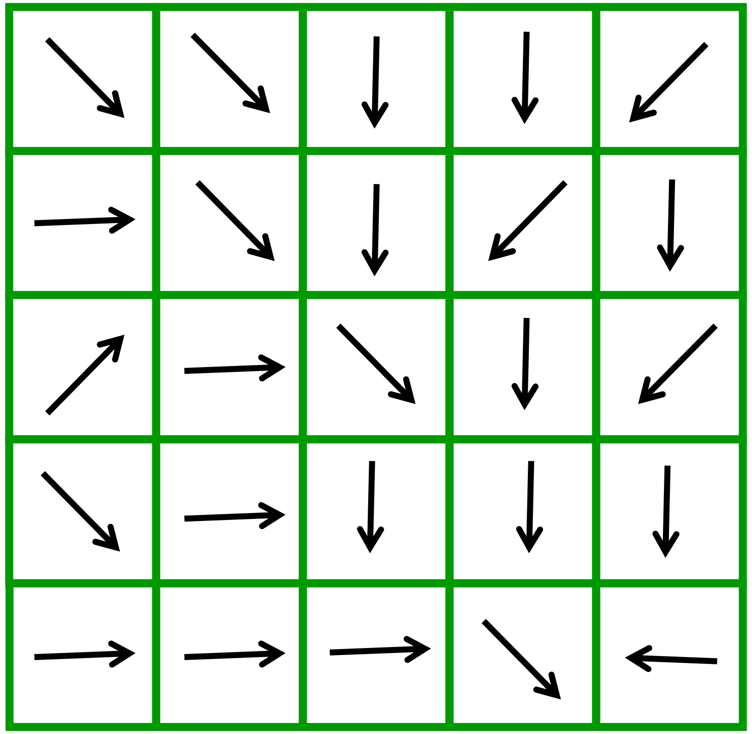
# Eight Direction Pour Point Model




**ESRI Direction encoding**

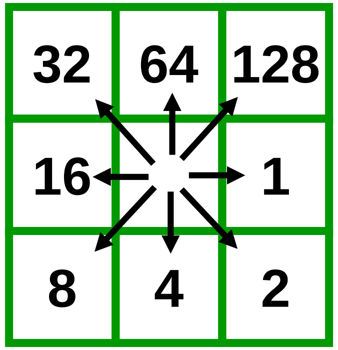
# Flow Direction Grid

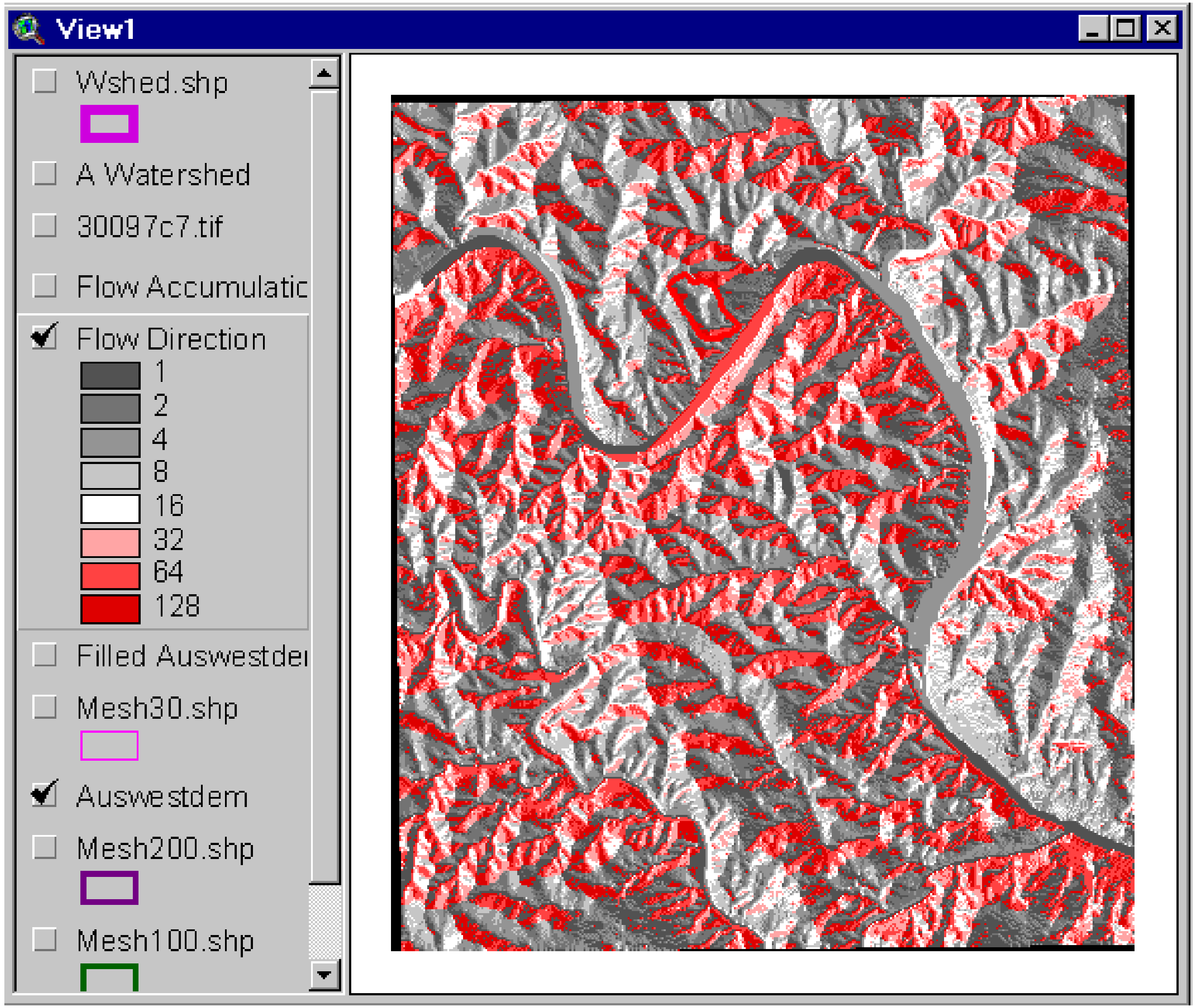


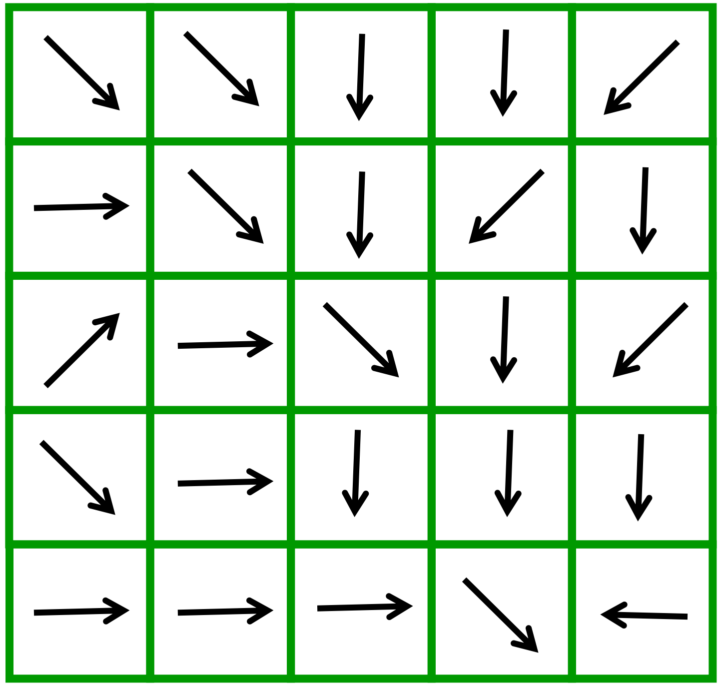
| | | | | |
|---|---|---|---|---|
| 2 | 2 | 4 | 4 | 8 |
| 1 | 2 | 4 | 8 | 4 |
| 128 | 1 | 2 | 4 | 8 |
| 2 | 1 | 4 | 4 | 4 |
| 1 | 1 | 1 | 2 | 16 |

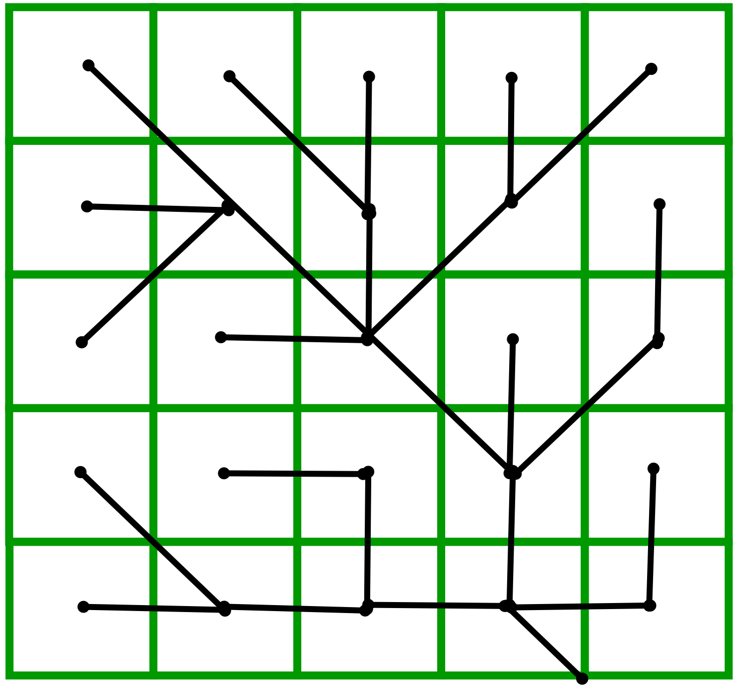
# Flow Direction Grid



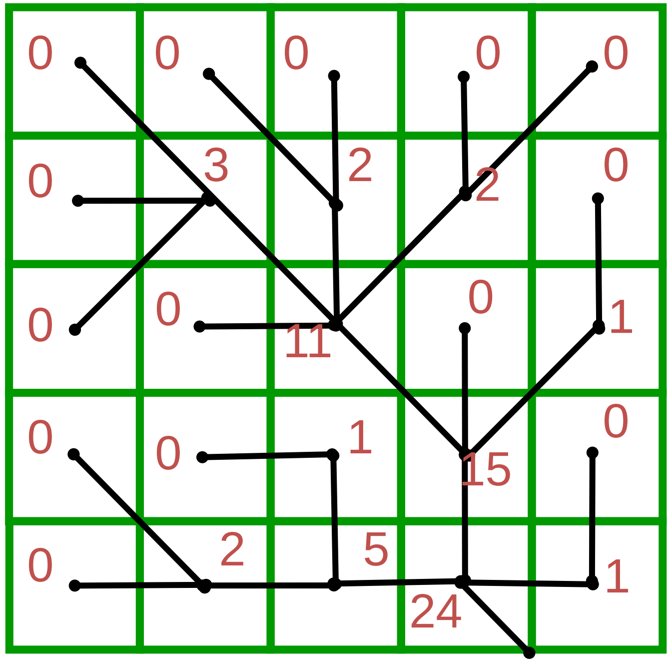



# Grid Network





# Flow Accumulation

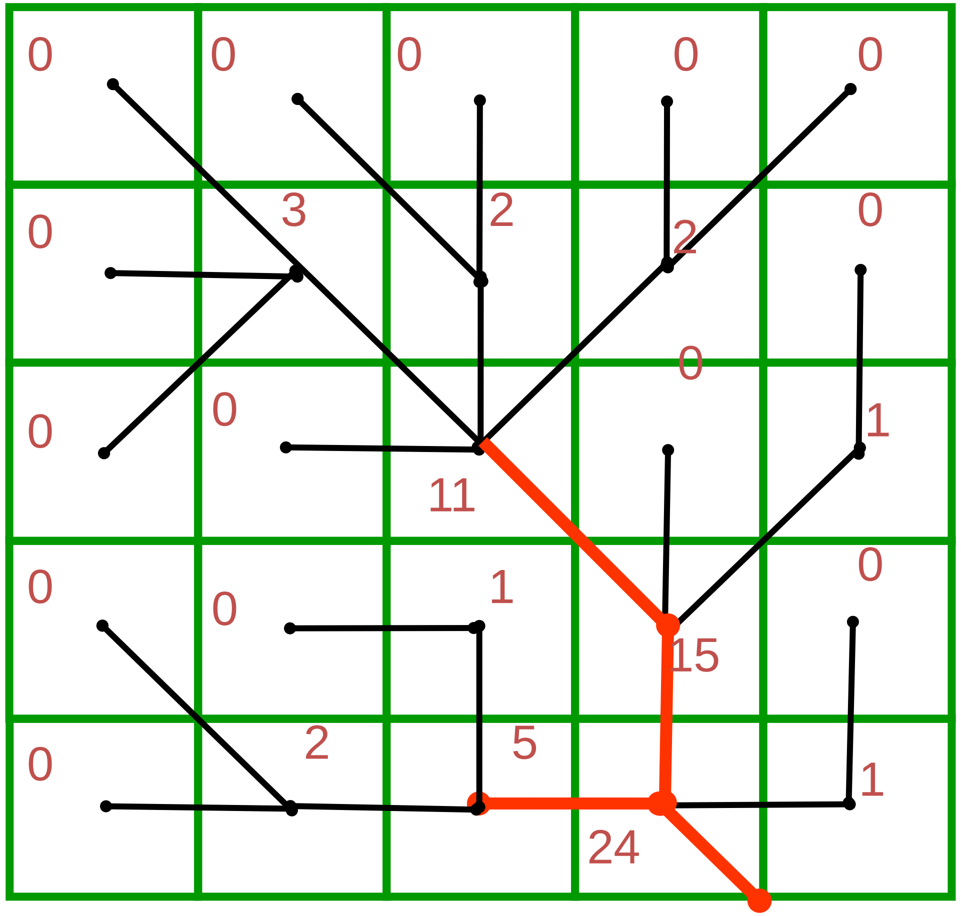



| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 3 | 2 | 2 | 0 |
| 0 | 0 | 11 | 0 | 1 |
| 0 | 0 | 1 | 15 | 0 |
| 0 | 2 | 5 | 24 | 1 |

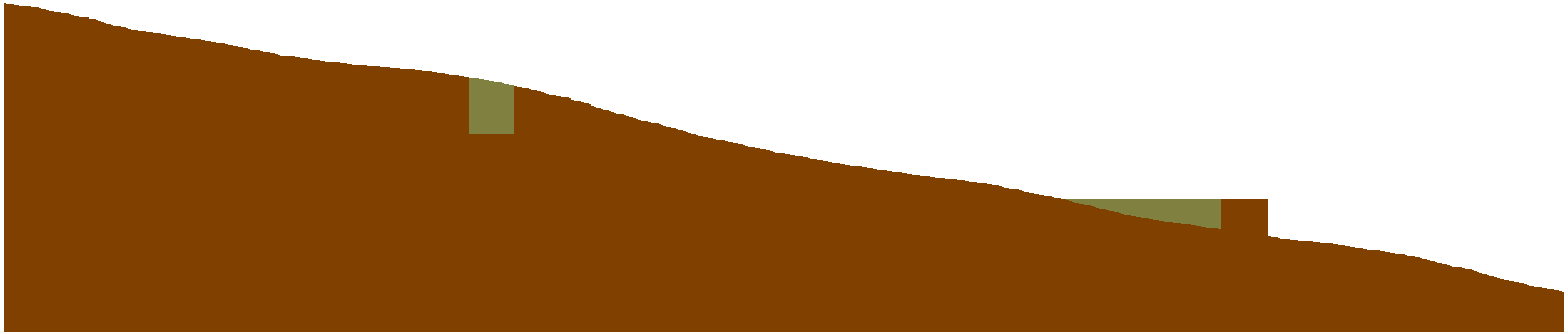
# Flow Accumulation > 5 Cell Threshold

| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 3 | 2 | 2 | 0 |
| 0 | 0 | 11 | 0 | 1 |
| 0 | 0 | 1 | 15 | 0 |
| 0 | 2 | 5 | 24 | 1 |

# Stream Network for 5 cell Threshold Drainage Area

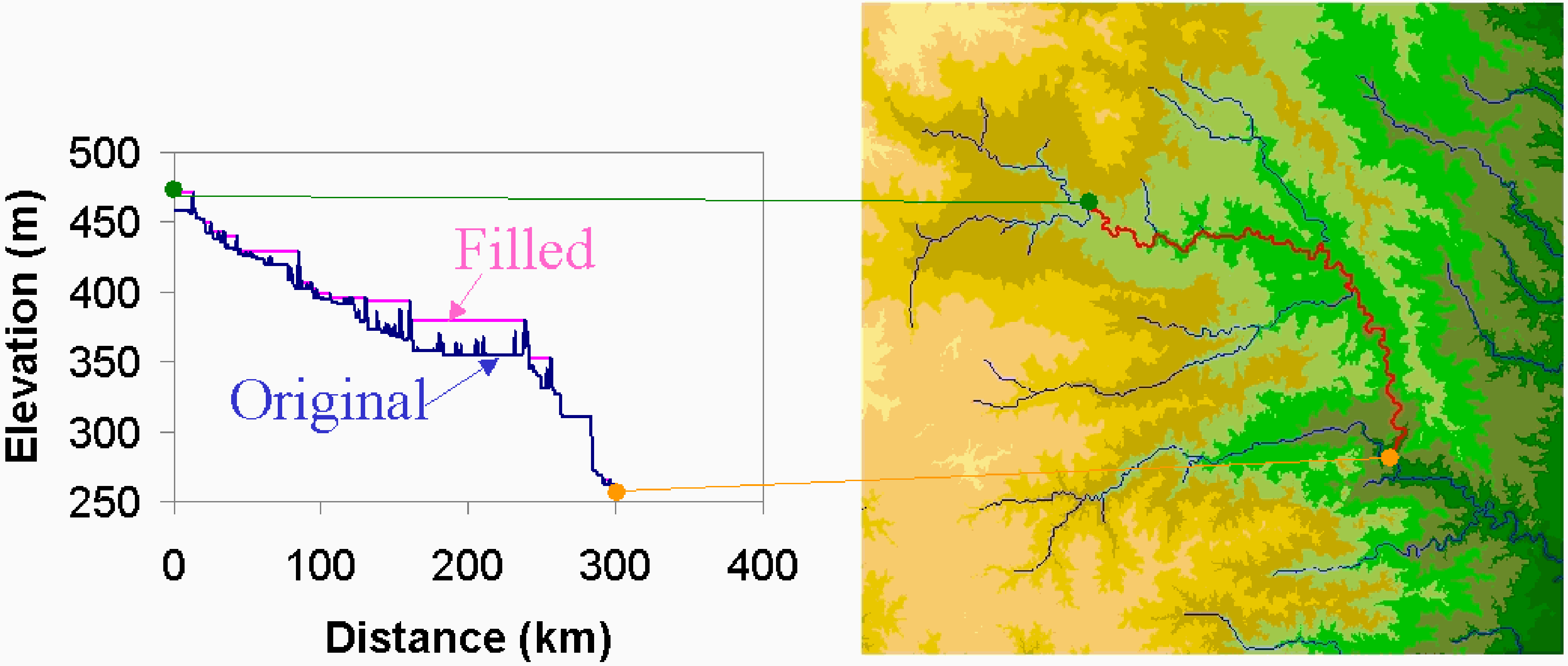


# Pit Filling



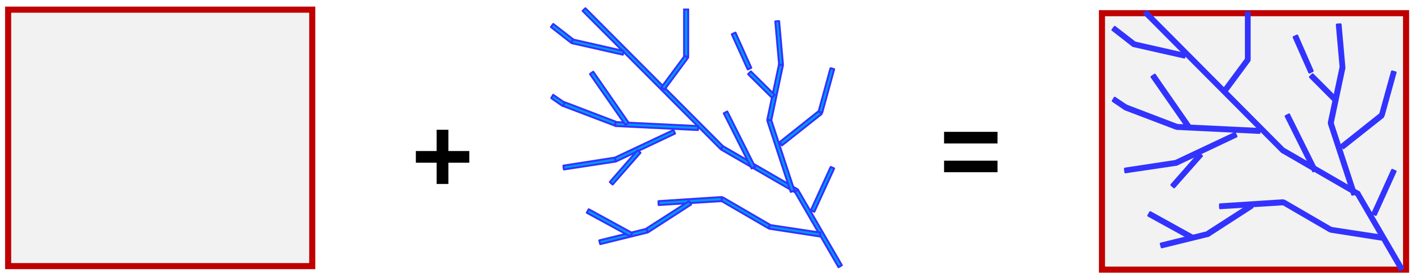
Increase elevation to the pour point elevation until the pit drains to a neighbor

# Effect of Pit Filling on Elevation

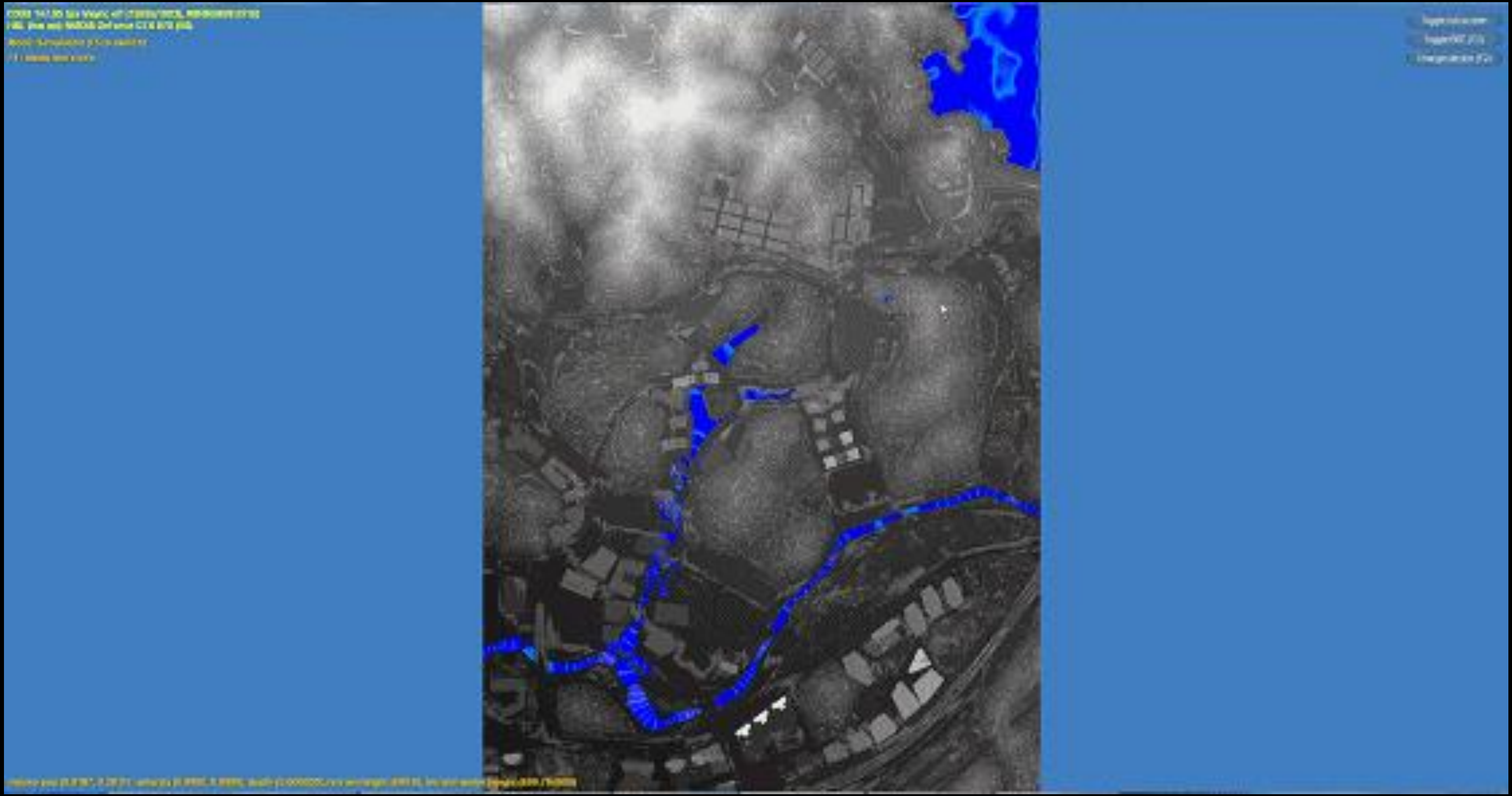


# “Burning In” the Streams

- Take a mapped stream network and a DEM
- Make a grid of the streams
- Raise the off-stream DEM cells by an arbitrary elevation increment
- Produces "burned in" DEM streams = mapped streams



# From “Static” Flow to Dynamic Flow



PDE Equations and Professionals with degrees (MS, PhD) are needed

# Nonpoint Source Pollution

- Some basic principles
- Example study of total pollution loads in the Copano Bay
  - rainfall-runoff relationship
  - point and nonpoint source loads
  - connection to bay water quality

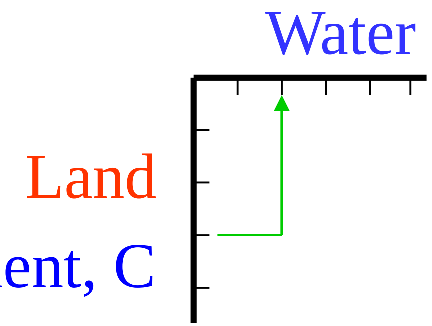
# Adapt Water to the Land System

***Water*** **Characterization**
(water yield, flooding, groundwater, pollution, sediment)

***Land***
**Characterization**
(Land use,
Soils,
Climate,
Terrain)

Non Point Source Pollution
(mean annual flows
and pollutant loads)

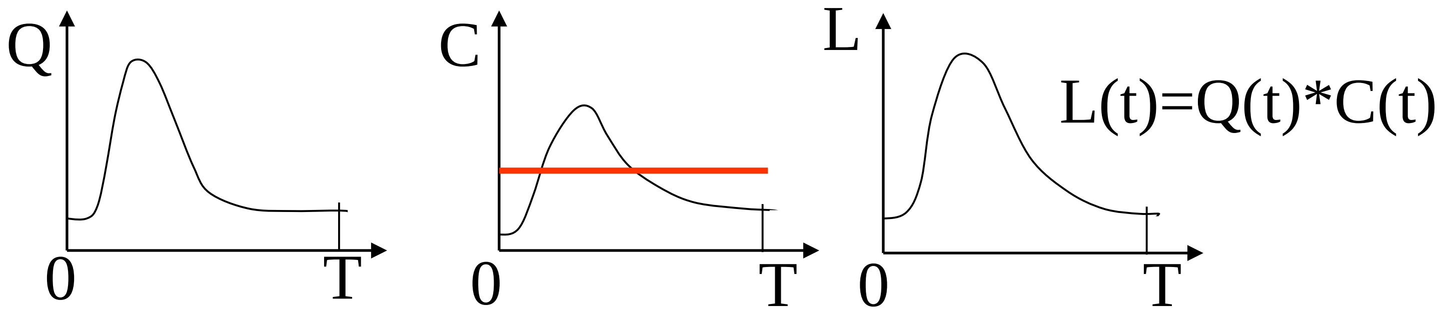
# Possible Land-Water Transform Coefficients




| **Land-Water Connection** | **Transform Coefficient** |
|---|---|
| Water yield | Runoff coefficient, C |
| Flood runoff | SCS Curve Number, CN |
| Groundwater | Recharge rate (mm/yr) |
| Water quality | Expected Mean Concentration (mg/l) |
| Sediment yield | Erosion rate (tons/ha-yr) |

# Expected Mean Concentration

- EMC = Load Mass/Flow Volume either on a single event basis or as an annual average




$$V = \int_0^T Q(t)dt$$

Flow

EMC =M/V

Concentration

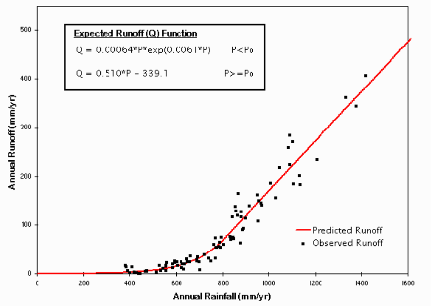
$$M = \int_0^T L(t)dt$$

Load

# Map-Based Surface Water Runoff

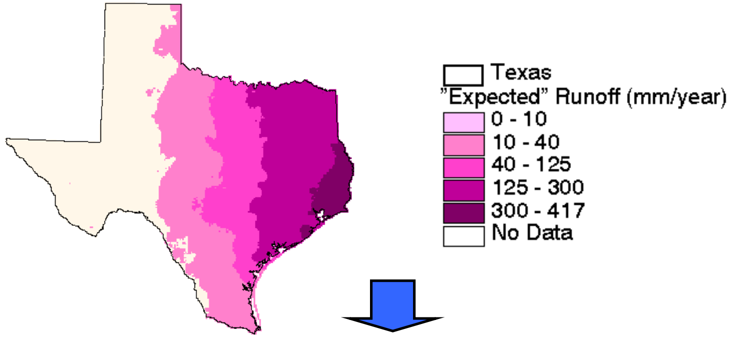
*Estimating the surface water yield by using a rainfall-runoff function*

Q




P

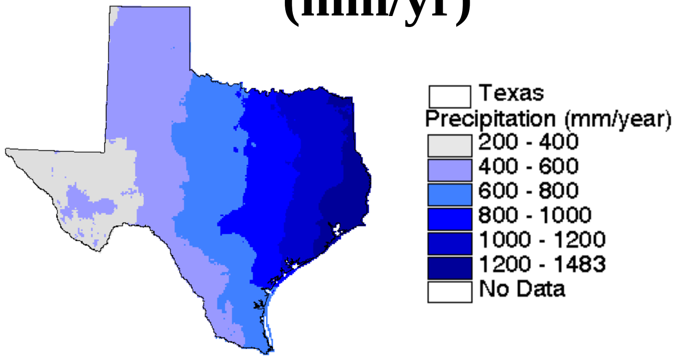
**Runoff, Q (mm/yr)**



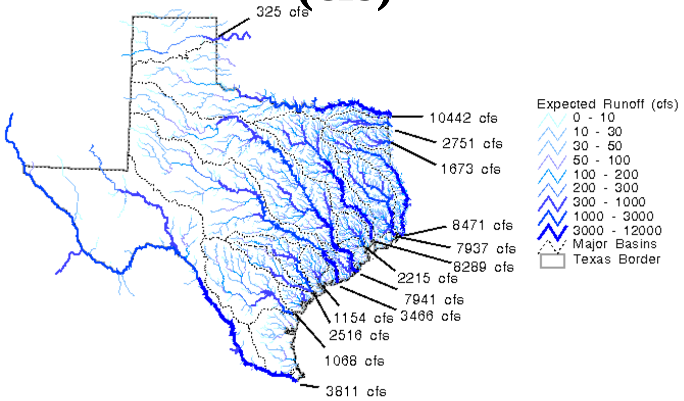

**Runoff Coefficient**

**C = Q/P**

**Precipitation, P (mm/yr)**



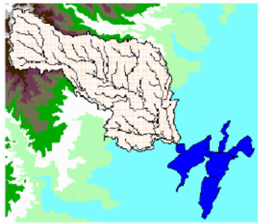

**Accumulated Runoff (cfs)**



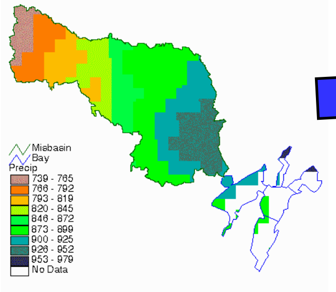
# Water Quality: Pollution Loading Module

***Load [Mass/Time]*** **=** ***Runoff [Vol/Time]*** **x** ***Concentration [Mass/Vol]***

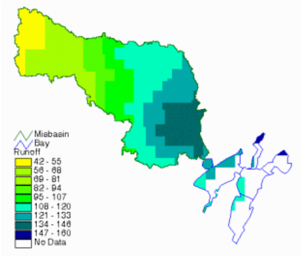
**DEM**



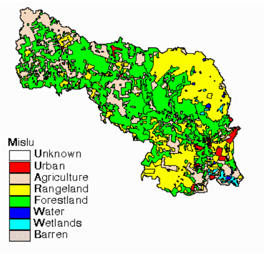
**Precip.**

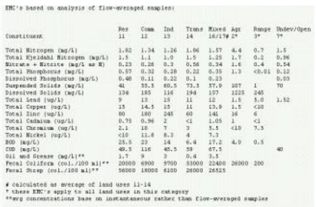



**Runoff**




**LandUse**



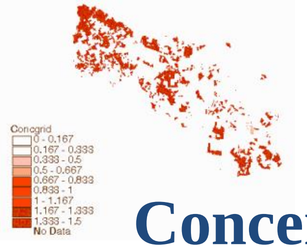



EMC's based on analysis of flow-averaged samples:

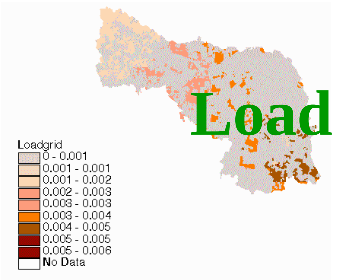
| Constituent | Res 11 | Comm 12 | Ind 13 | Trans 14 | Mixed 16/17# | Agr 2* | Range 3* | Undev/Open 7* |
|---|---|---|---|---|---|---|---|---|
| Total Nitrogen (mg/L) | 1.82 | 1.34 | 1.26 | 1.06 | 1.57 | 4.4 | 0.7 | 1.5 |
| Total Kjeldahl Nitrogen (mg/L) | 1.5 | 1.1 | 1.0 | 1.5 | 1.25 | 1.7 | 0.2 | 0.96 |
| Nitrate + Nitrite (mg/L as N) | 0.23 | 0.26 | 0.3 | 0.56 | 0.34 | 1.6 | 0.4 | 0.54 |
| Total Phosphorus (mg/L) | 0.57 | 0.32 | 0.28 | 0.22 | 0.35 | 1.3 | <0.01 | 0.12 |
| Dissolved Phosphorus (mg/L) | 0.48 | 0.11 | 0.22 | 0.1 | 0.23 | | | 0.03 |
| Suspended Solids (mg/L) | 41 | 55.5 | 60.5 | 73.5 | 57.9 | 107 | 1 | 70 |
| Dissolved Solids (mg/L) | 134 | 185 | 116 | 194 | 157 | 1225 | 245 | |
| Total Lead (ug/L) | 9 | 13 | 15 | 11 | 12 | 1.5 | 5.0 | 1.52 |
| Total Copper (ug/L) | 15 | 14.5 | 15 | 11 | 13.9 | 1.5 | <10 | |
| Total Zinc (ug/L) | 80 | 180 | 245 | 60 | 141 | 16 | 6 | |
| Total Cadmium (ug/L) | 0.75 | 0.96 | 2 | <1 | 1.05 | 1 | <1 | |
| Total Chromium (ug/L) | 2.1 | 10 | 7 | 3 | 5.5 | <10 | 7.5 | |
| Total Nickel (ug/L) | <10 | 11.8 | 8.3 | 4 | 7.3 | | | |
| BOD (mg/L) | 25.5 | 23 | 14 | 6.4 | 17.2 | 4.0 | 0.5 | |
| COD (mg/L) | 49.5 | 116 | 45.5 | 59 | 67.5 | | | 40 |
| Oil and Grease (mg/L)** | 1.7 | 9 | 3 | 0.4 | 3.5 | | | |
| Fecal Coliform (col./100 ml)** | 20000 | 6900 | 9700 | 53000 | 22400 | 26000 | 200 | |
| Fecal Strep (col./100 ml)** | 56000 | 18000 | 6100 | 26000 | 26525 | | | |

# calculated as average of land uses 11-14
* these EMC's apply to all land uses in this category
**avg concentrations base on instantaneous rather than flow-averaged samples

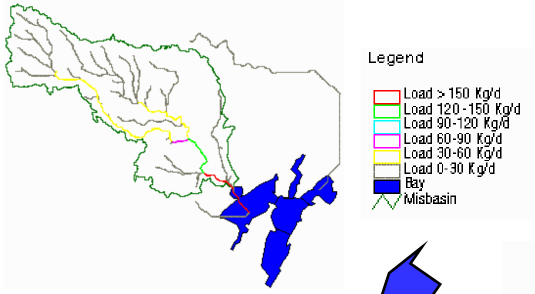
**EMC Table**




**Concentration**




**Load**




**Accumulated Load**

# Expected Mean Concentration

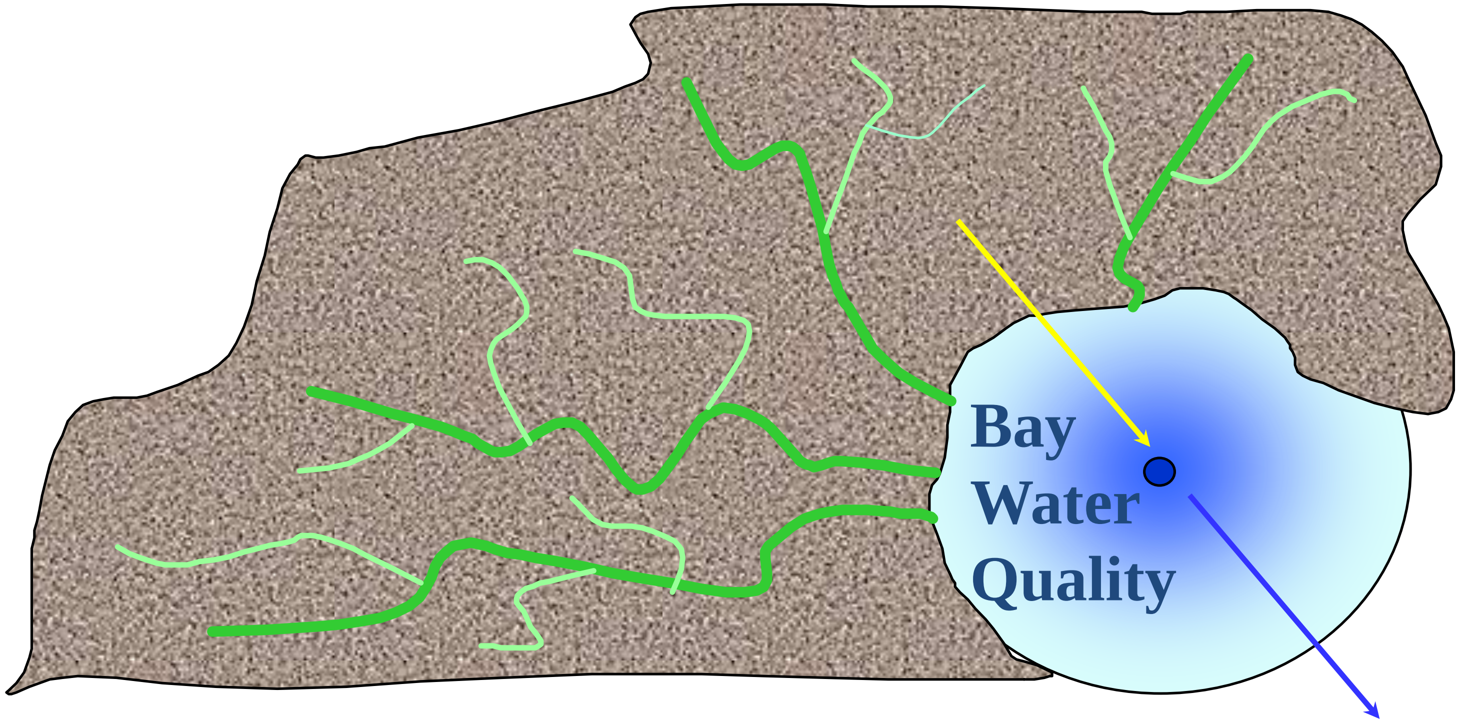
## Land Use

**EMC**

| Constituent | Resident. | Comm. | Indust. | Transp. | Agric. | Range | Undevel |
|---|---|---|---|---|---|---|---|
| Total Nitrogen (mg/l) | 1.82 | 1.34 | 1.26 | 1.86 | 4.40 | 0.70 | 1.50 |
| Total Phosphorus (mg/l) | 0.57 | 0.32 | 0.28 | 0.22 | 1.30 | <0.01 | 0.12 |
| Oil and Grease (mg/l) | 1.7 | 9.0 | 3.0 | 0.4 | | | |
| Copper (ug/l) | 15.0 | 14.5 | 15.0 | 11.0 | 1.5 | <10 | |
| Chromium (ug/l) | 2.1 | 10.0 | 7.0 | 3.0 | <10 | 7.5 | |
| Zinc (ug/l) | 80 | 180 | 245 | 60 | 141 | 16 | 6 |

**Table derived from USGS water quality monitoring sites**

# Water Quality: Land Surface -Water Body Connection




Total Constituent Loads

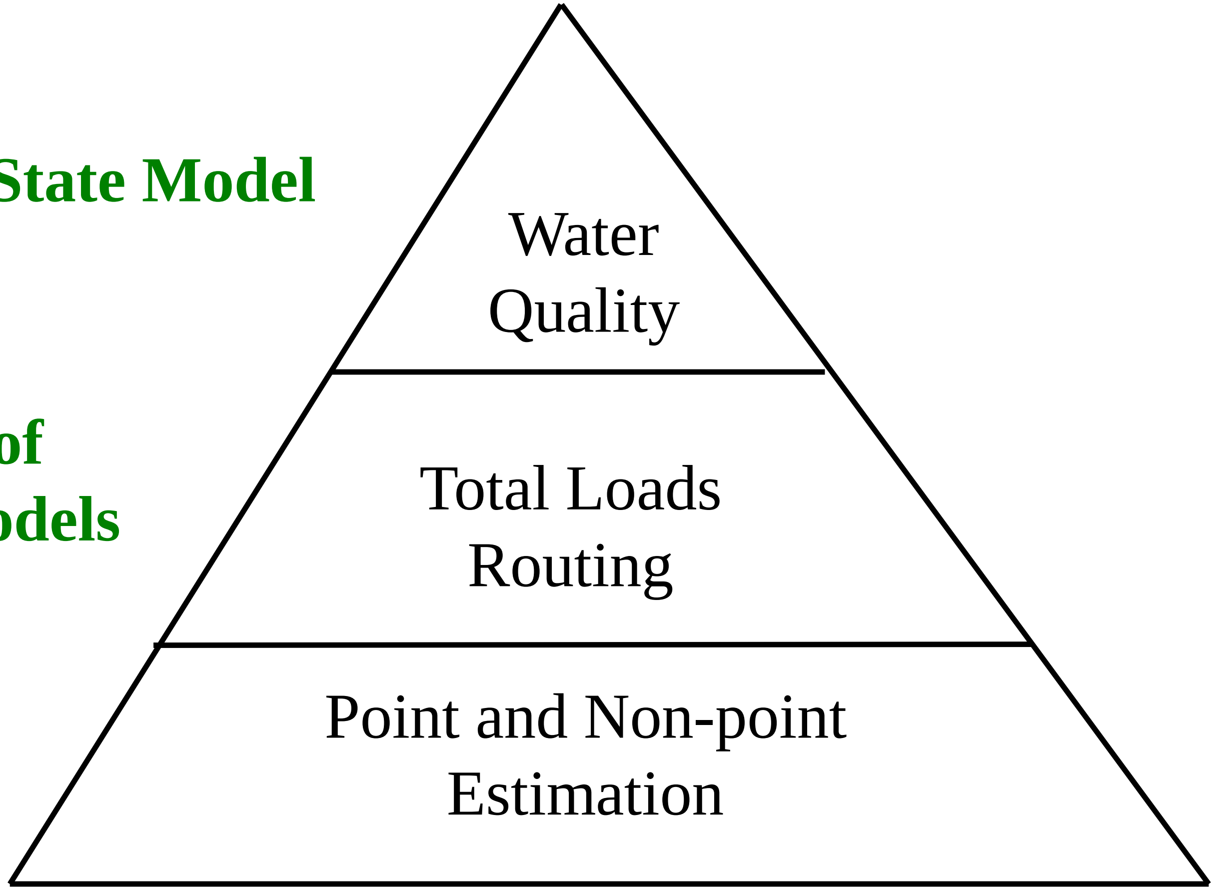
Input for Water Quality Model

# Basic Concept

**Steady-State Model**

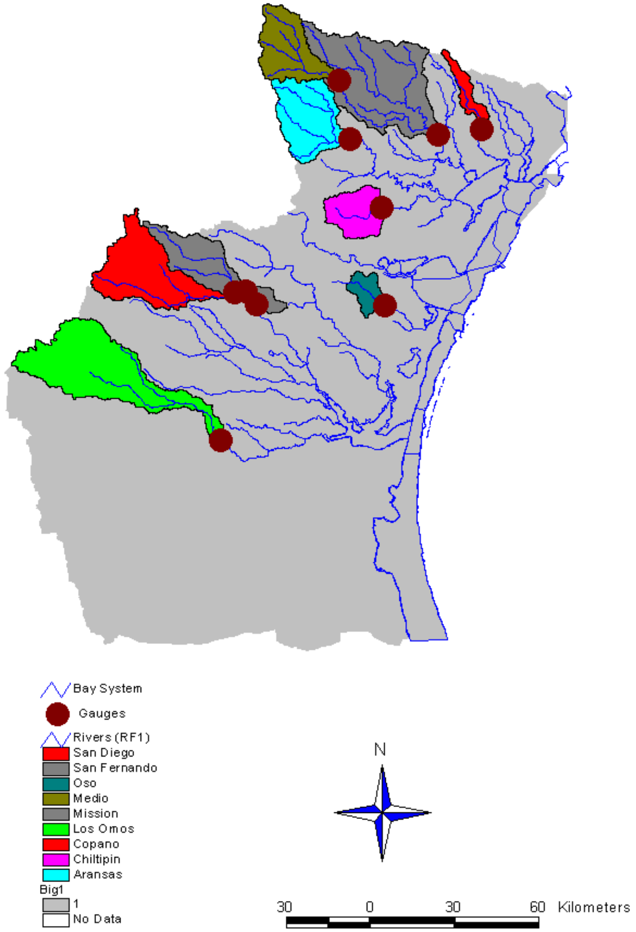
**Linkage of the Two Models**

**Calculate Flow and Total Loads**

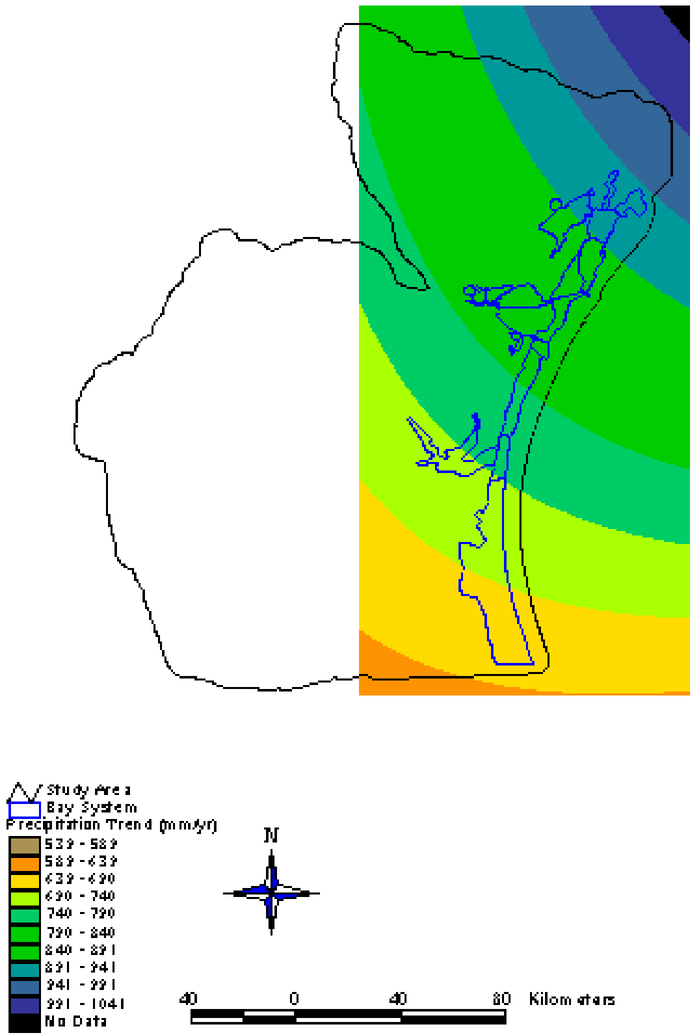


# Watershed Delineation

**Sub-Watersheds**



# Precipitation - Spatial Interpolation



# Regression Inputs and Outputs

| Watershed | Streamflow (mm/yr) | Precipitation (mm/yr) | %Agric | %Range |
|---|---|---|---|---|
| Los Omos | 4.07 | 618.25 | 12.24 | 87.21 |
| Chiltipin | 105.80 | 841.17 | 86.40 | 10.92 |
| San Fernand | 12.36 | 661.08 | 22.09 | 76.53 |
| San Diego | 7.65 | 664.78 | 13.29 | 85.63 |
| Oso | 112.64 | 774.75 | 96.87 | 0.97 |
| Aransas | 46.03 | 809.99 | 58.07 | 37.91 |
| Mission | 73.51 | 846.89 | 25.22 | 73.04 |
| Medio | 29.14 | 786.75 | 40.82 | 58.30 |
| Copano | 163.90 | 927.41 | 6.56 | 66.80 |

## Agriculture

$Q = 0.008312 * \exp(0.011415 * P)$

where: Q = runoff depth (mm/yr)
P = precipitation depth (mm/yr)
$0.008312 = \exp(-4.79004056)$

## Range Land, Barren, Forest Land, Other

$Q = 0.0053 * \exp(0.010993 * P)$

where: Q = runoff depth (mm/yr)
P = precipitation depth (mm/yr)
$0.0053 = \exp(-5.239702)$

## Urban

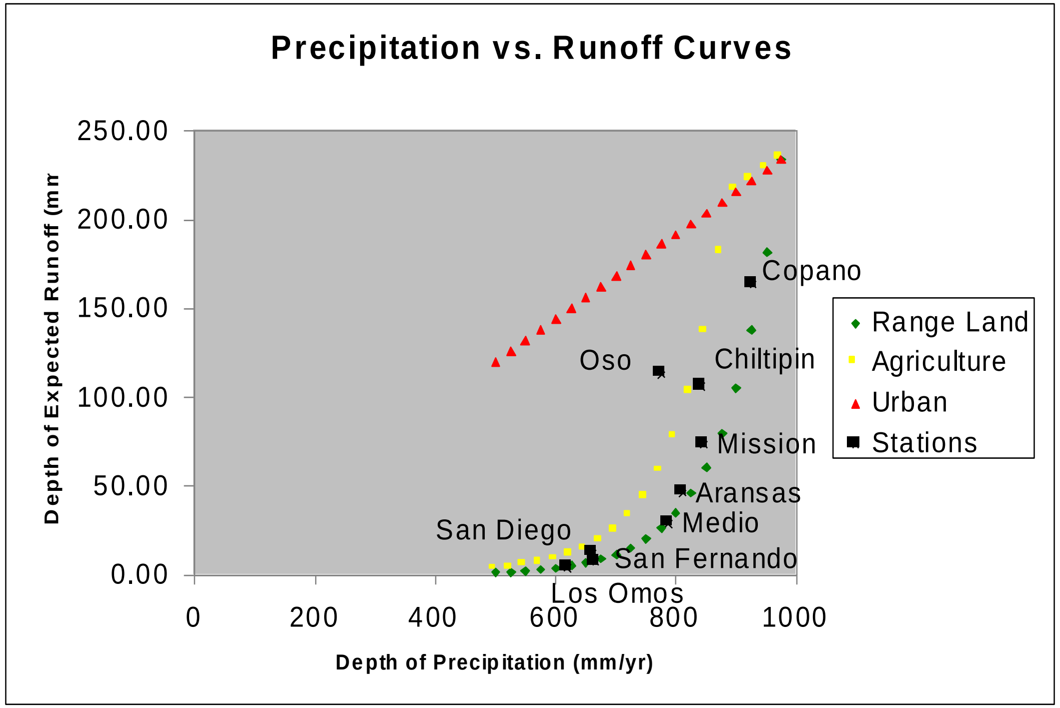
$Q = 0.24 * P$

where: Q = runoff depth (mm/yr)
P = precipitation depth (mm/yr)

## Water

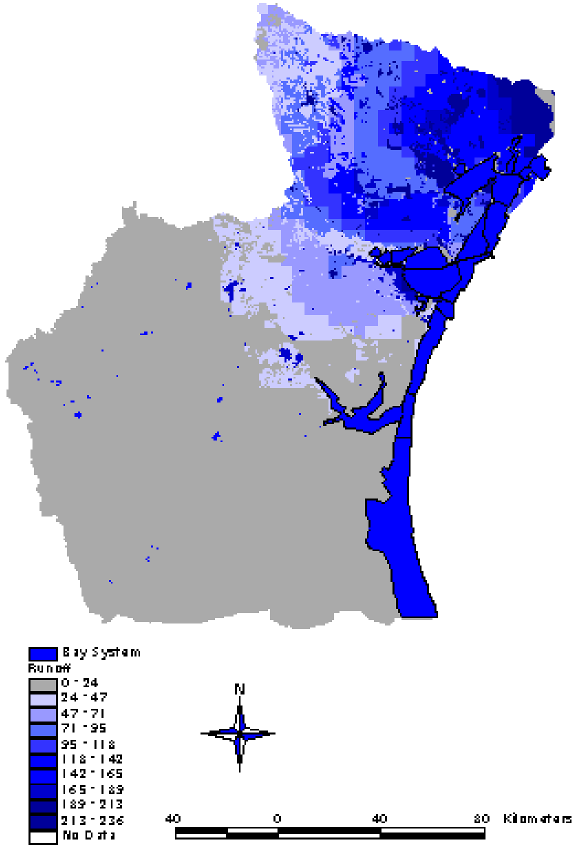
$Q = 0$

# Surface Water Runoff




Land Use
+
Precipitation

Mean Annual Runoff (mm/yr)



# Total Constituent Loading

Point Source Load

Land Surface Load

Nueces River Load

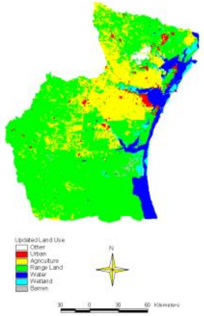
Atmospheric Load

? Sediment Load ?

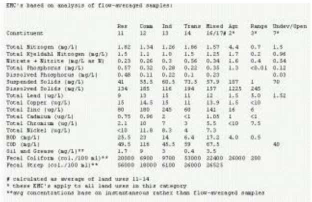
Total Loads

# Land Surface Constituent Loading

***Load [Mass/Time]*** **=** ***Runoff [Vol/Time]*** **x** ***Concentration [Mass/Vol]***




**Land Use**

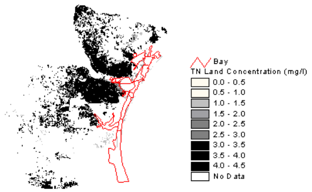


EMC's based on analysis of flow-averaged samples:

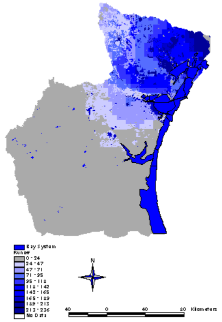
| Constituent | Res 11 | Comm 12 | Ind 13 | Trans 14 | Mixed 16/17# | Agr 2* | Range 3* | Undev/Open 7* |
|---|---|---|---|---|---|---|---|---|
| Total Nitrogen (mg/l) | 1.82 | 1.34 | 1.26 | 1.86 | 1.57 | 4.4 | 0.7 | 1.5 |
| Total Kjeldahl Nitrogen (mg/L) | 1.5 | 1.1 | 1.0 | 1.5 | 1.25 | 1.7 | 0.2 | 0.96 |
| Nitrate + Nitrite (mg/L as N) | 0.23 | 0.26 | 0.3 | 0.56 | 0.34 | 1.6 | 0.4 | 0.54 |
| Total Phosphorus (mg/L) | 0.57 | 0.32 | 0.28 | 0.22 | 0.35 | 1.3 | <0.01 | 0.12 |
| Dissolved Phosphorus (mg/l) | 0.48 | 0.11 | 0.22 | 0.1 | 0.23 | | | 0.03 |
| Suspended Solids (mg/l) | 41 | 55.5 | 60.5 | 73.5 | 57.9 | 107 | 1 | 70 |
| Dissolved Solids (mg/L) | 134 | 185 | 116 | 194 | 157 | 1225 | 245 | |
| Total Lead (ug/l) | 9 | 13 | 15 | 11 | 12 | 1.5 | 5.0 | 1.52 |
| Total Copper (ug/L) | 15 | 14.5 | 15 | 11 | 13.9 | 1.5 | <10 | |
| Total Zinc (ug/l) | 80 | 180 | 245 | 60 | 141 | 16 | 6 | |
| Total Cadmium (ug/L) | 0.75 | 0.96 | 2 | <1 | 1.05 | 1 | <1 | |
| Total Chromium (ug/l) | 2.1 | 10 | 7 | 3 | 5.5 | <10 | 7.5 | |
| Total Nickel (ug/L) | <10 | 11.8 | 8.3 | 4 | 7.3 | | | |
| BOD (mg/l) | 25.5 | 23 | 14 | 6.4 | 17.2 | 4.0 | 0.5 | |
| COD (mg/l) | 49.5 | 116 | 45.5 | 59 | 67.5 | | | 40 |
| Oil and Grease (mg/l)** | 1.7 | 9 | 3 | 0.4 | 3.5 | | | |
| Fecal Coliform (col./100 ml)** | 20000 | 6900 | 9700 | 53000 | 22400 | 26000 | 200 | |
| Fecal Strep (col./100 ml)** | 56000 | 18000 | 6100 | 26000 | 26525 | | | |

# calculated as average of land uses 11-14
* these EMC's apply to all land uses in this category
**avg concentrations base on instantaneous rather than flow-averaged samples

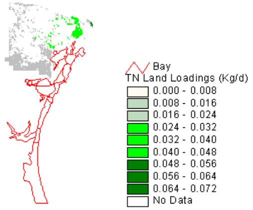
**EMC Table**




**Concentration**



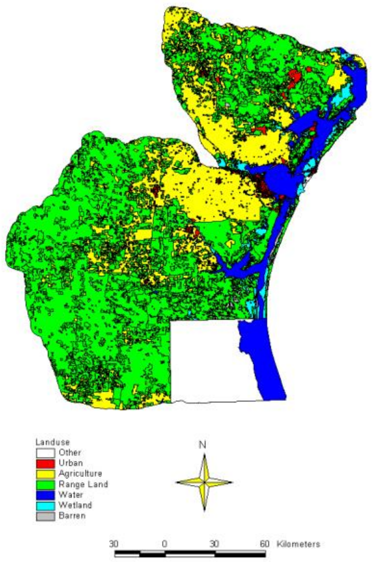
**Runoff**



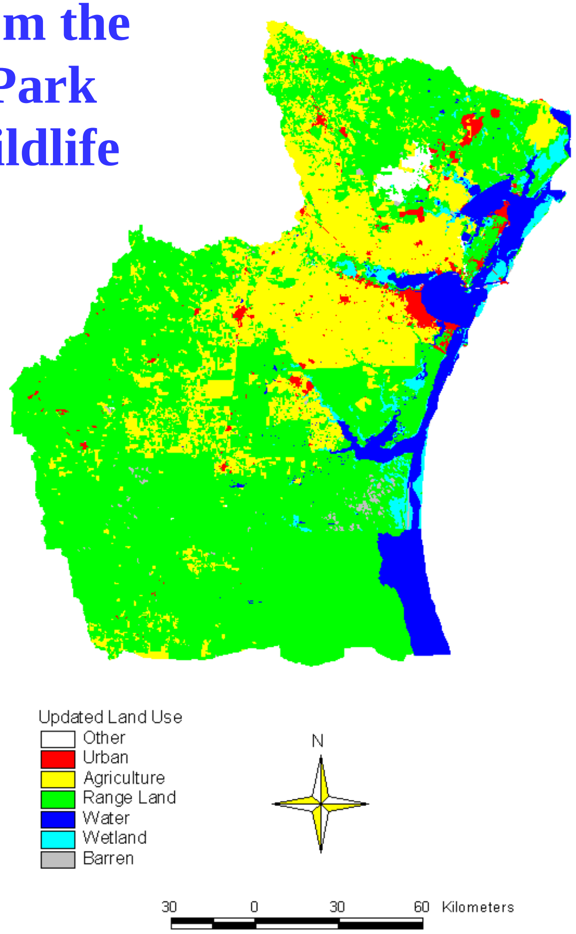

**Load**

# Land Use

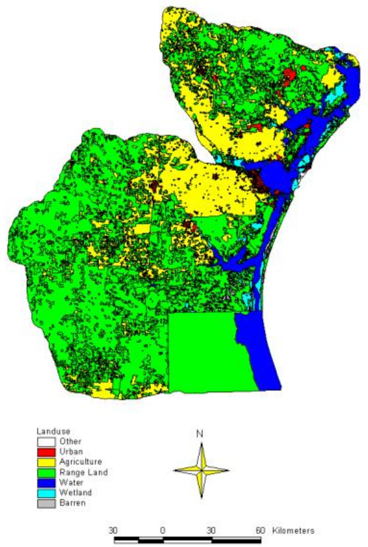
USGS Land Use (1970's)




Updated Land Use from the Texas Park and Wildlife




Addition of Missing Land Use



# EMC Table

| Constituent | Res | Comm | Ind | Trans | Agr | Range | Undev |
|---|---|---|---|---|---|---|---|
| Total Nitrogen (mg/l) | 1.82 | 1.34 | 1.26 | 1.86 | 4.40 | 0.70 | 1.50 |
| Total Phosphorus (mg/l) | 0.57 | 0.32 | 0.28 | 0.22 | 1.30 | <0.01 | 0.12 |
| Oil and Grease (mg/l) | 1.7 | 9.0 | 3.0 | 0.4 | | | |
| Copper (ug/l) | 15.0 | 14.5 | 15.0 | 11.0 | 1.5 | <10 | |
| Chromium (ug/l) | 2.1 | 10.0 | 7.0 | 3.0 | <10 | 7.5 | |
| Zinc (ug/l) | 80 | 180 | 245 | 60 | 141 | 16 | 6 |

# Atmospheric Contribution

**<u>Total Nitrogen</u>**

Atmospheric Load to Land Surface = 2,700 Kg/d

which is 35% of Land Surface Load from agricultural land use. This calculation is made assuming the EMC of 4.4 mg/l for agriculture and a Nitrogen concentration of 1.1 mg/l in precipitation

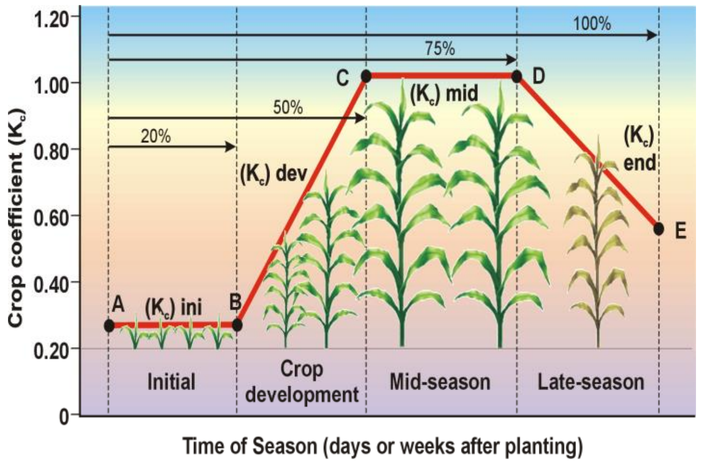
# Estimating ET using Remote Sensing

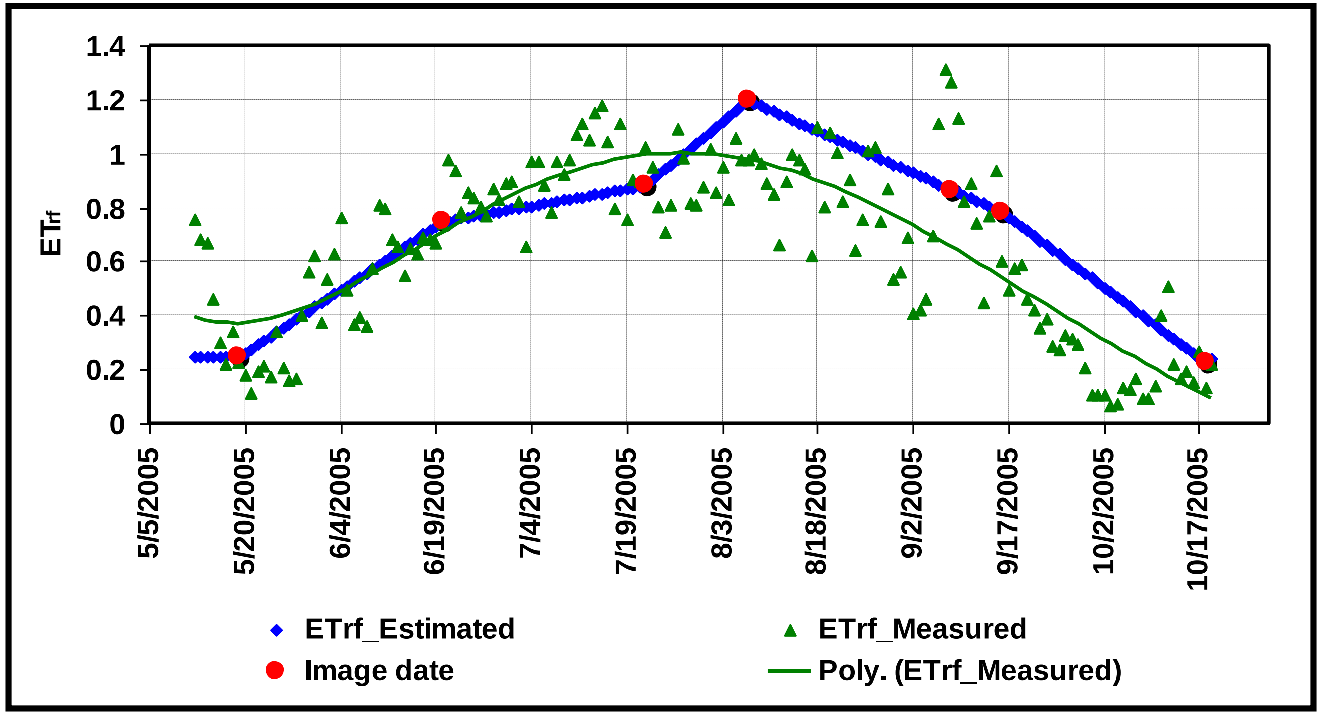
# Methods Estimate Evaporation

- Conventional class A pans
- Ground-based measurements using instrumented weather stations (Bowen Ratio, Eddy covariance)
- Buoys (water bodies)
- Remote sensing technology
- Climate models

# Crop coefficient, Evaporative fraction, relative ET

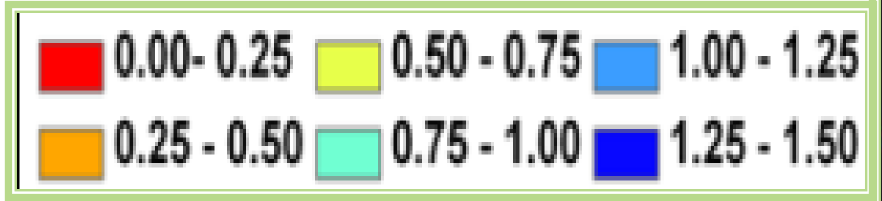
$$ET_rF = ET_c/ET_r$$

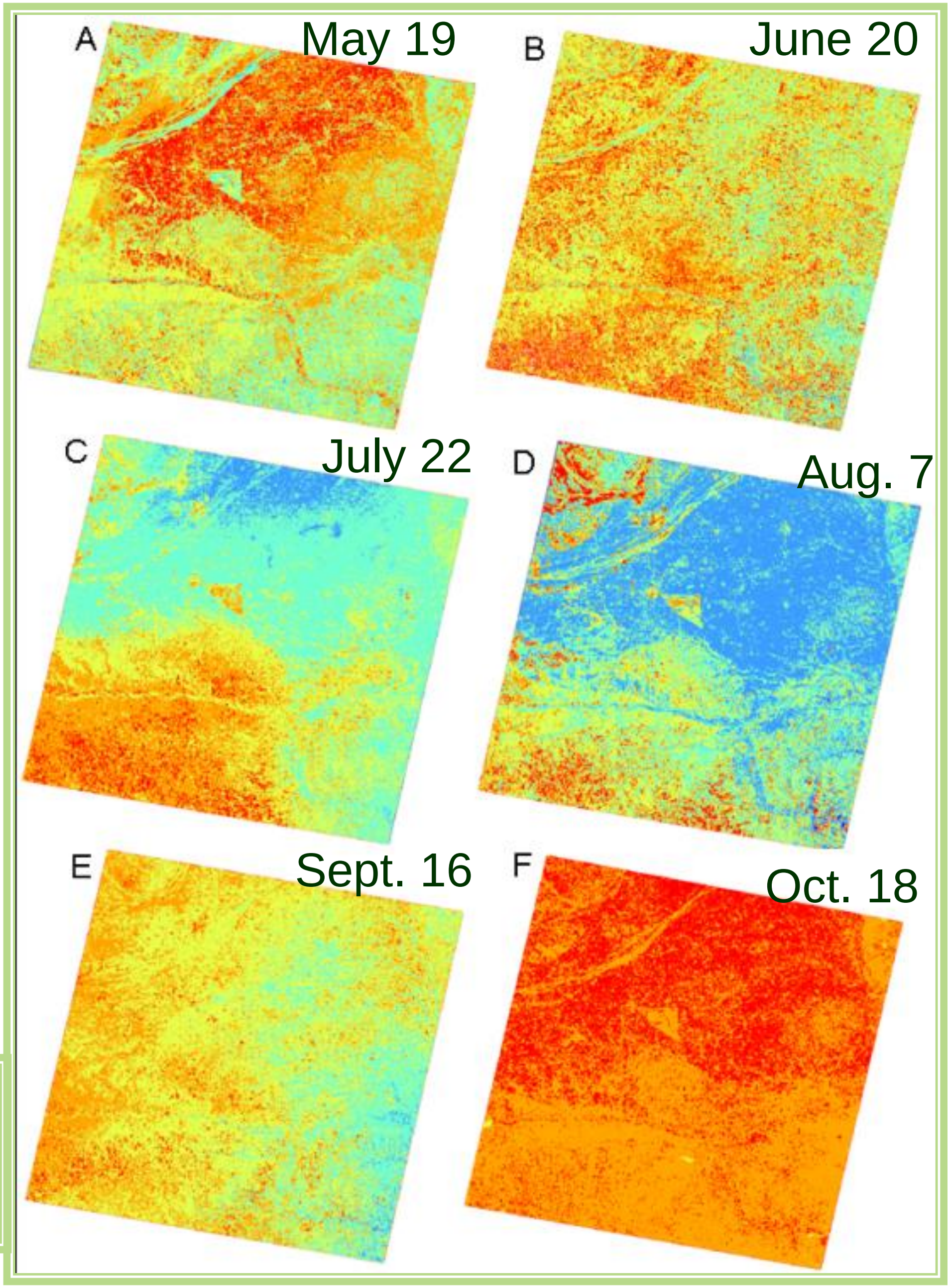


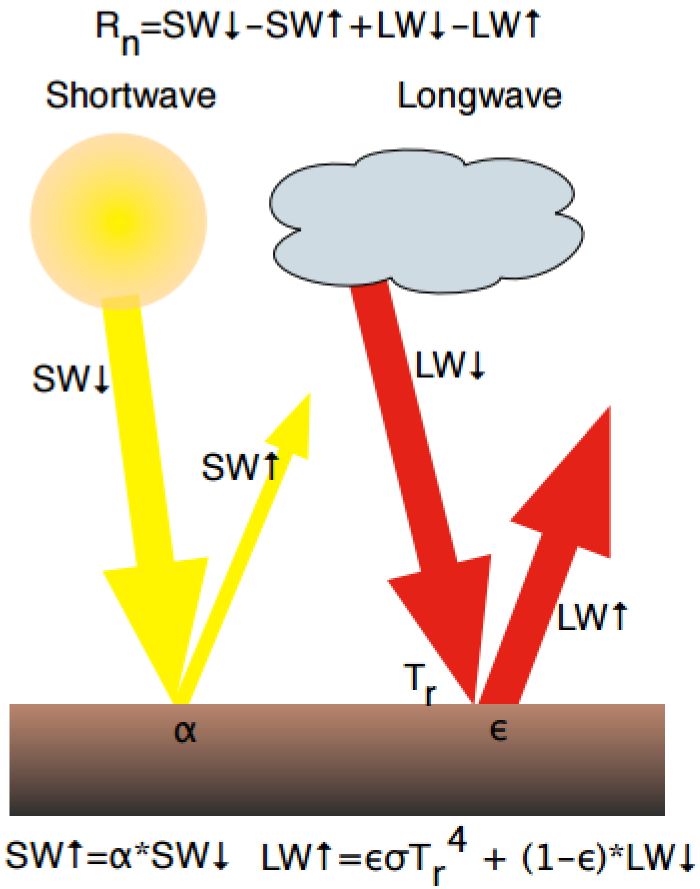



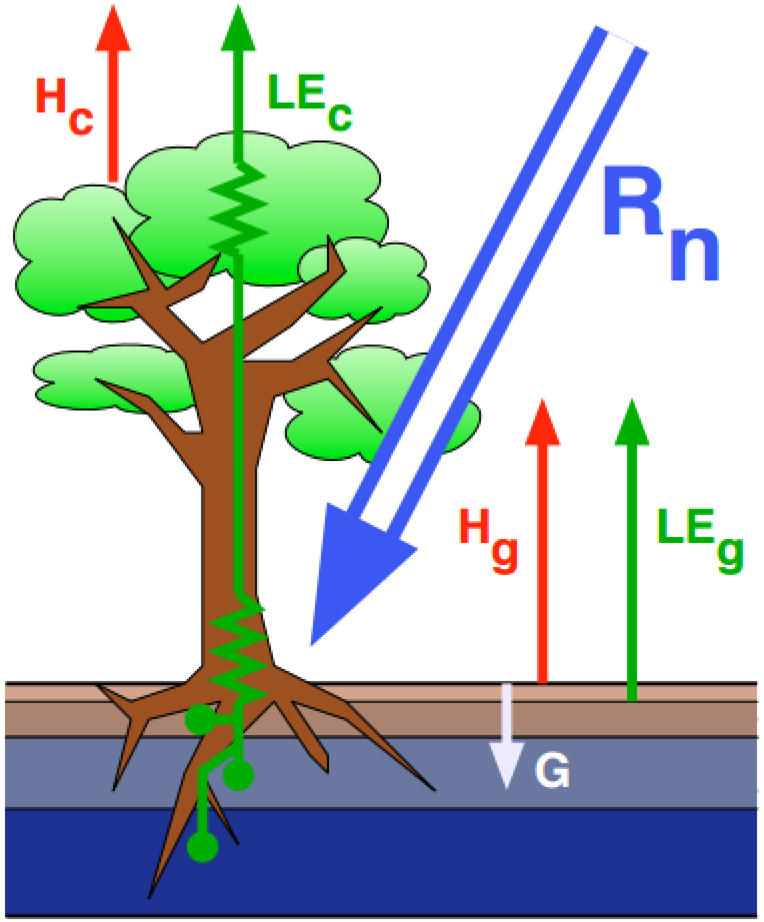
# Crop coefficients

$$K_{cr} = \frac{ET_c}{ET_r}$$






$$\begin{aligned}
R_n &= SW_{\downarrow} - SW_{\uparrow} + LW_{\downarrow} - LW_{\uparrow} && (1)\\
SW_{\uparrow} &= \alpha SW_{\downarrow} && (2)\\
LW_{\uparrow} &= \epsilon \sigma T_r^4. && (3)\\
& && (4)
\end{aligned}$$

At the surface net radiation $R_n$ is partitioned into the sensible heat flux $H$ , the latent heat flux $\lambda E$ and the ground heat flux $G$ through the energy balance (Equation 5).

$$R_n = H + \lambda E + G. \tag{5}$$

$E$ is also called evapotranspiration and $\lambda = 2.52\,\mathrm{J\,kg^{-1}}$ is the latent heat of evaporation of water. Evapotranspiration thus links the energy to the water balance (Equation 5)

$$\frac{dS}{dt} = P - E + Q, \tag{6}$$

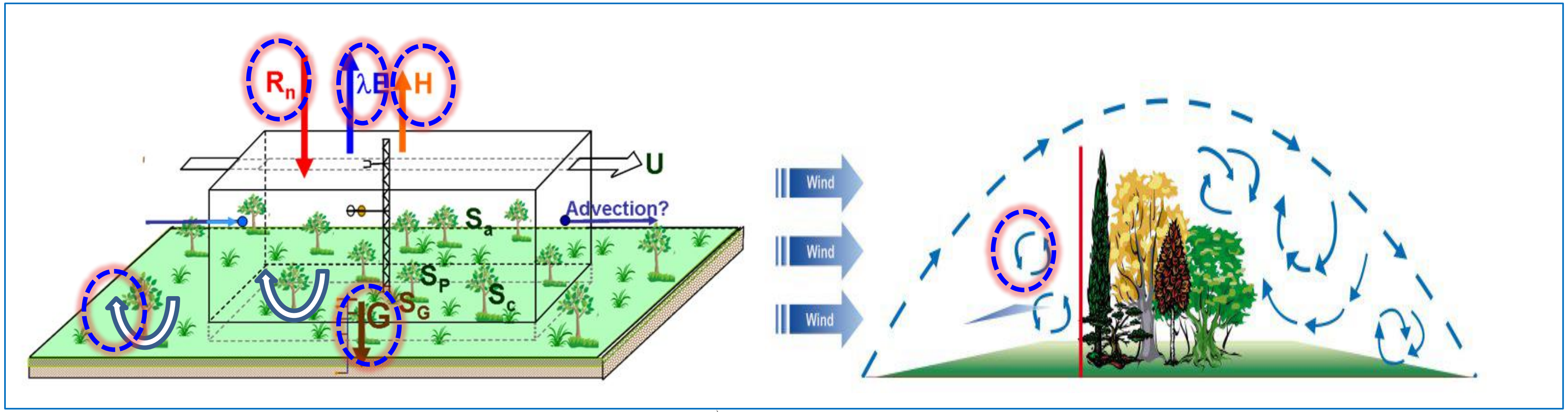
where which relates evapotranspiration $E$ to changes in terrestrial water storage ($dS/dt$), precipitation $P$ and runoff $Q$. In an first order approximation the latent and the sensible heat flux can be expressed as

$$\begin{aligned} H &= \rho c_p K_h \frac{\Delta T}{\Delta z} && (7)\\ E &= \lambda \rho K_E \frac{\Delta q}{\Delta z}, && (8)\\ & && (9) \end{aligned}$$

where $\rho$ is the air density, $c_p$ the specific heat of air, $\Delta q/\Delta z$ is the change of specific humidity and $\Delta T/\Delta z$ is the change of air temperature with height. The transfer coefficients ($K_H$, $K_E$) summarise the combined effects of processes such as atmospheric turbulence or vegetation activity and are difficult to estimate.

The relation between the latent and the sensible heat flux can be described using the Bowen ratio, which is specified as

$$Bo = \frac{H}{\lambda E} = \frac{c_p \Delta T}{\lambda \Delta q} = \gamma \frac{\Delta T}{\Delta e}, \tag{10}$$

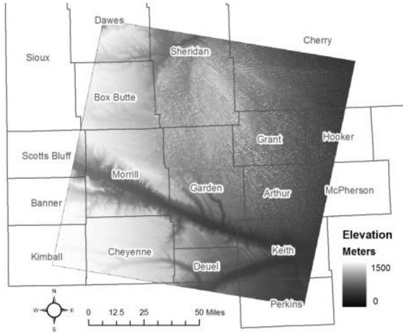


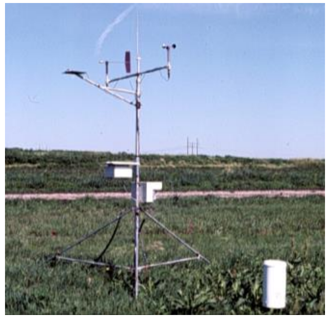

- 净辐射（Rn）
- 土壤热通量(G)
- 感热通量(H)
  - 粗糙度
  - 边界层高度
  - 饱和水汽压差
- 时间拓展

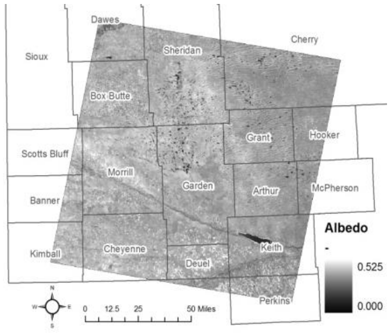
参数化

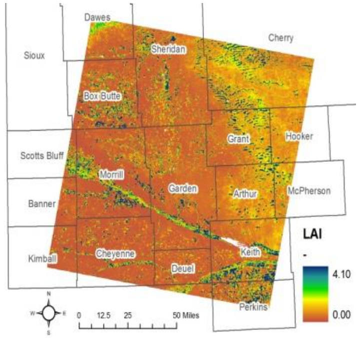
$$\lambda E = Rn - H - G$$

Digital Elevation Model + Weather Data + Surface Albedo + Leaf Area Index

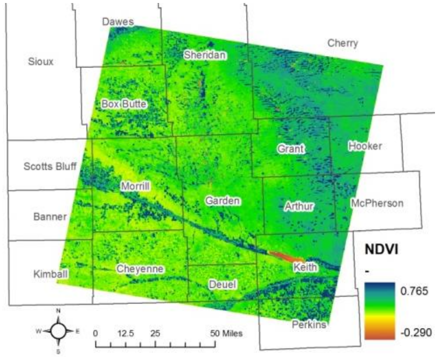


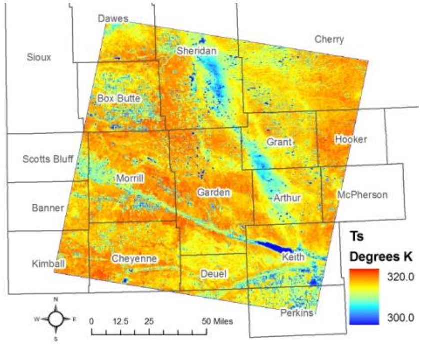



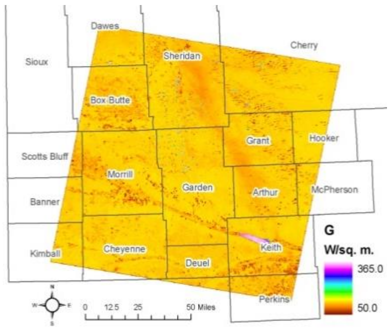


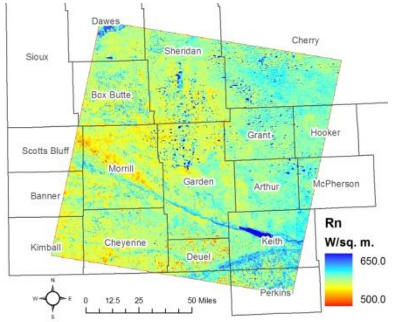




NDVI + Surface Temperature + Soil Heat Flux + Net Radiation




Momentum Roughness + Sensible Heat Flux + Fraction of Reference ET