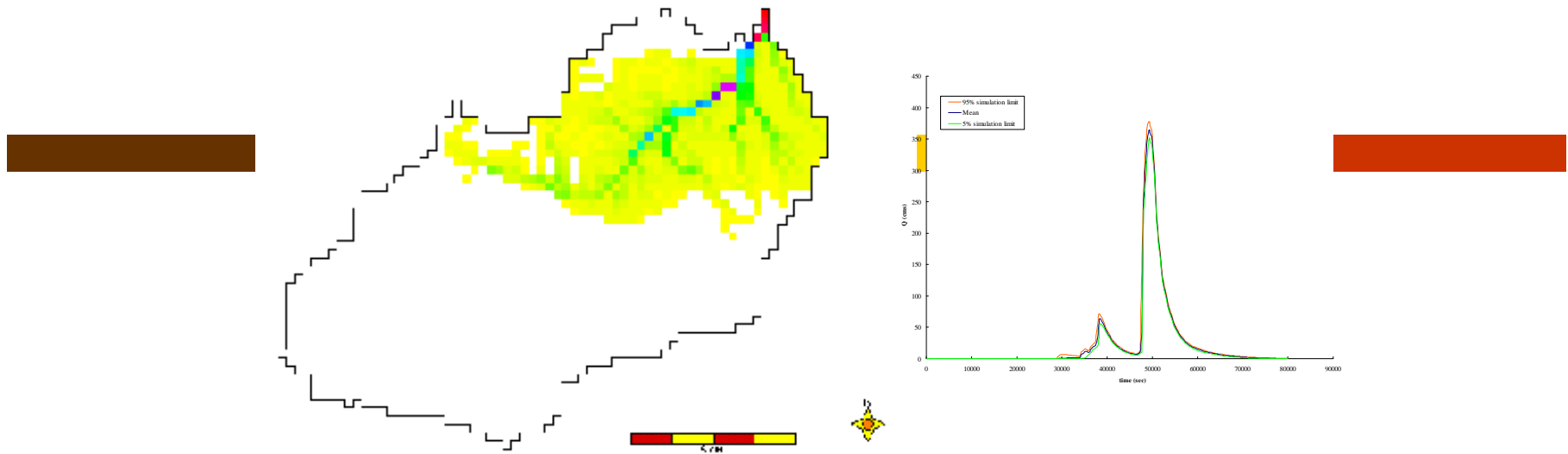# GIS in Water Resources Engineering

Lynn Johnson
University of Colorado Denver
9 April 2008

Outline

- GIS Overview
- Water Resources
- WR Data
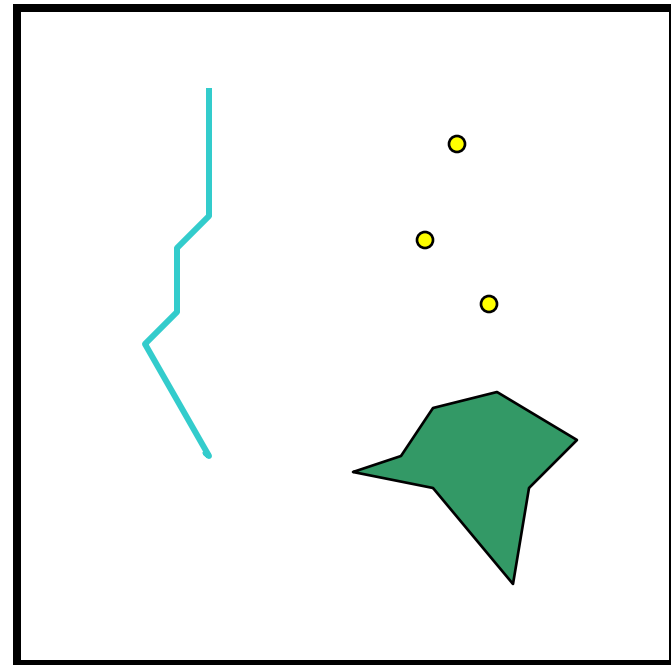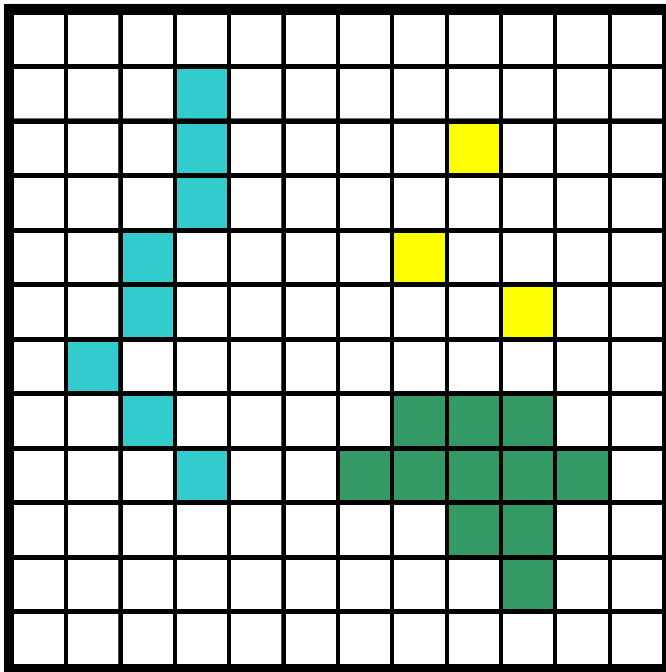- WR Data Management
- WR Modeling
- WR Decision Support Systems

GIS Overview

- GIS is built upon knowledge from engineering, geography, cartography, computer science, mathematics, ...

- Automated system for the capture, storage, retrieval, analysis, and display of spatial data.

- "the main purpose of these GIS is to help politicans and bureaucrats make sensible decisions on the management of ... resources."
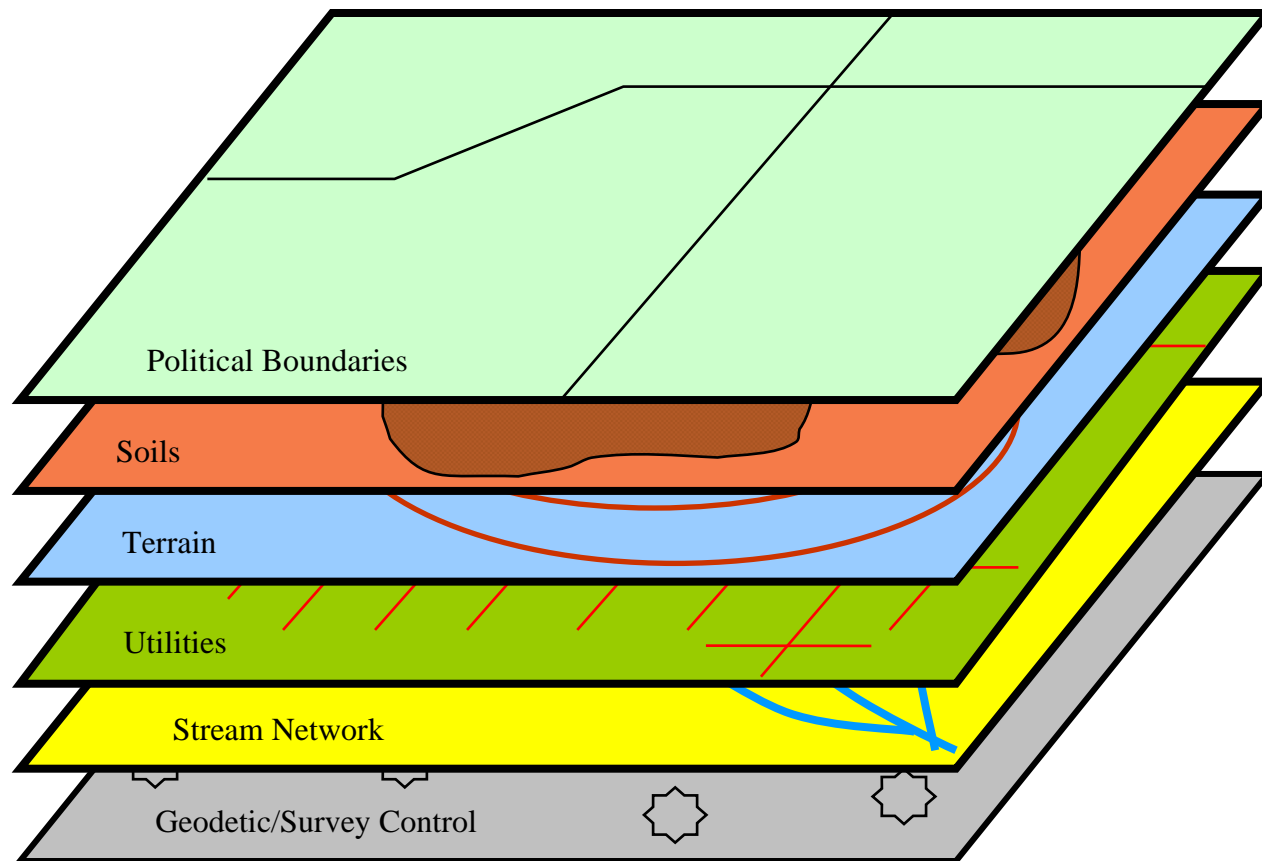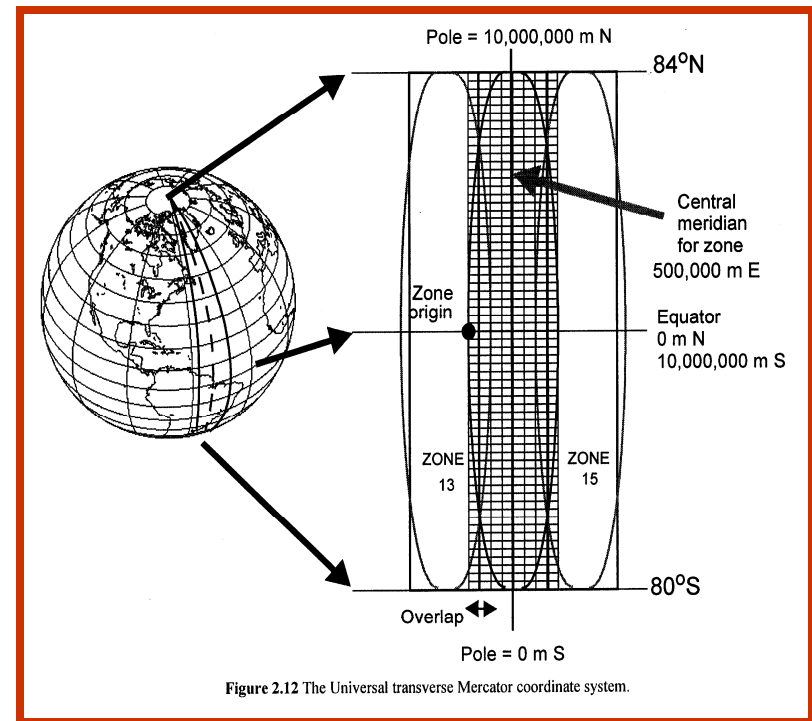
Raster & Vector Data Structures

GIS as Data Theme Layers

Political Boundaries

Soils

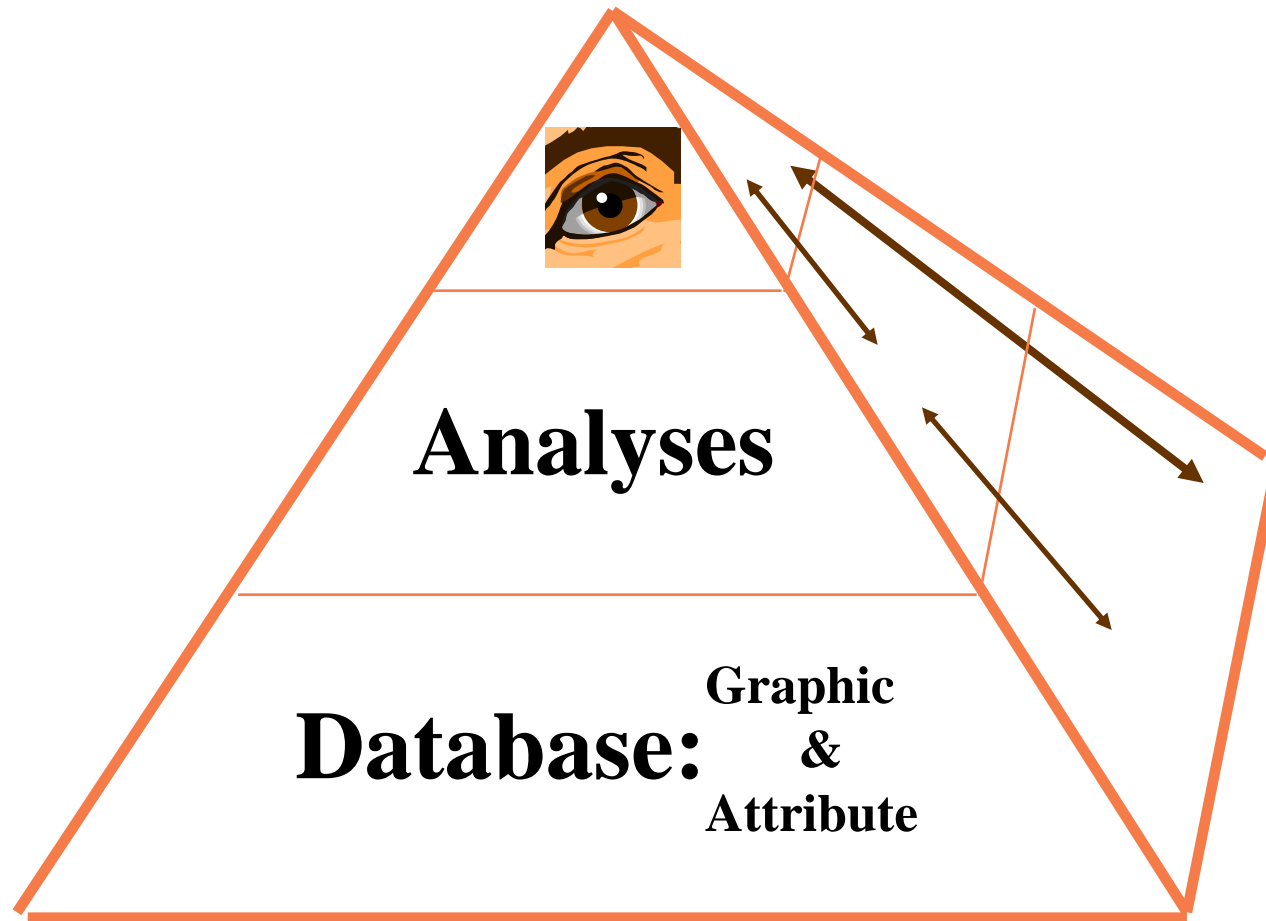Terrain

Utilities

Stream Network

Geodetic/Survey Control

MAP PROJECTIONS

- A map is a depiction of all or part of the earth as a set of symbols and at a scale whose representative fraction is less than one to one.

- Map projection is the transformation of the spherical or ellipsoidal earth onto a flat map.

- To manipulate, overlay or edge-match multiple data sets, all maps MUST be at the same scale, and have the same extent and projection.
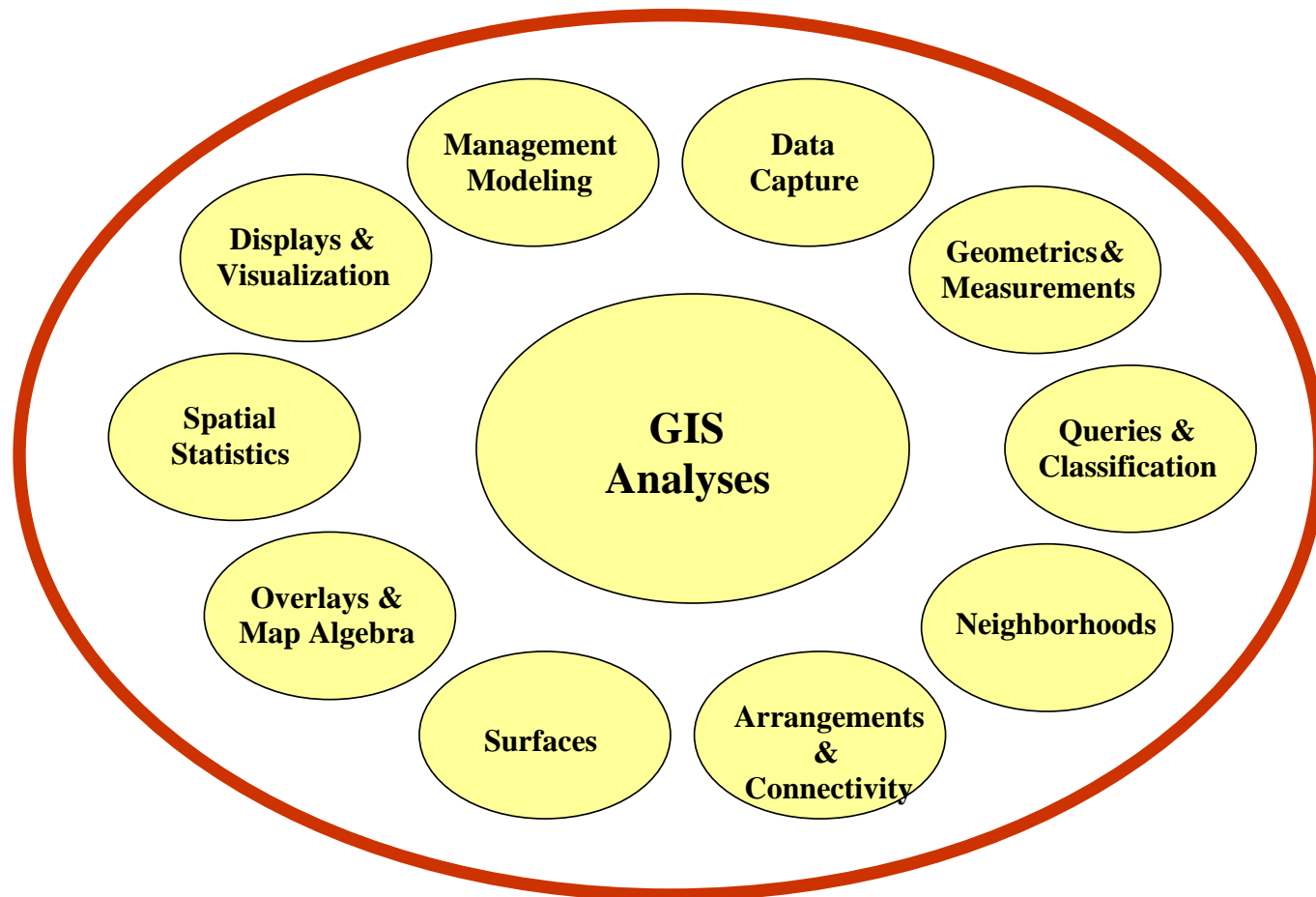

Figure 2.12 The Universal transverse Mercator coordinate system.

GIS PYRAMID

Analyses

Database: Graphic
&
Attribute

GIS Analyses

Water Resources

- *Surface Water Hydrology
- Water Supply & Irrigation Systems
- Wastewater & *Stormwater Systems
- *Floodplain Management
- *Groundwater Hydrology
- Water Quality
- WR Monitoring and Forecasting
- *River Basin Planning and Management

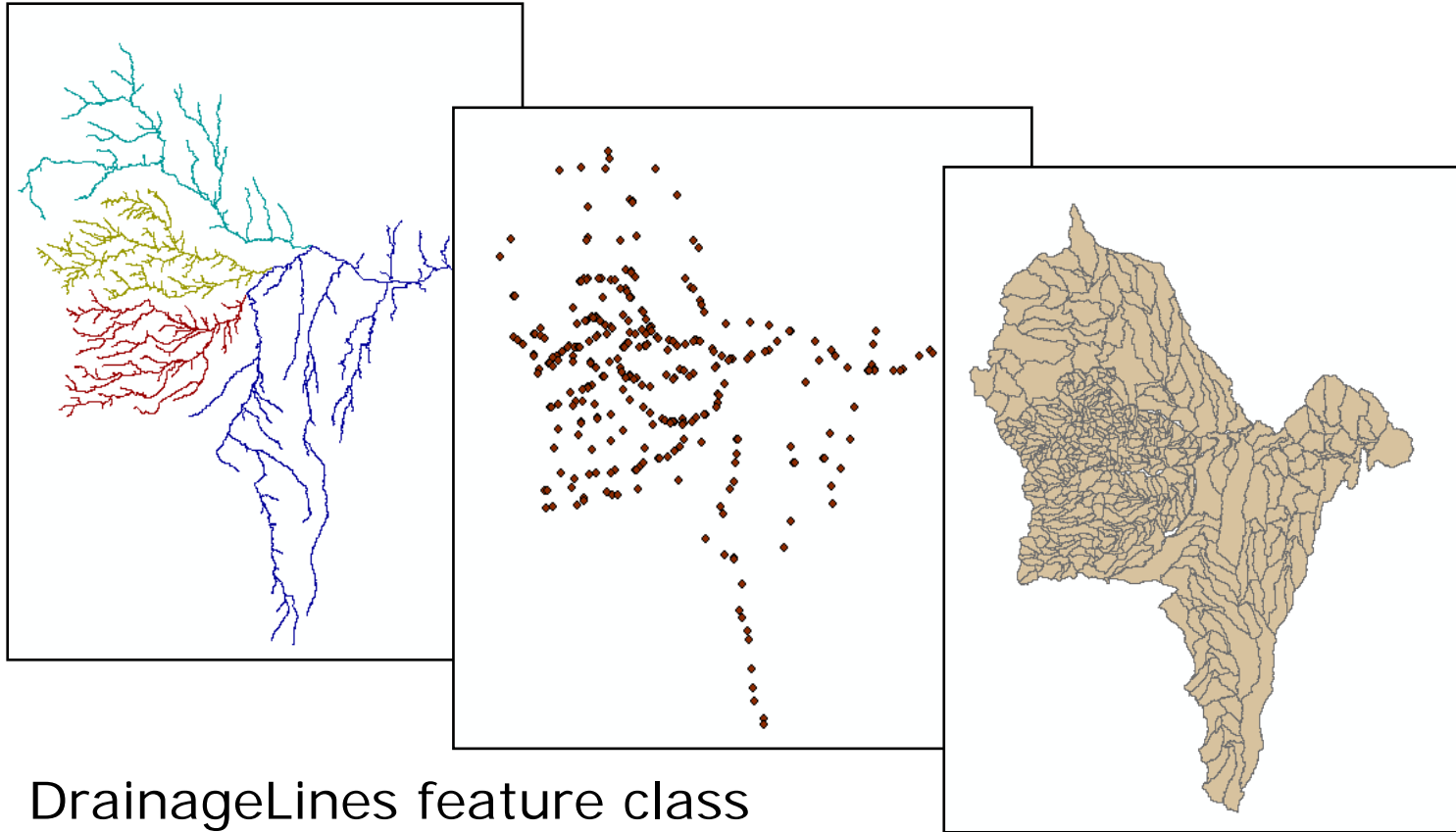* = emphasis for this presentation

Water Resources Data

- Topogaphy
- Hydrography / Hydrology
- Meteorology
- Land use / Land cover
- Vegetation
- Soils and geology
- Dams, pipelines, facilities
- Transportation
- Jurisdictions
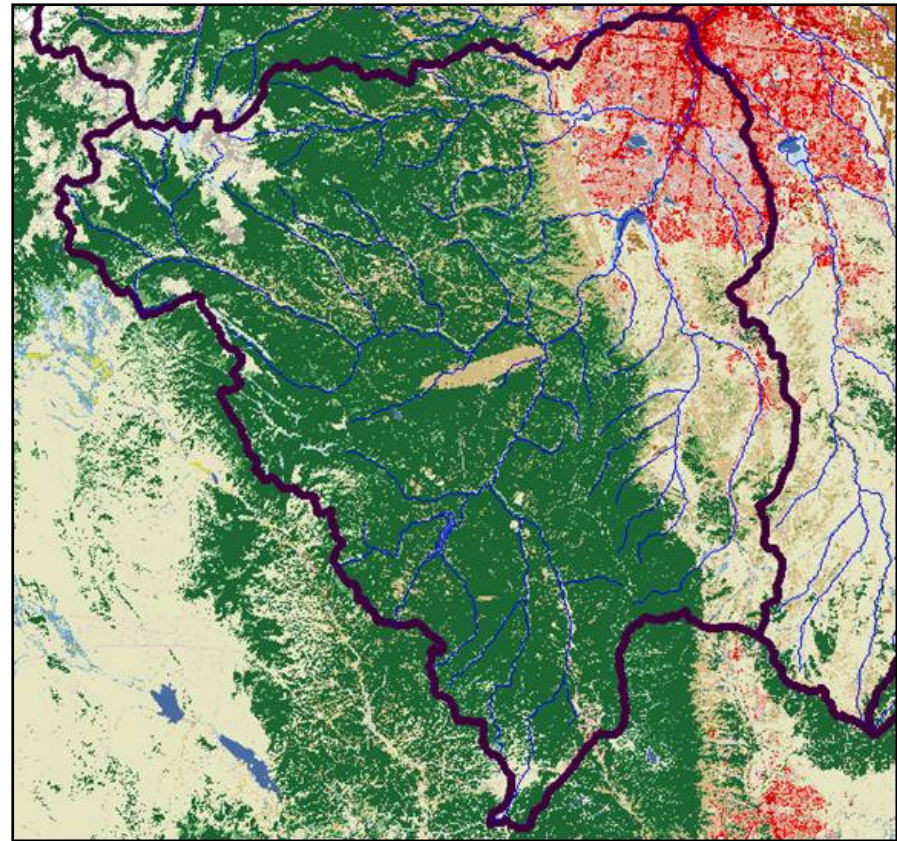
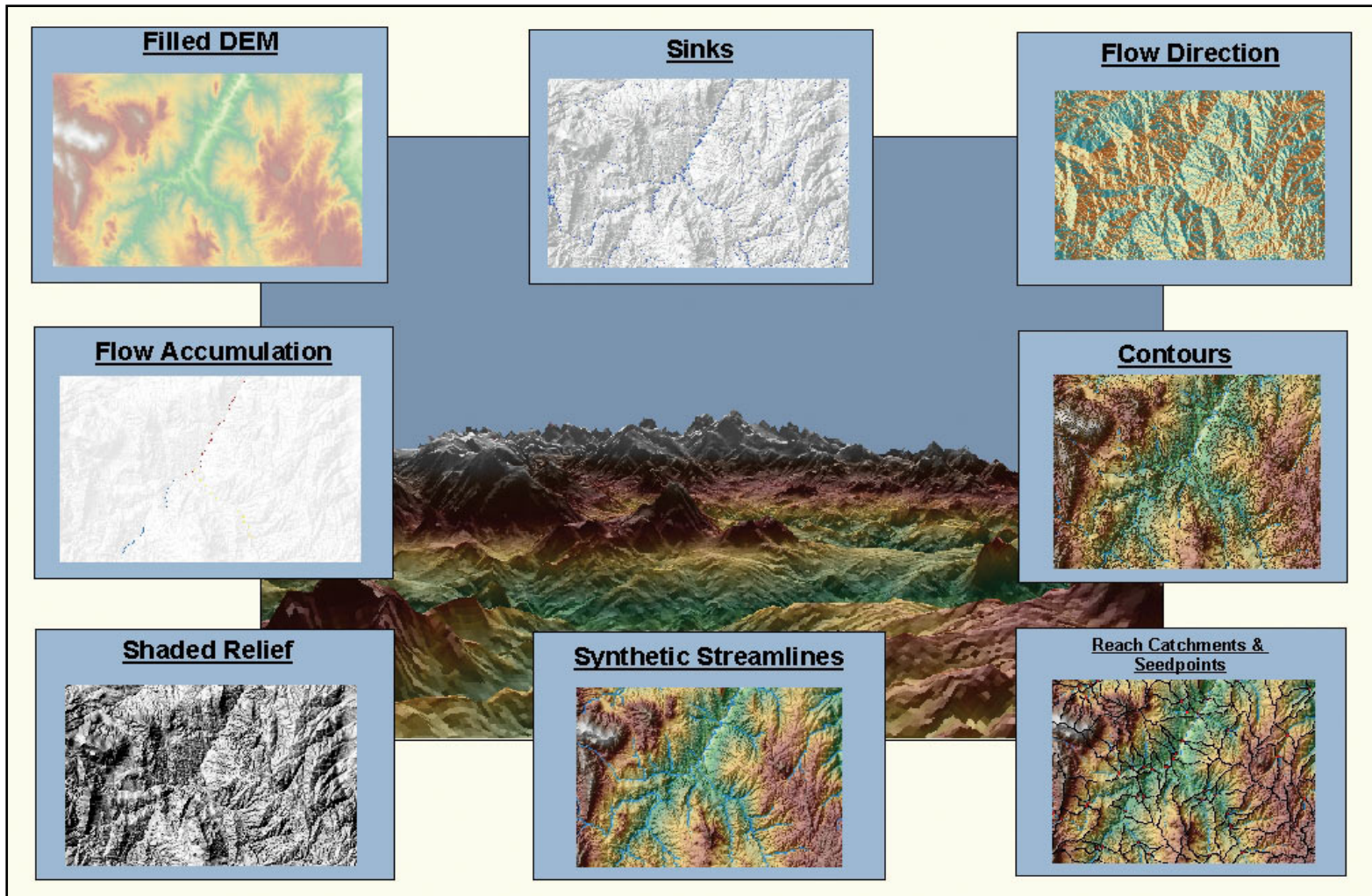Upper South Platte Basin

Terrain Processing for Hydrography

a) DrainageLines feature class

b) DrainagePoint feature class

c) Catchment feature classes merged into a regional layer
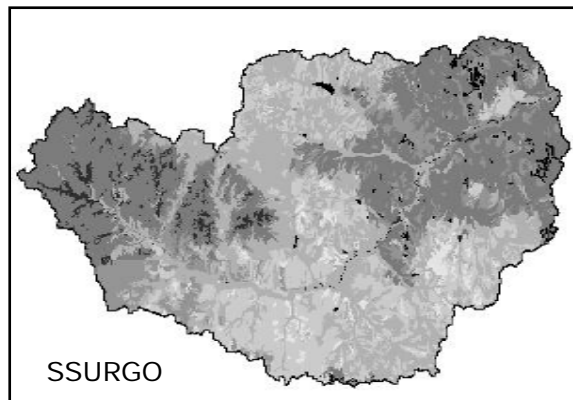
Elevation Derivatives for National Applications (EDNA)

National Hydrography Dataset

- □ Nationwide system for:
  - ■ Stream addressing,
  - ■ Upstream/downstream flow direction modeling,
  - ■ Maintenance of hydrographic infrastructure.
- □ Available Nationwide at 1:100,000-scale; much of the Country as high resolution at 1:24,000-scale.
- □ Six Feature Classes for ArcGIS:
  - ■ a. HYDRO_NET_Junctions
  - ■ b. NHDFlowline
  - ■ c. NHDWaterbody
  - ■ d. NHDPoint
  - ■ e. NHDLine
  - ■ f. NHDArea

- ■ 21 regions
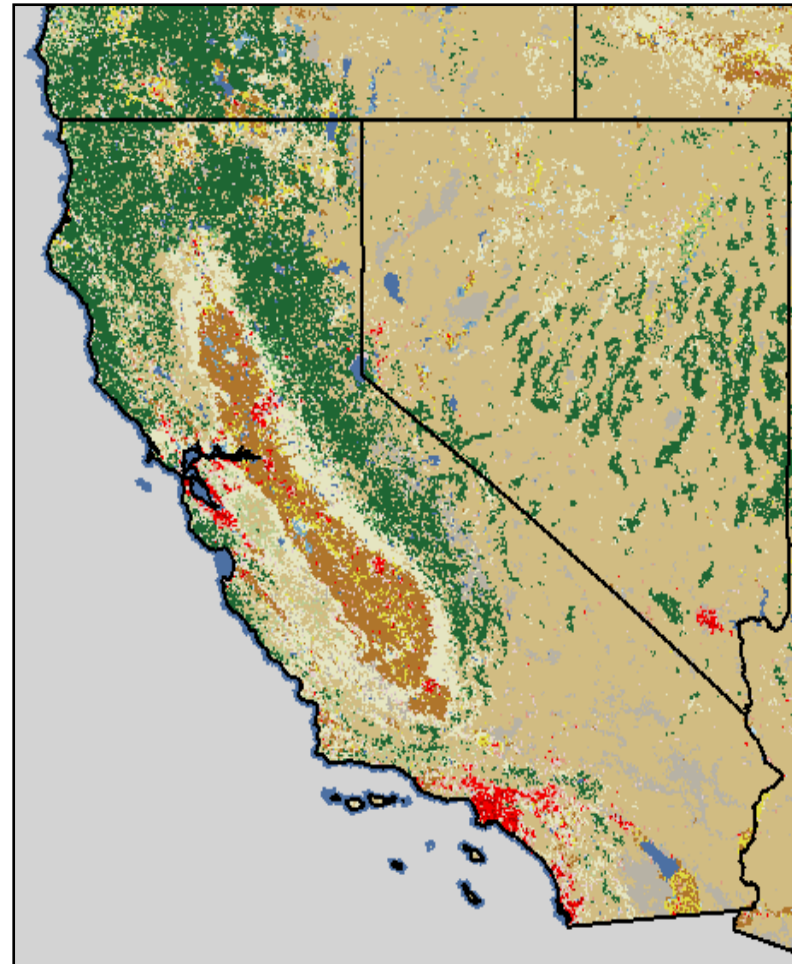- ■ 2264 watersheds

http://nhd.usgs.gov/
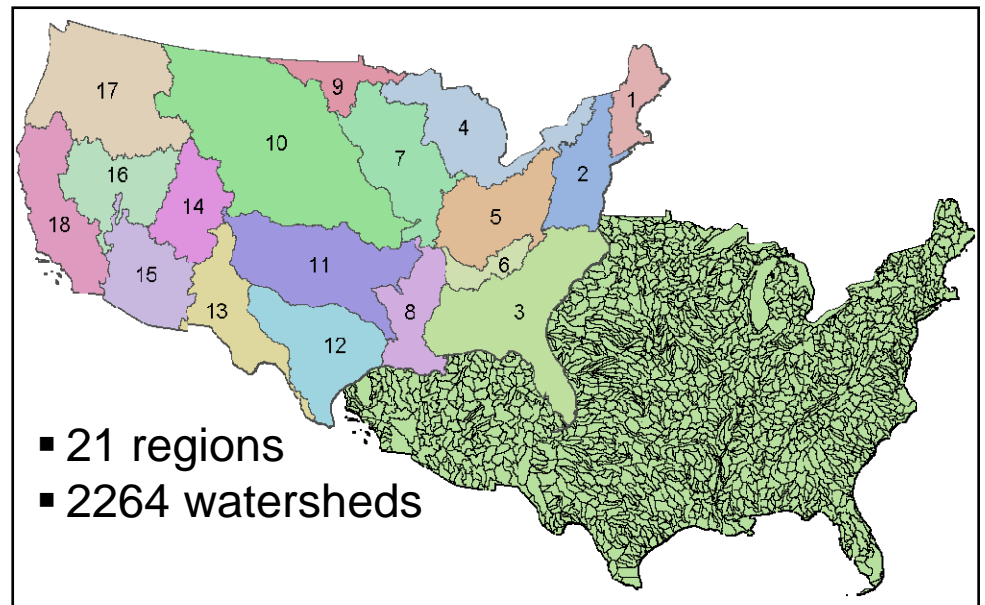
Soils

- NRCS download
- STATSCO
  - Statewide
  - Generalized
- SSURGO
  - County scale
  - 1:24K – 63K
  - Need RDMS retrieval
- Used for soil moisture, erosion modeling, …

STATSCO

SSURGO

http://www.soils.usda.gov/

Land Use / Land Cover

- Multi-Resolution Land Characteristics (MRLC) Consortium
  - NLCD 1992
    - Landsat 5 imagery
    - 21 classes
    - 30-meter resolution
  - NLCD 2001
    - Landsat 7 imagery
    - Imperviousness and tree canopy
- Used for:
  - Hydrological modeling
    - Rainfall abstractions
    - Surface roughness
  - Urban water demands
  - ...

http://www.mrlc.gov/

Land Use Change Analysis
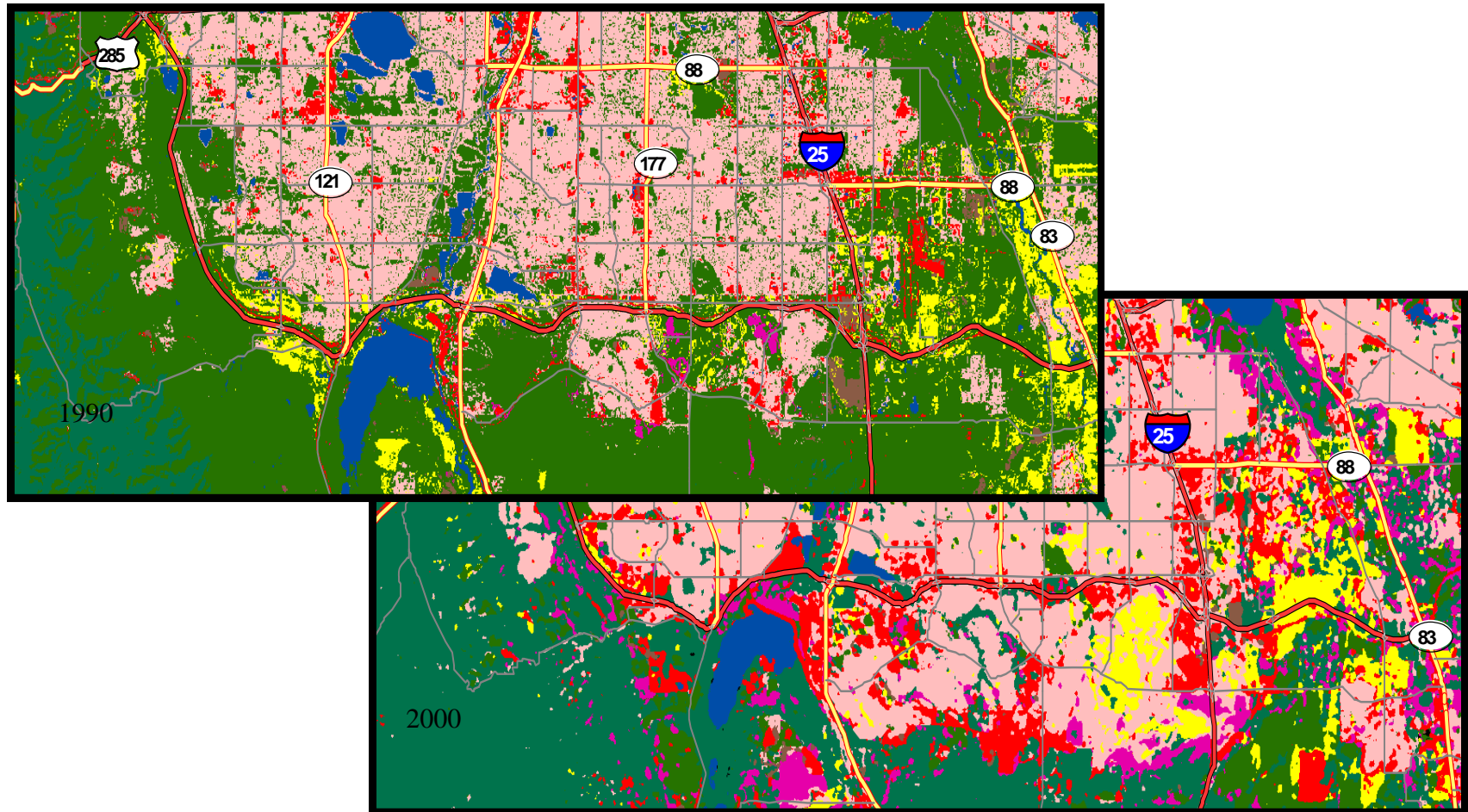
South Denver metro region (Liang & Johnson, 2002)

Impervious Area Forecasts

(Johnson and Kundu, 2007)
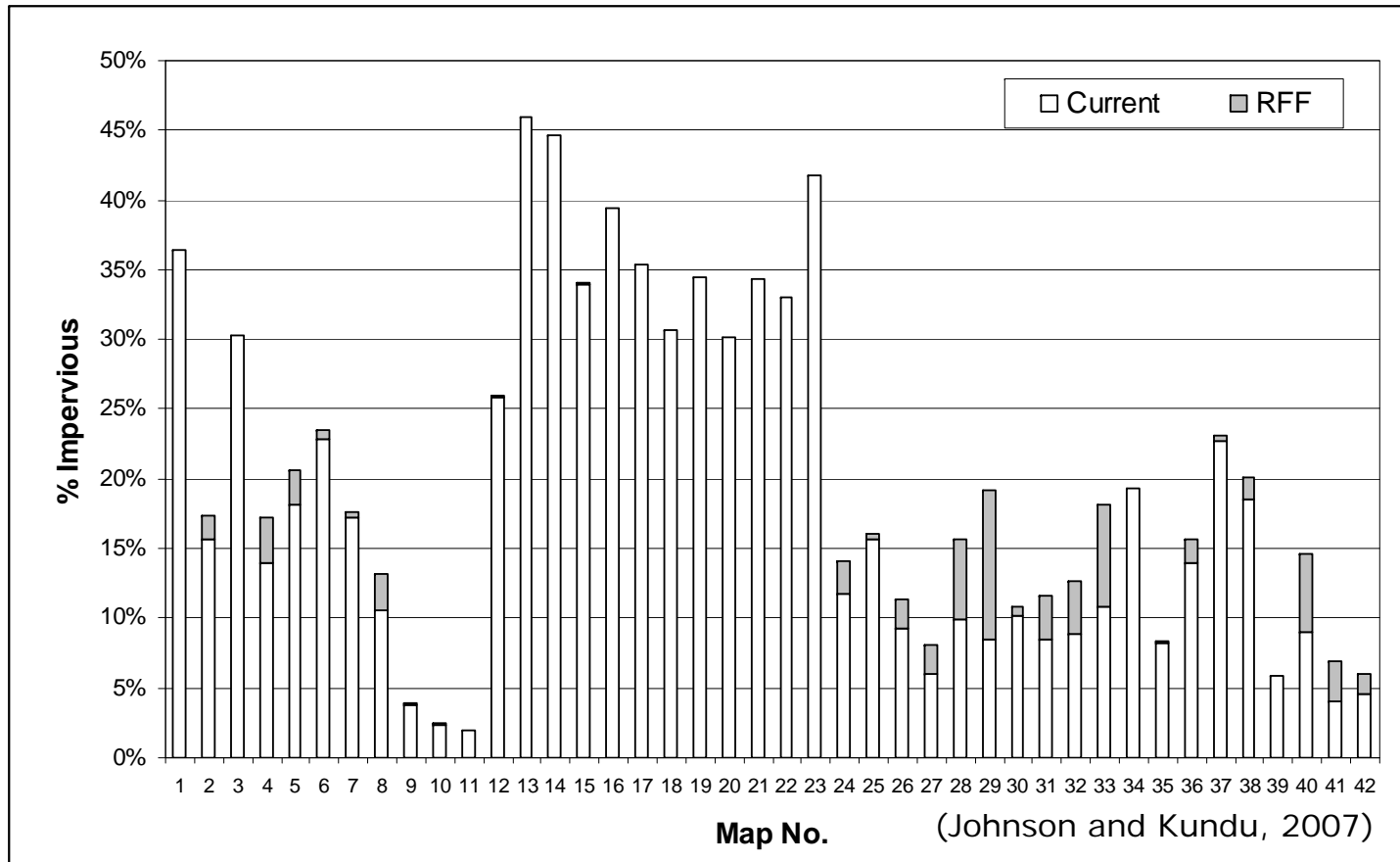
- **Percentage impervious areas of C470 area watersheds.**
- **RFF = Reasonably Foreseeable Future based on land use plans.**

Radar-Rainfall Data

- NEXRAD
  - 1-hour
  - 3-hour
  - Storm total
  - Digital Precipitation Array (DPA)
- Real-time applications for flood threats
  - RFCs NWSRFS
  - WFOs
    - AWIPs display
    - AMBER
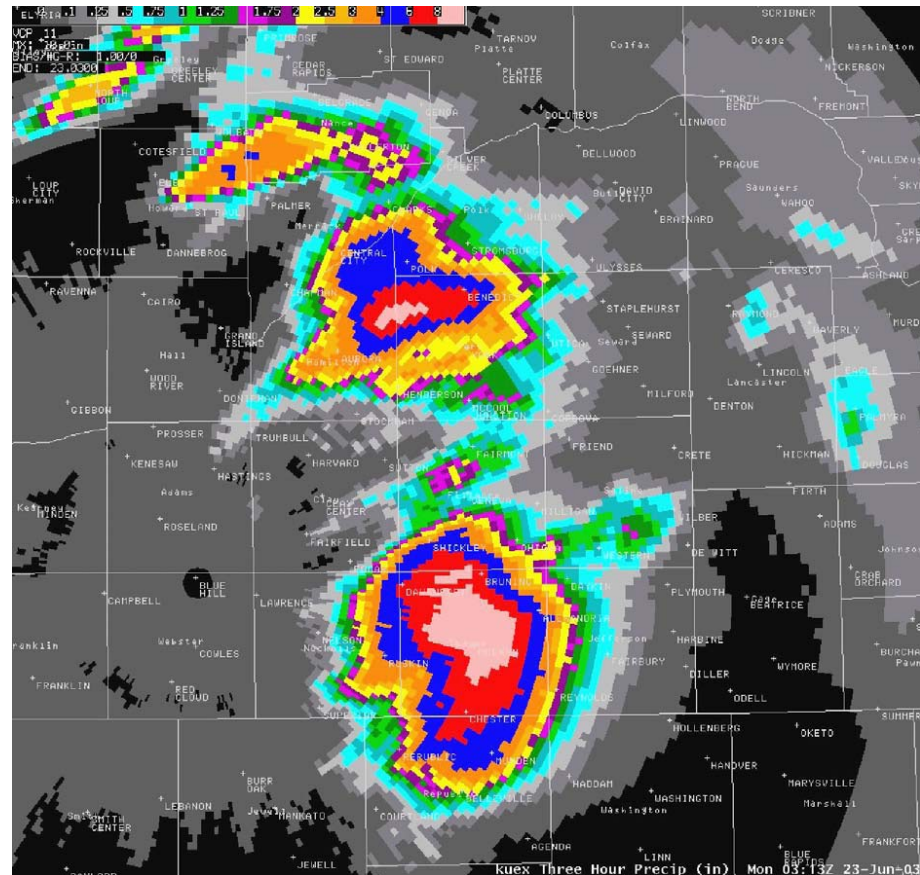
Extreme Precipitation Analysis Tool (EPAT)

1. GIS-based tool for PMP
2. "Storm Library"
   - Available in shapefile format from the NCDC http://www.ncdc.noaa.gov/oa/radar/radarresources.html
   - Requires ground truthing (UDD gages shown)
3. Historical storms that developed in the same geographic region to be used when determining the PMP
4. SS-PMP/HMR STEPS
   a. Develop Historical Extreme Precipitation Event Evaluation (Storm Library)
   b. In-place moisture maximization of the event and Seasonal adjustment (15 days to warmer)
   c. Transposition factor
   d. Elevation-Adjusted Maximized Precipitation
   e. Storm Placement
   f. Aerial Point Reduction

June 27, 2004
Storm Total Precip Map with Ground Truth
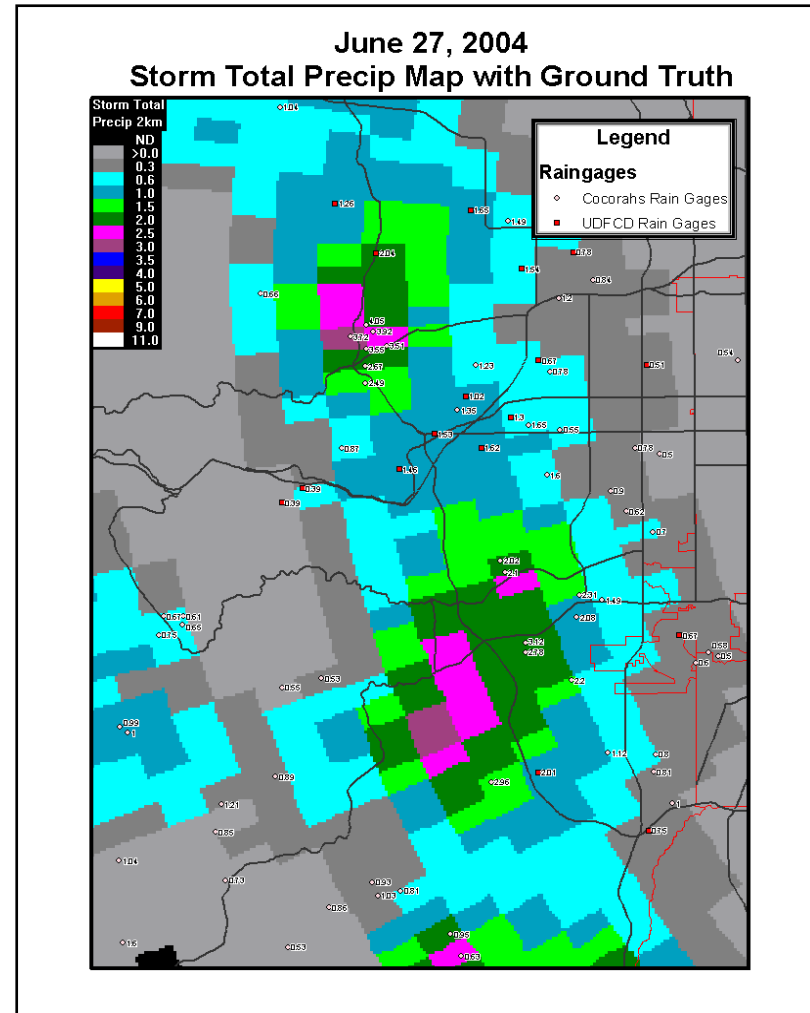
Rob Rahrs, HDR Engineering Inc., 2007

ArcHydro Data Model

- Generic GIS-based data framework for spatial and temporal data.
- Components
  - Network,
  - Drainage,
  - Channel,
  - Hydrography,
  - Time Series.
- Allows data and applications sharing.
- Framework for integration with hydrologic computational programs.

http://www.crwr.utexas.edu/giswr/hydro/
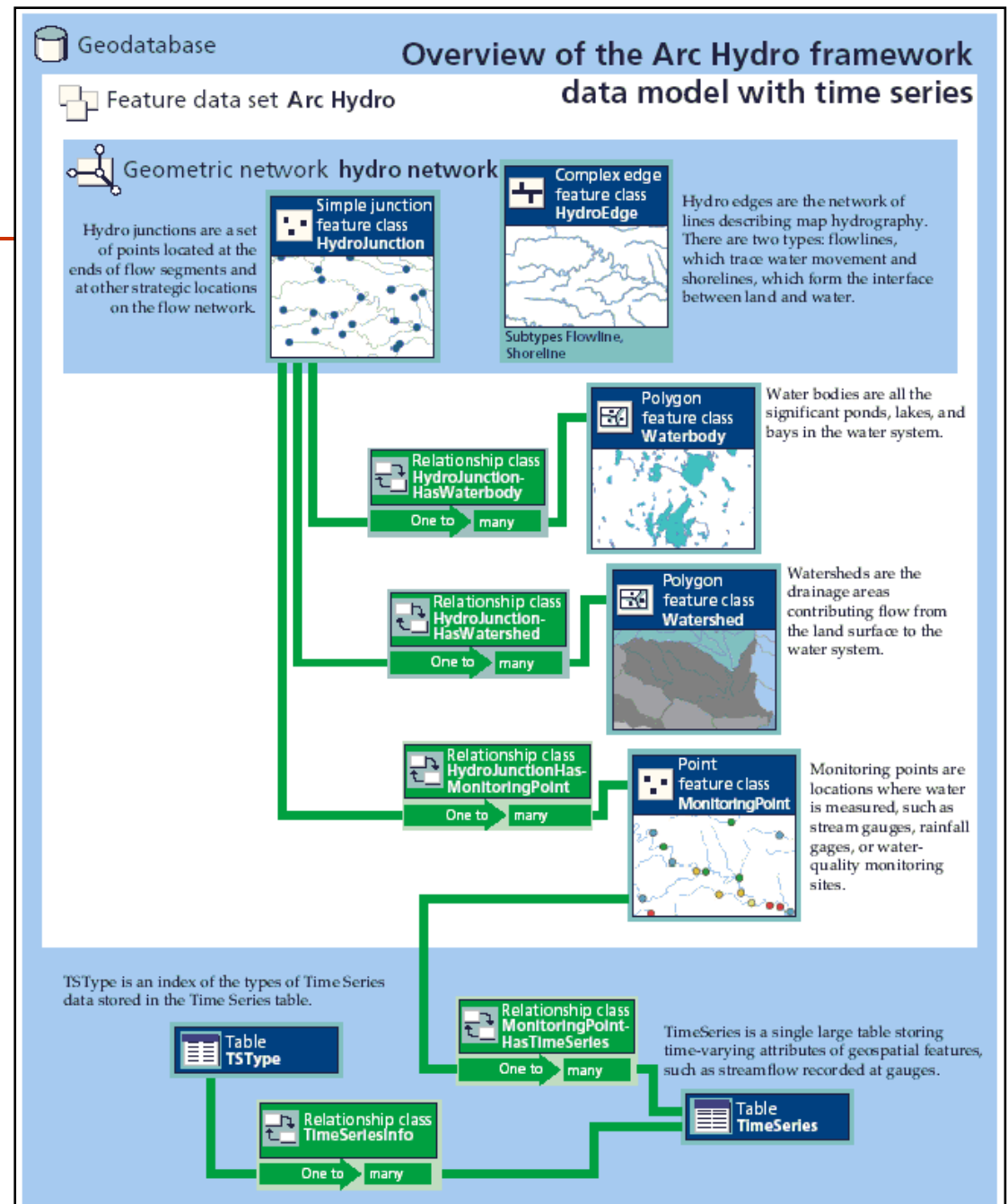
Hydrological Modeling
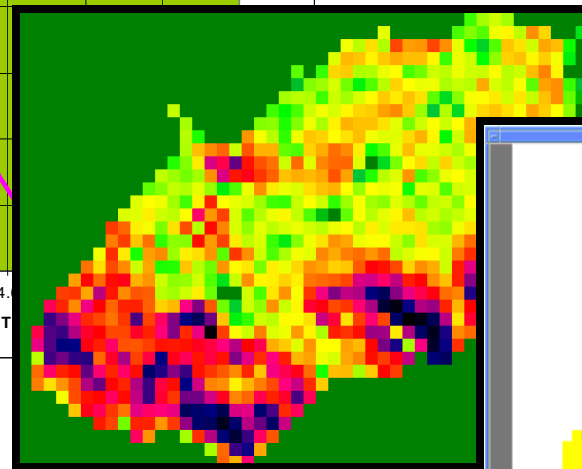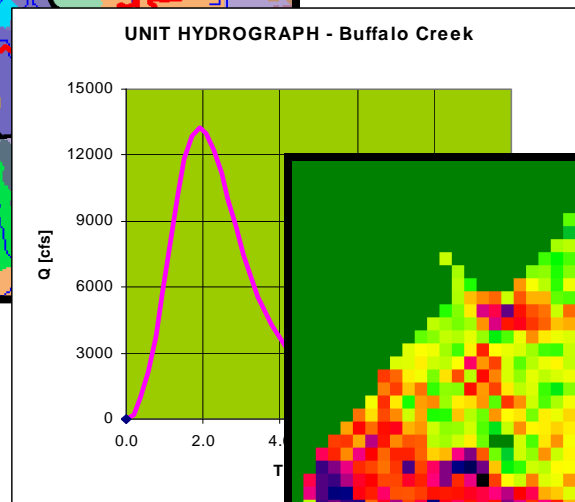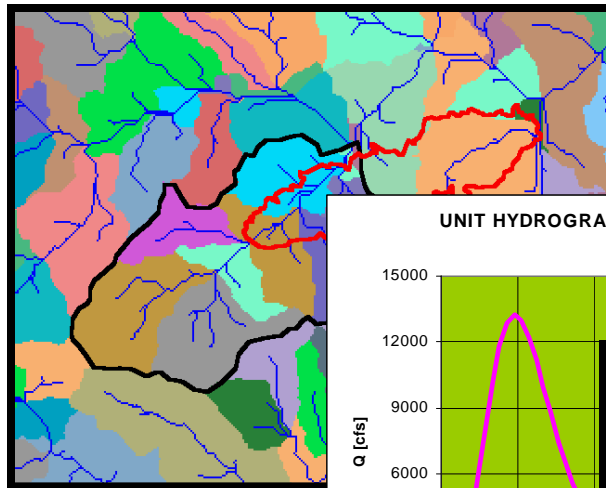
- AMBER
- Unit Hydrograph
- Time-Area
- 2-D Distributed
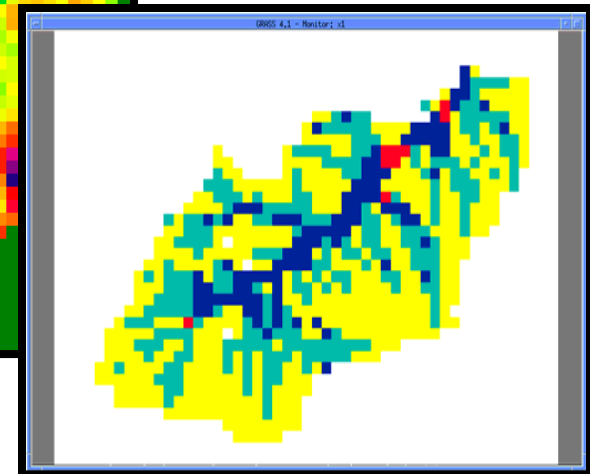
AMBER

- Area Mean Basin Effective Rainfall
- WFO flash flood potential
- Implemented nationwide with basin delineation database (4 to 5 levels)
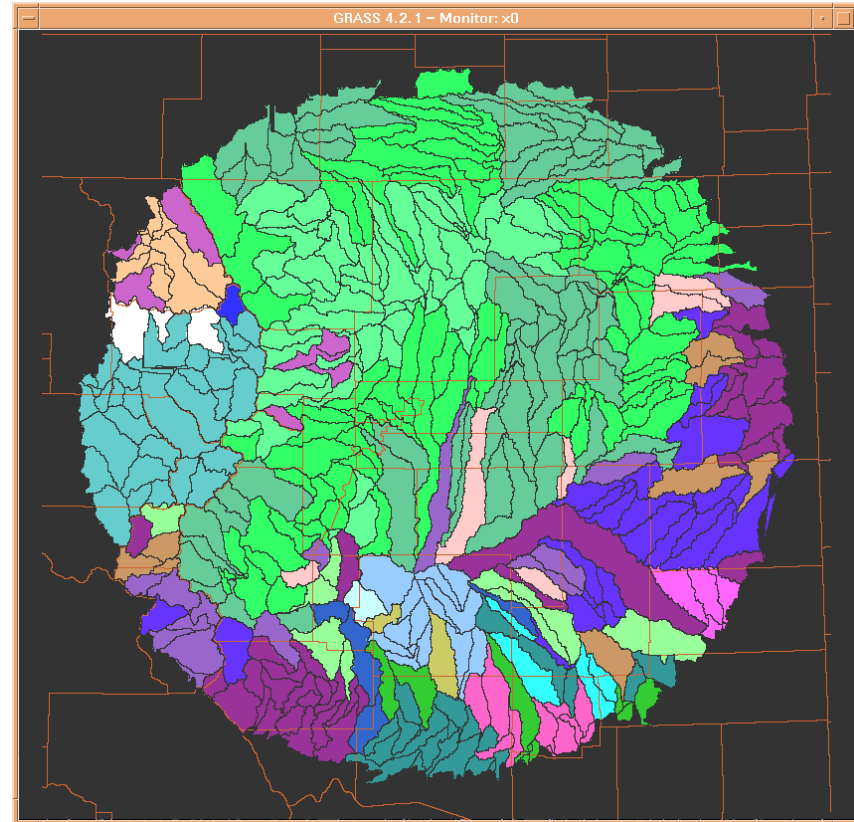
Unit Hydrograph Time-Area Derivation
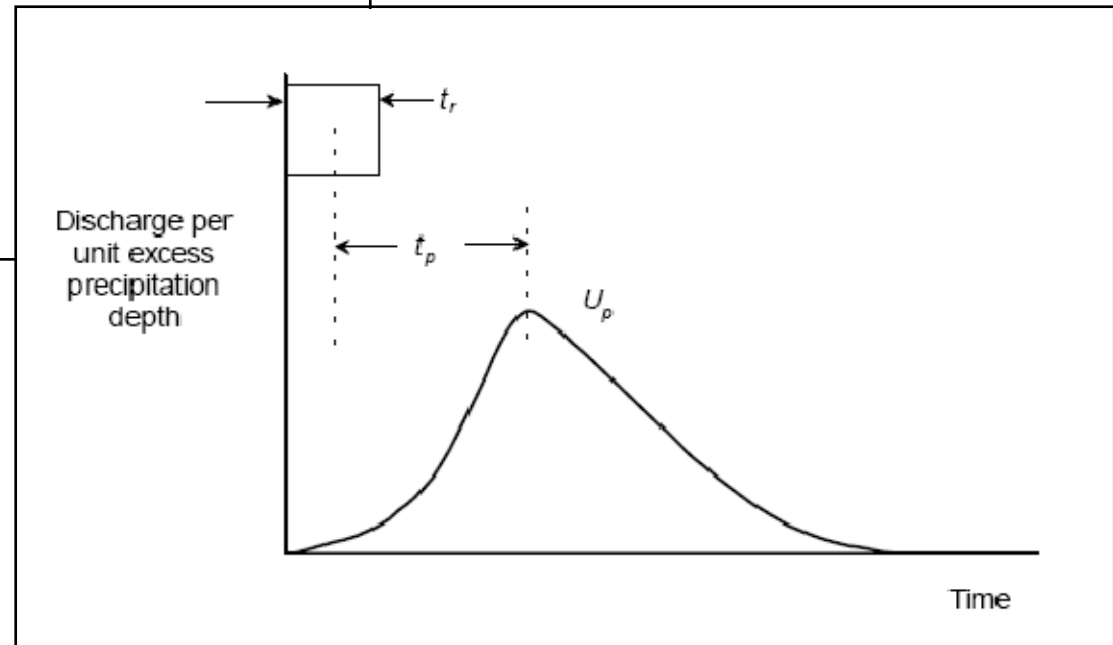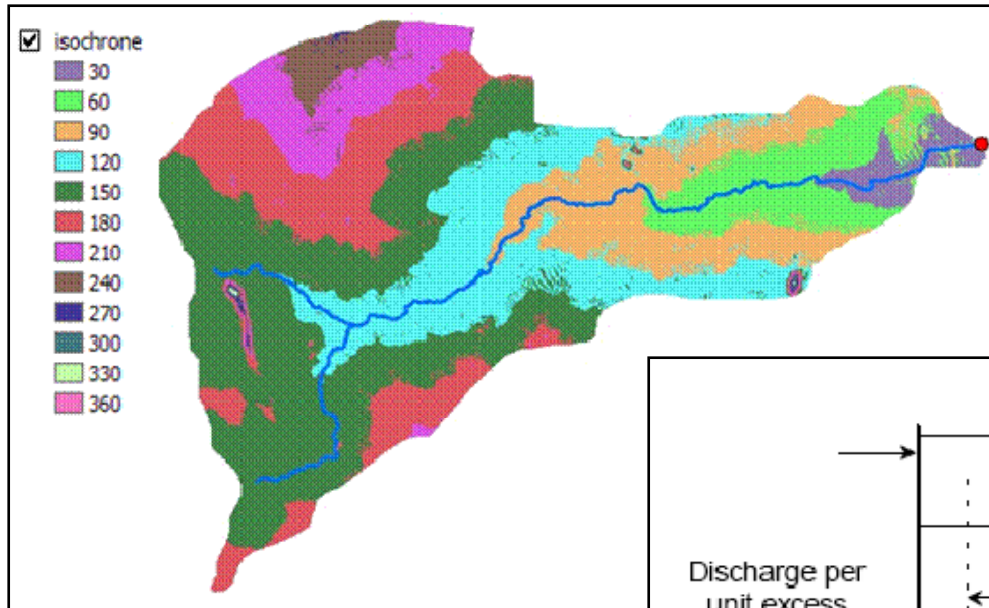
F2D Model

- F2D components include:
  - spatially-varied infiltration-excess,
  - inter-storm redistribution of soil moisture, and
  - kinematic-wave overland flow and channel flow routing.
- Spatially and temporally varied radar-rainfall.
- Operates on DEM grid
  - Variable resolution (100 m - 1 km)
  - Slope and D-8 flow direction,
  - Stream network topology.
- Soil texture.
- Land use/land cover, % urban impervious.
- Initialized daily.
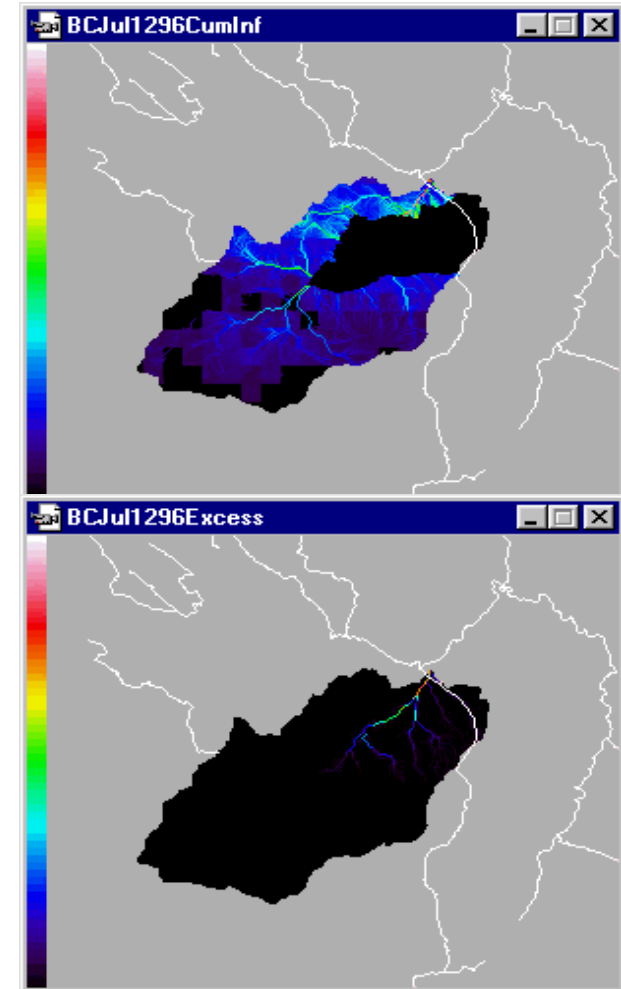
Skahill & Johnson, 2001

Hydrology Lab Research Modeling System

- Ingests NEXRAD products
- Basic unit NEXRAD grid cell (~4 km)
- Rainfall-runoff calcs done independently for each grid cell
- Runoff routed over hillslopes within a model cell.
- Channel routing from cell-to-cell.
- Rainfall-runoff calcs:
  - lumped or distributed rainfall
  - lumped or distributed parameters
- Uses SAC-SMA
- Kinematic method hillslope and channel routing
- Writes outputs to ArcView GIS

HRAP Drainage Network
HRAP Basin Boundary
Blue HRAP Bins
Select NHD Streams
DEM Basin Boundary

http://www.weather.gov/ohd/hrl/
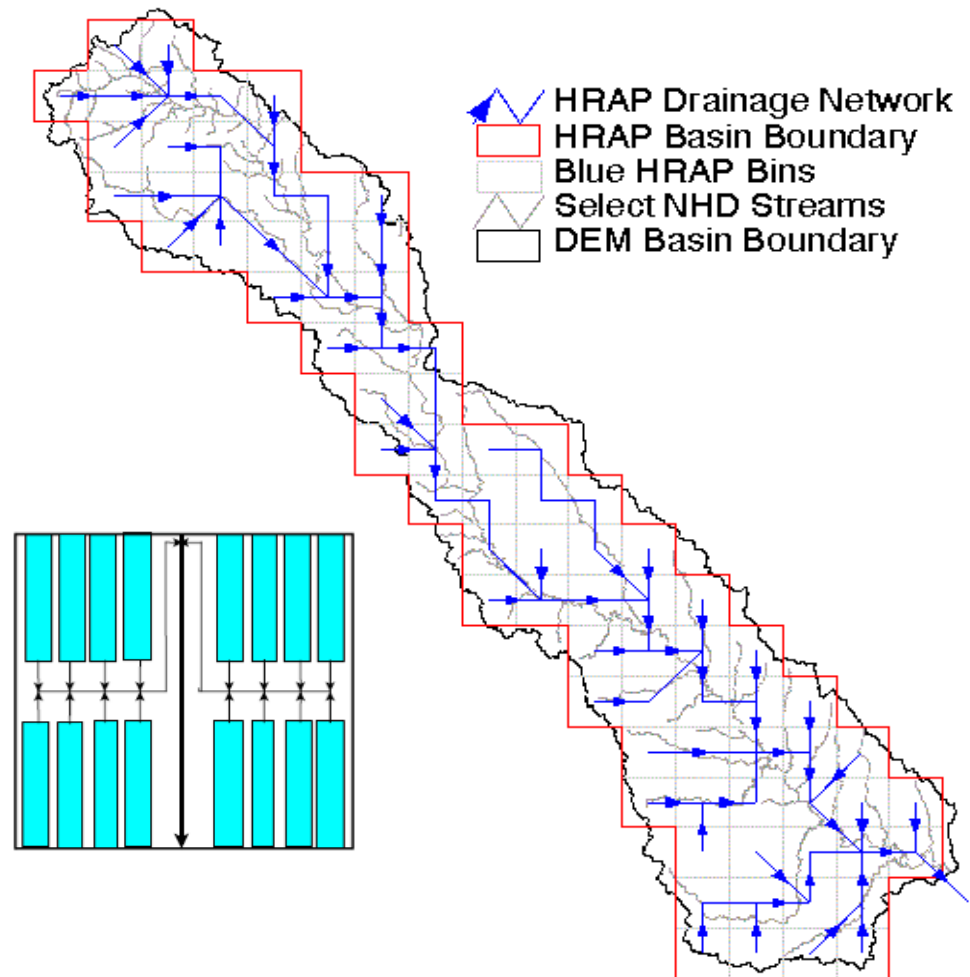
Hydrologic Modeling Workflow Sequencing

Flood map as output

Simulation of flood discharge

HMS

Nexrad rainfall map as input

Simulation of flood elevation

Maidment, 2005
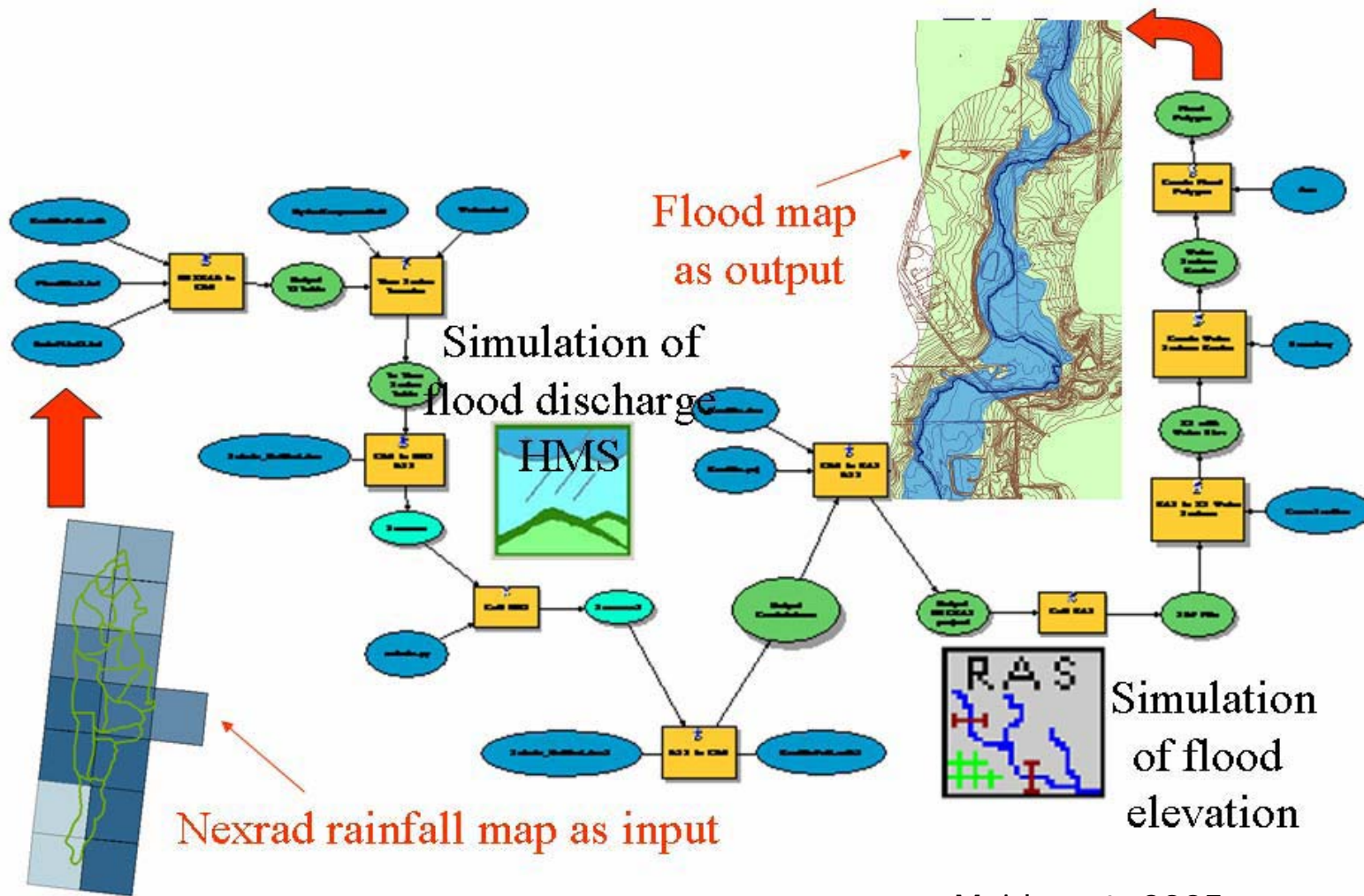
S. Boulder Creek Hydrology

- **Climatology**
  - Radar-rainfall
  - NOAA Atlas Frequency
- **Hydrology**
  - MIKE Flood
  - 27 sub-basins
  - Conceptual rainfall-runoff
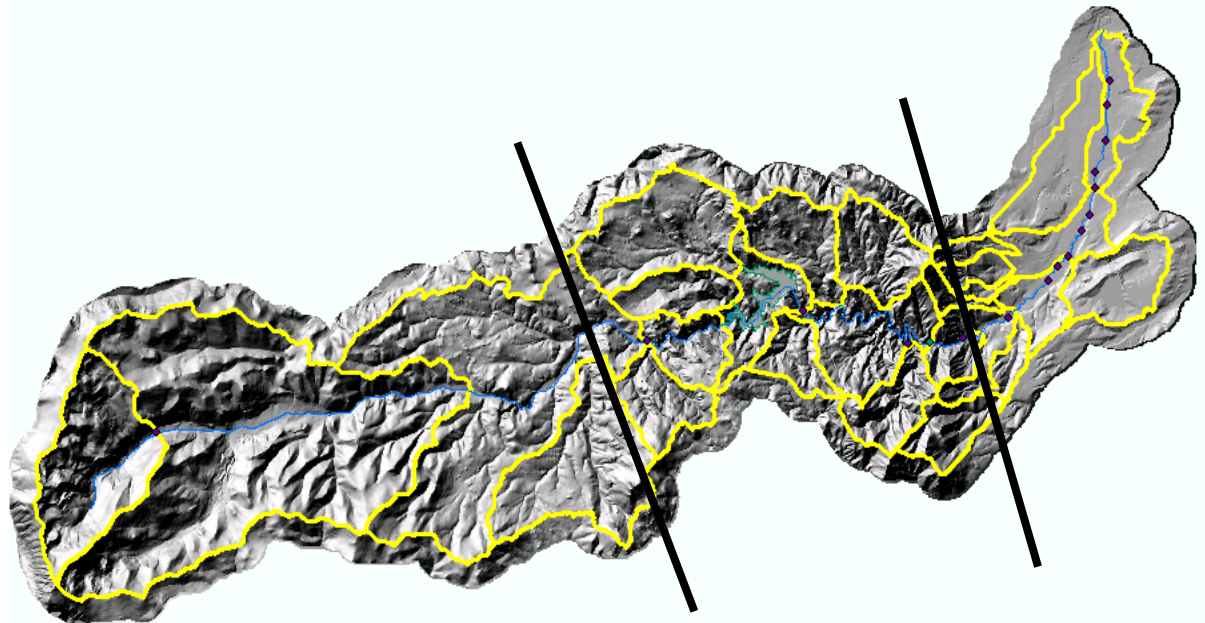
South Boulder Creek Hydraulics Model

- 1D model used to describe
  - In channel flows and structures
  - Off channel structures
- 2D model used to describe out-of-bank flow; 1 m terrain from LIDAR
- Fully dynamic hydraulic routing of inflow hydrographs
- Structures
  - Channels, bridges, culverts, gates, diversions
  - Dams and levees
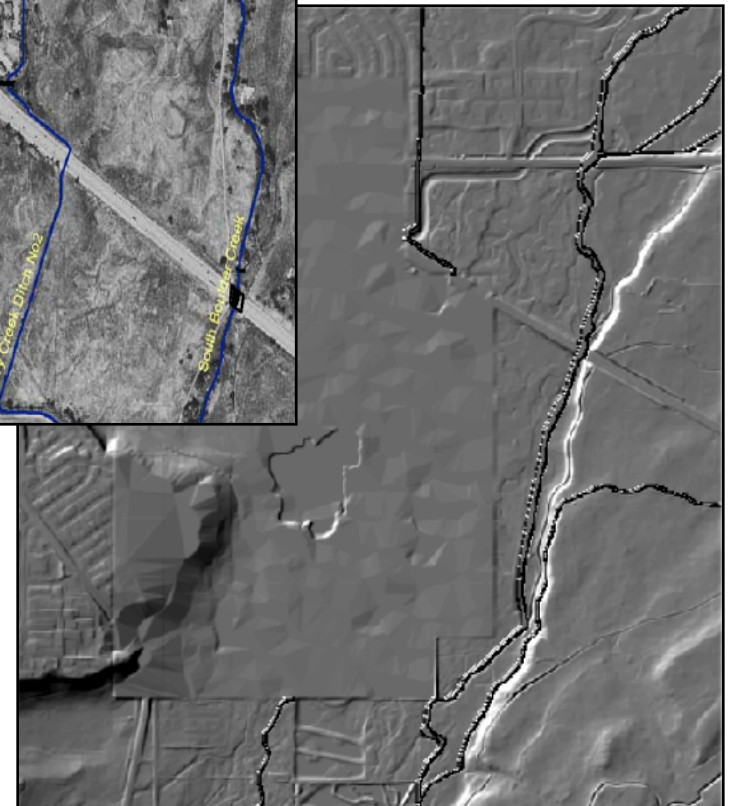
SBC Flood Plain Strategies

- Modify susceptibility
  - Restrict building
  - Flood warning
  - Flood proofing
- Modify flooding
  - Dams
  - Levees
  - Diversions
- Modify impacts
  - Insurance
- Restore natural conditions

Proposed Floodplain

EXPLAINATION OF ZONE DESIGNATIONS

ZONE   EXPLAINATION

AE Zone — Defined as areas of special flood hazard inside the 100-year floodplain where water surface elevations have been determined. A 100-year flood event is a flood that has a one-percent chance of being equaled or exceeded in any given year.

X Shaded — Defined as areas of moderate flood hazard that are determined to be within the 500-year floodplain where there is a 0.2-percent chance of being equaled or exceeded in any given year; areas in the 100-year floodplain where average depths are less than one foot; and areas protected by levees from the 100-year flood.

X Unshaded — Areas determined to be outside 500-year floodplain

Date: August 2007

http://gisweb.ci.boulder.co.us/website/pds/sbc_flood/

Floodplain Damage Assessments

- New Orleans, Katrina Flood
- Residential direct property damages by census block
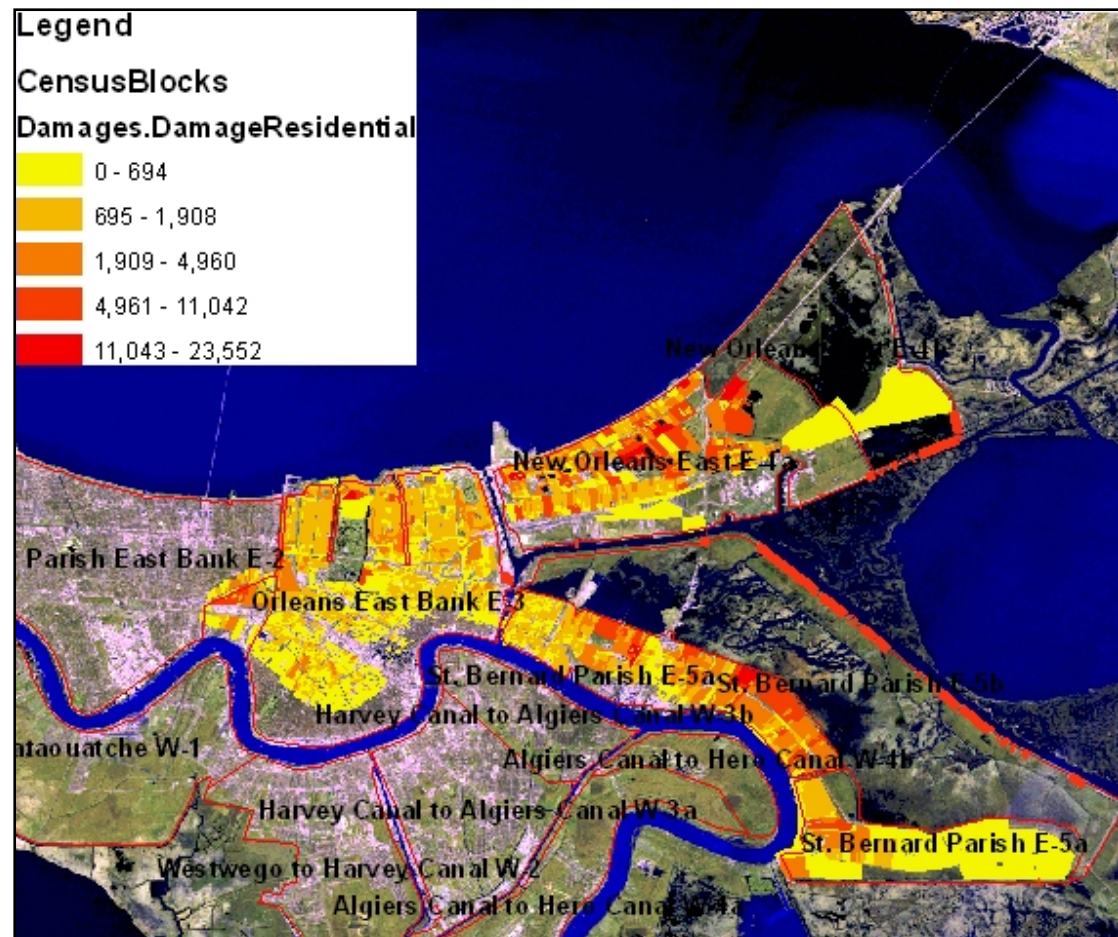
Distribution of Katrina-generated residential direct property damages by census block; damages in thousands of dollars. (Source: IPET, 2007)

Stormwater

- Surface hydrology that focuses on urban drainage
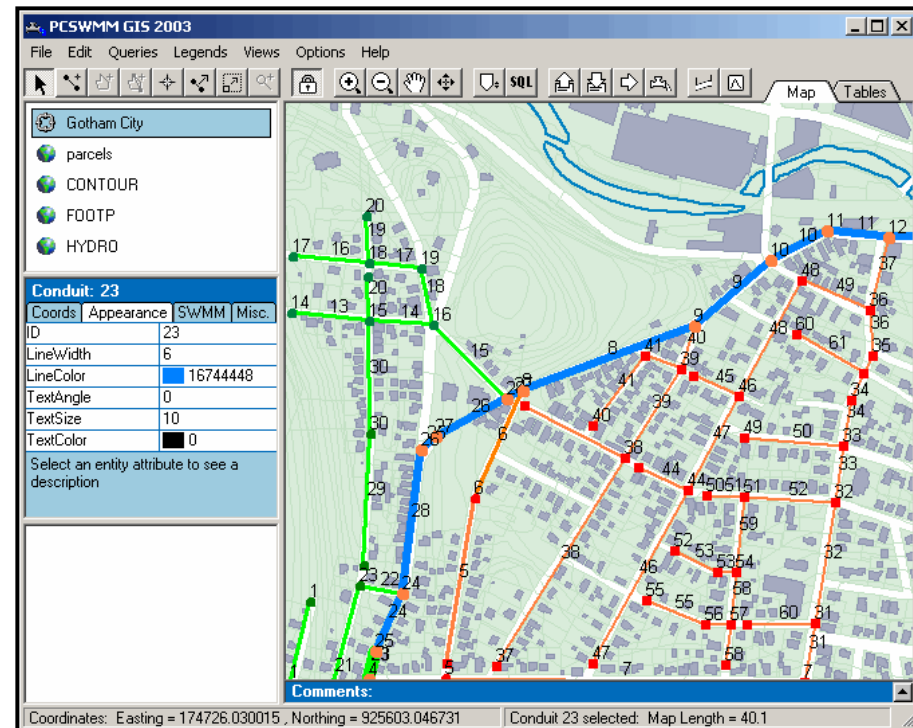- Large-scale mapping (1:400); 1-ft contours
- Network of pipes
- Facilities
  - Junctions / Man-holes
  - Diversions
  - Detention ponds
  - Outfalls

PCSWMM interface window
(Source: ttp://www.computationalhydraulics.com/)

Stormwater Quality

- Non-point source of pollution
- Impervious surface mapping
- Runoff models have WQ module
- Total Maximum Daily Loads (TMDL)
- Best management practices
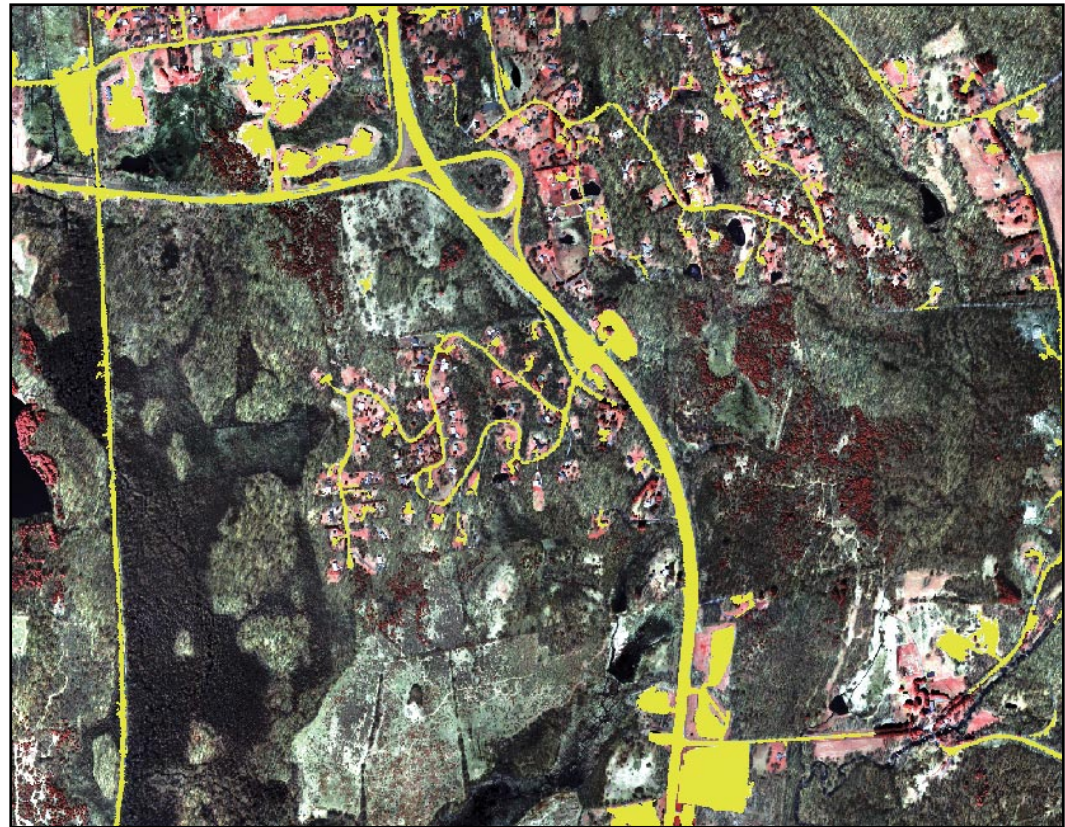
Impervious surface areas (shown in yellow) extracted by image processing (Washburn et al., 2003).

Municipal Databases

- Enterprise systems
  - Work management systems (WMSs),
  - Document management systems (DMSs),
  - Infrastructure management systems (IMSs),
  - Materials management systems (MMSs),
  - Customer information systems (CISs)
- Capacity planning and capital improvement projects
- Update GIS databases with as-built data
- Standard and custom map products
- Integrate CAD drawings Manage operations activities, such as leaks, repairs, and inspections
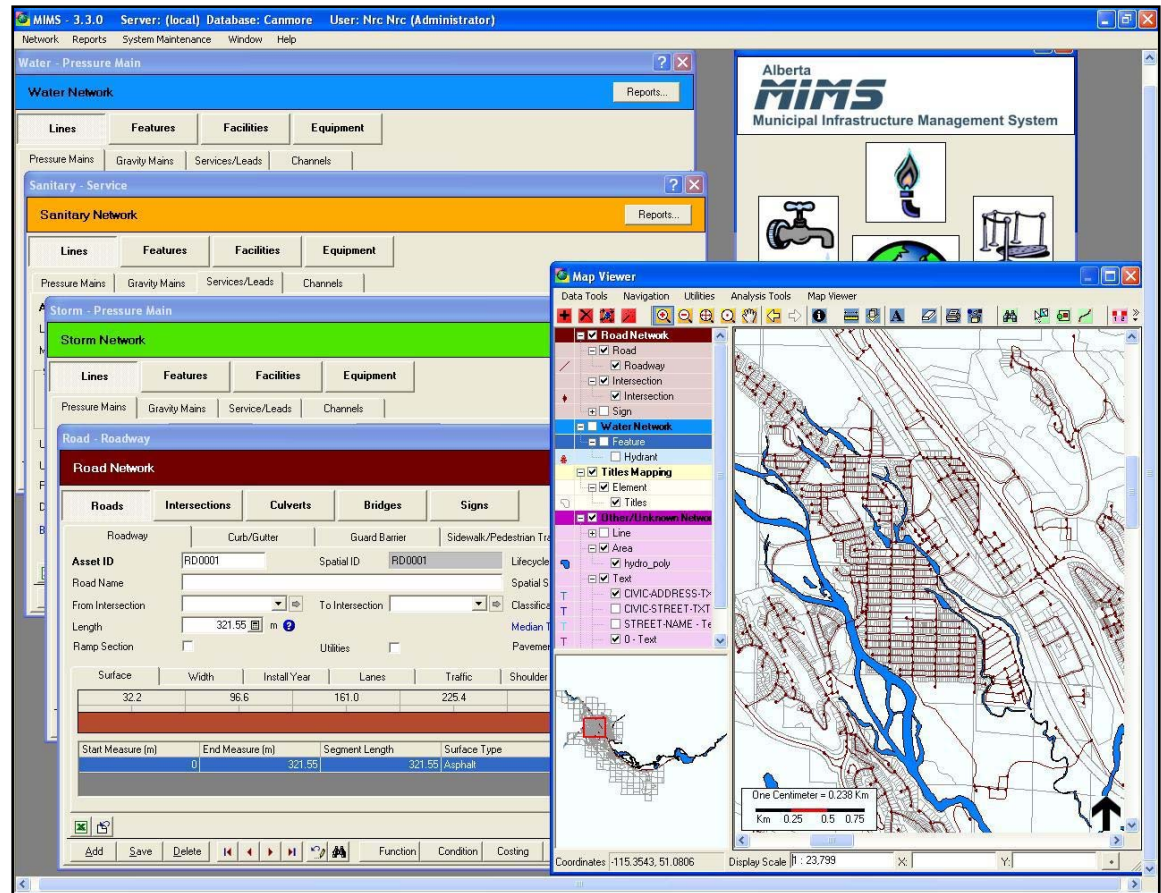
MIMS MapViewer and forms for managing water, sanitary, storm water, and roads networks

Groundwater

- MODFLOW the most popular model
- GIS used for:
  - 3-D data management
  - Boundary conditions
  - Design of FD/FE grids
  - Parameter assignments
  - Interactive simulations
  - Visualization of data and results
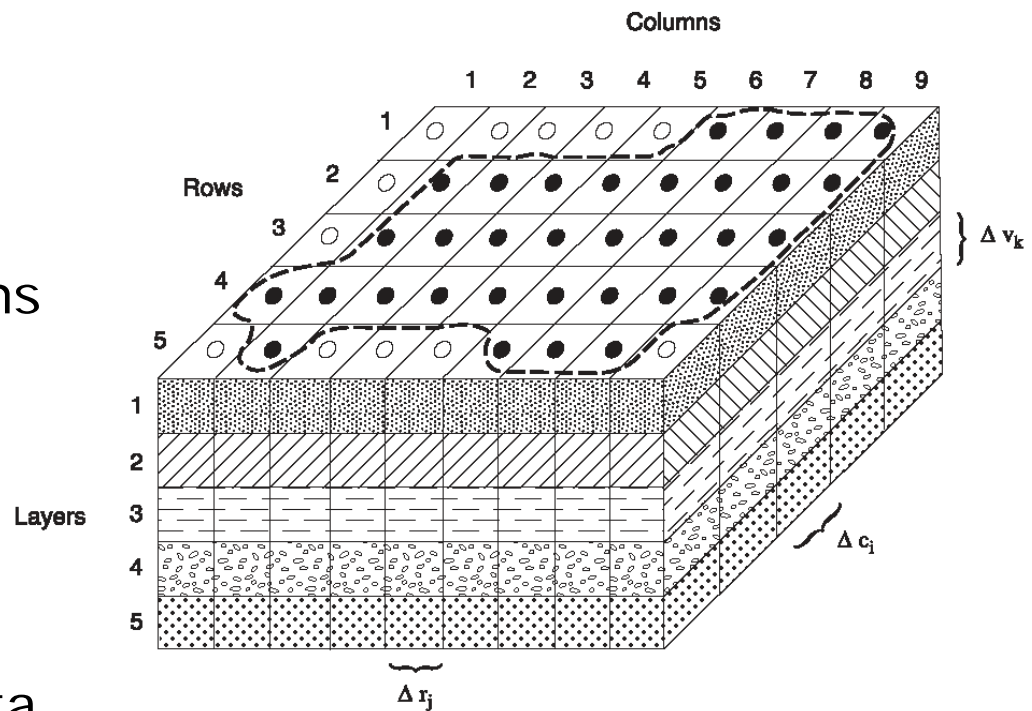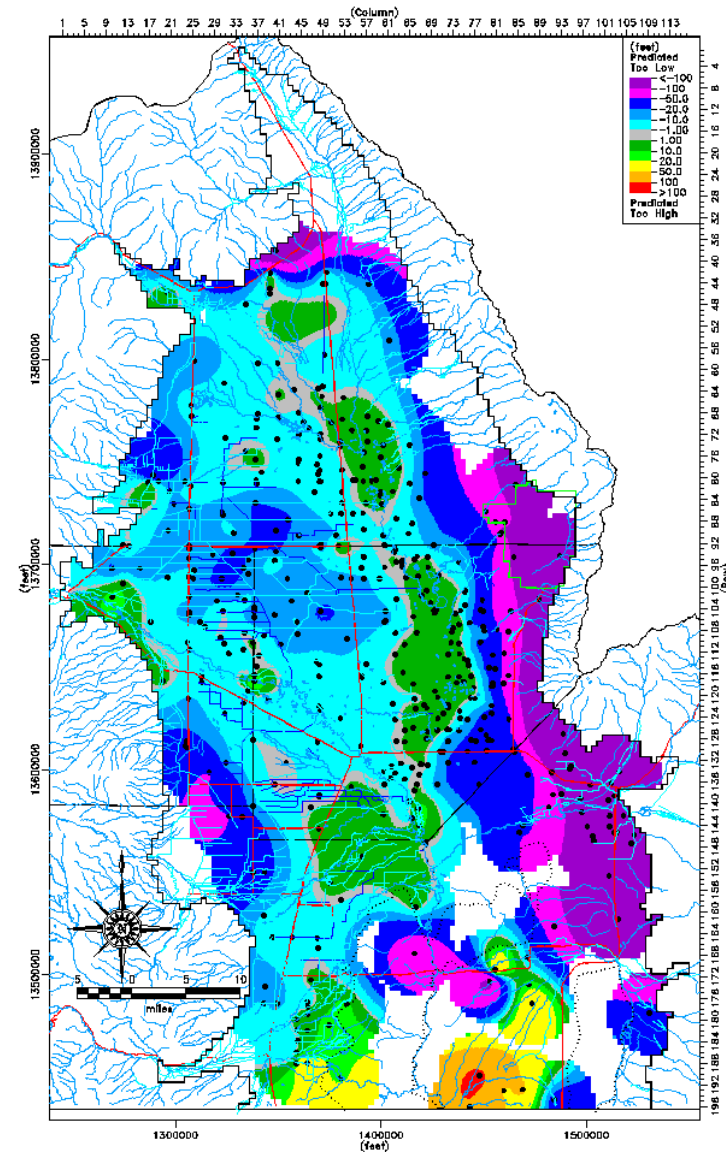
Rio Grande Valley

- GIS data:
  - Rivers/Streams
  - Canals, Drains
  - Irrigated Lands
  - Wells
  - Soils
  - Rim Inflows
  - Diversions
  - Gages
- Calibration trial shown
- Water rights assessment for:
  - Rio Grande Compact
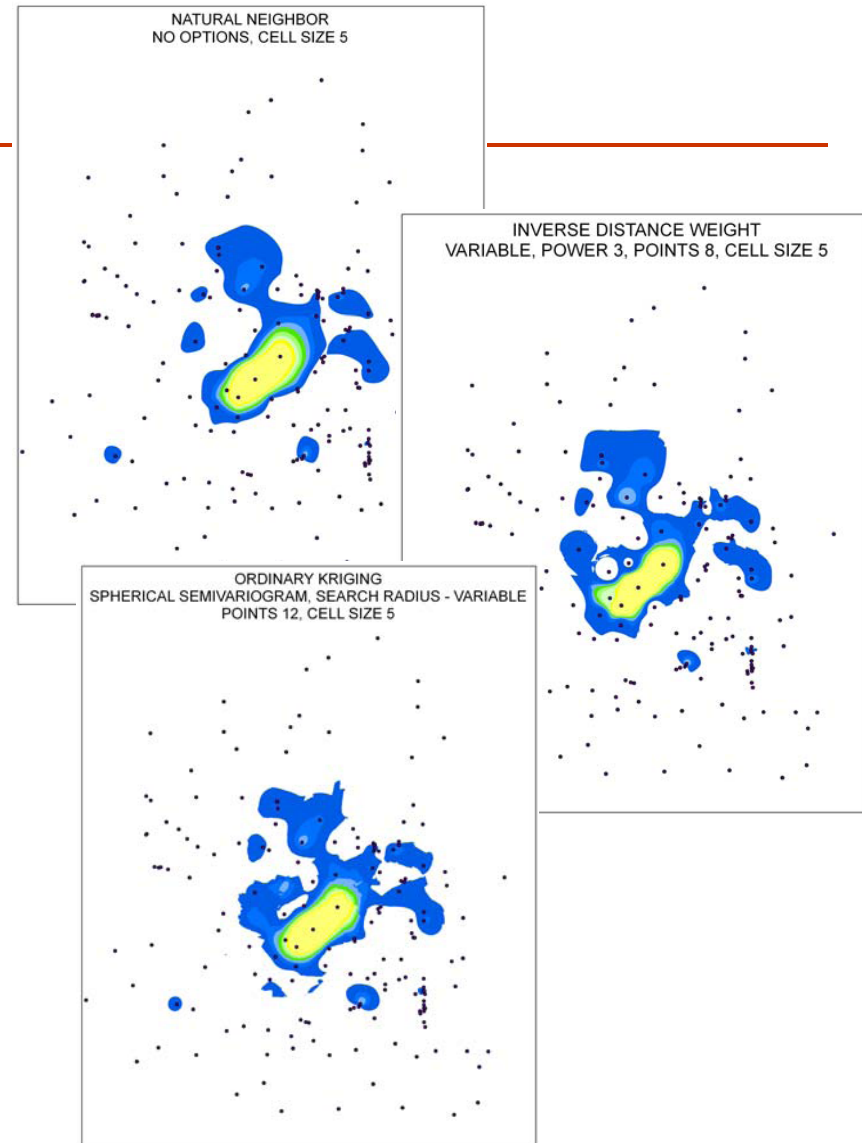 - San Luis Valley Closed Basin Project

Monthly Head Residual Layer 1
Rio Grande Decision Support System Phase 4
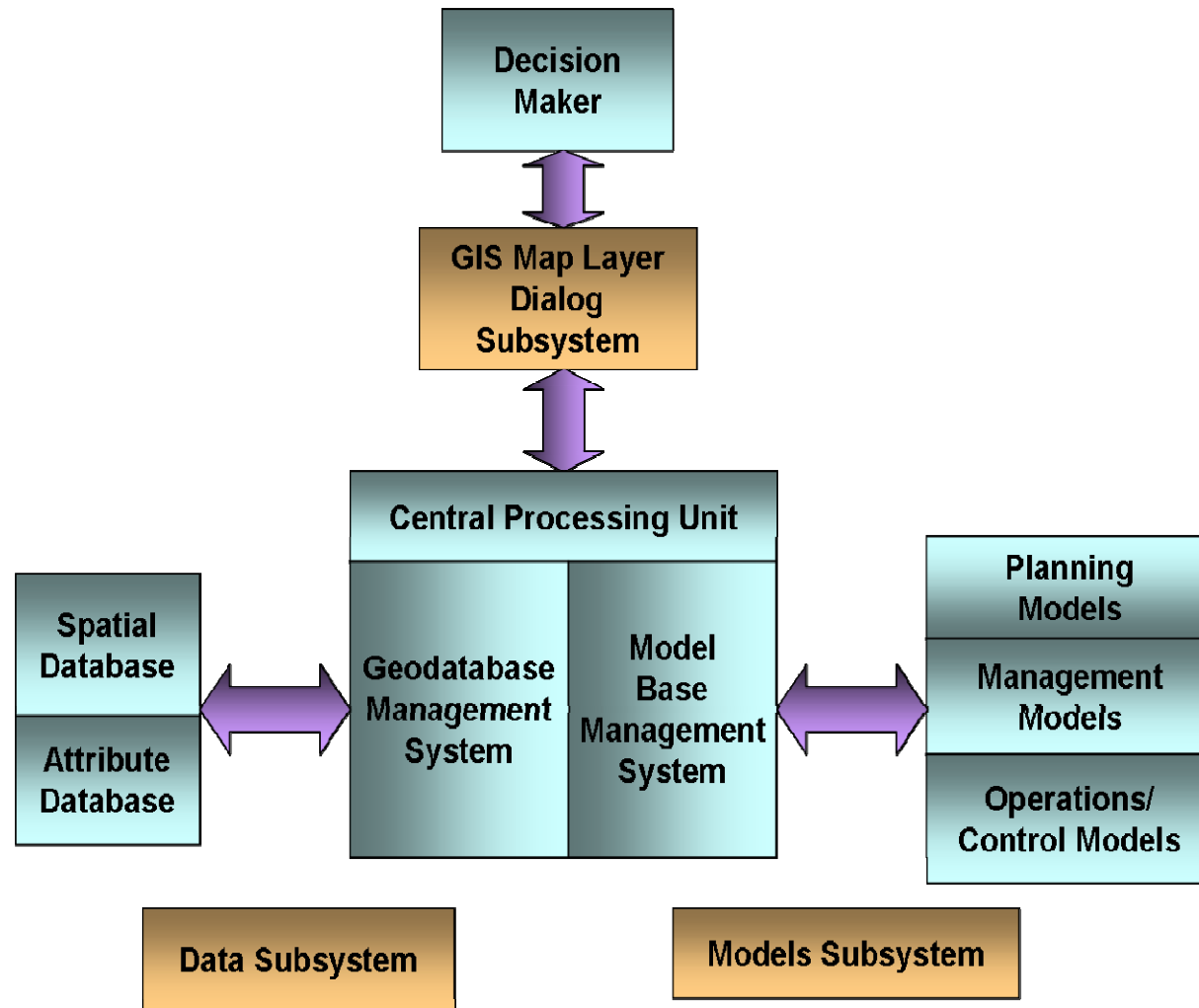
Geostatistics

- Many applications:
  - Groundwater
  - Precipitation
  - …
- Point measurement interpolations

NATURAL NEIGHBOR
NO OPTIONS, CELL SIZE 5

INVERSE DISTANCE WEIGHT
VARIABLE, POWER 3, POINTS 8, CELL SIZE 5

ORDINARY KRIGING
SPHERICAL SEMIVARIOGRAM, SEARCH RADIUS - VARIABLE
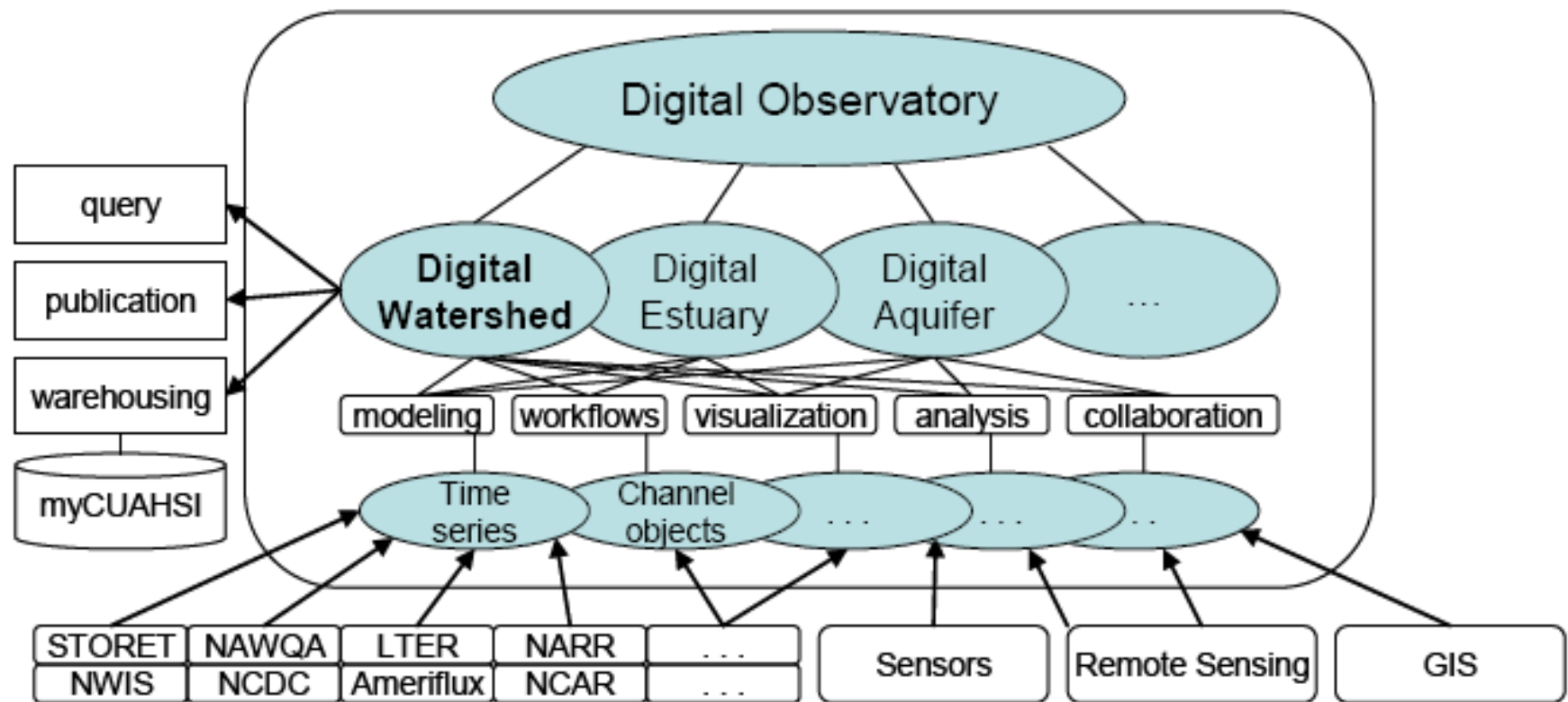POINTS 12, CELL SIZE 5

Fleetwood, 2008

Water Resources Spatial Decision Support Systems

CUAHSI* Hydrologic Information System (HIS)

- Distributed network of hydrologic data sources and functions that are integrated using web services.

*Consortium of Universities for the Advancement of Hydrologic Science; http://www.cuahsi.org/his/toolkit.html (Maidment, 2005)

River Basin Systems Modeling

- HEC ResSim
- Colorado Decision Support System (CDSS)
- GeoMODSIM
- RiverWare
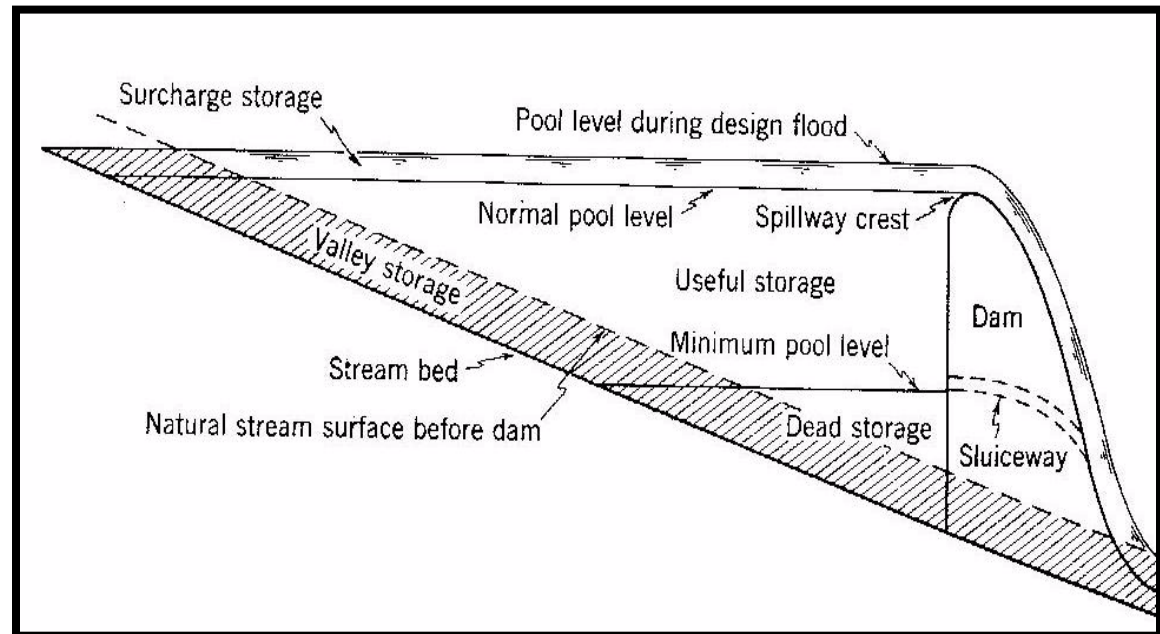
HEC Reservoir Simulation System (ResSim)

- Reservoir operations planning and real-time operations
- Features
  - Pumps
  - Power Plants
  - Pump-back Storage Operation
  - System Hydropower Operation
  - Enhanced "At-Site" Hydropower Rules
  - If-Then-Else Logic for Rule Application
  - User-Scripted State Variables
  - User-Scripted Rules
  - Release Allocation / Outlet Prioritization
  - Scheduled Outlet Outages
  - Outlet Capacity Overrides
  - Improved Tandem and Parallel System Operation
  - Period of Record (long term) simulation

http://www.hec.usace.army.mil/software/hec-ressim/index.html
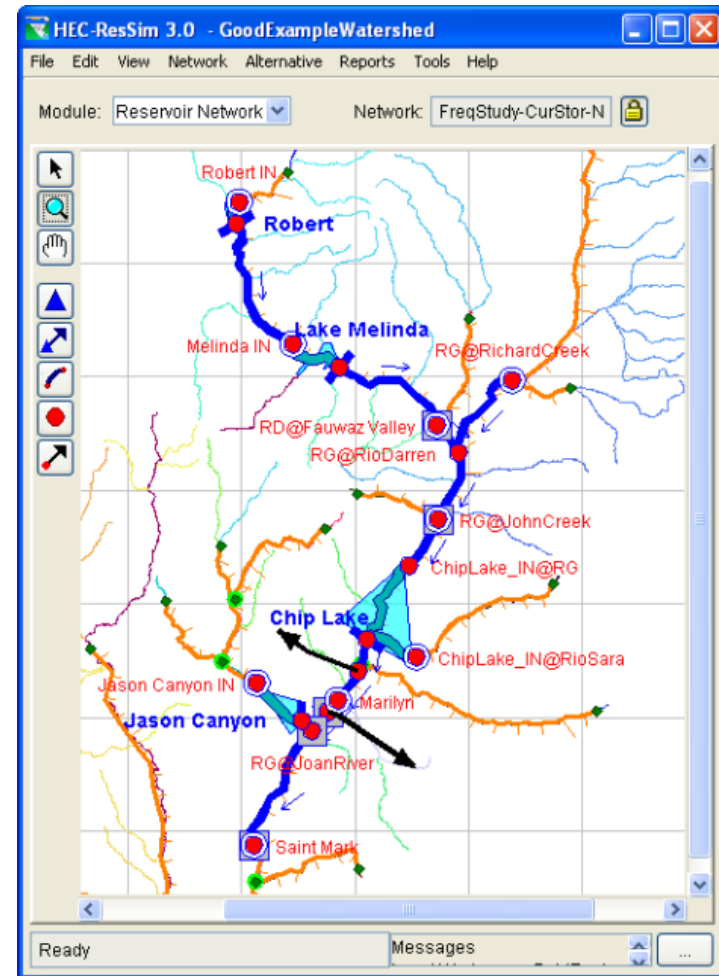
Colorado's Decision Support Systems (CDSS)

- Databases and models to support Colorado water management
- Hydrobase
  - Streamflows
  - Diversions
  - Water rights
  - Irrigated lands
  - Wells
  - Climate
- Models
  - StateCU – Consumptive use model
  - StateMod - River basin model
  - StateWB - Water budget model
  - ModFlow – Groundwater model
  - CWRAT - Water rights administration tool
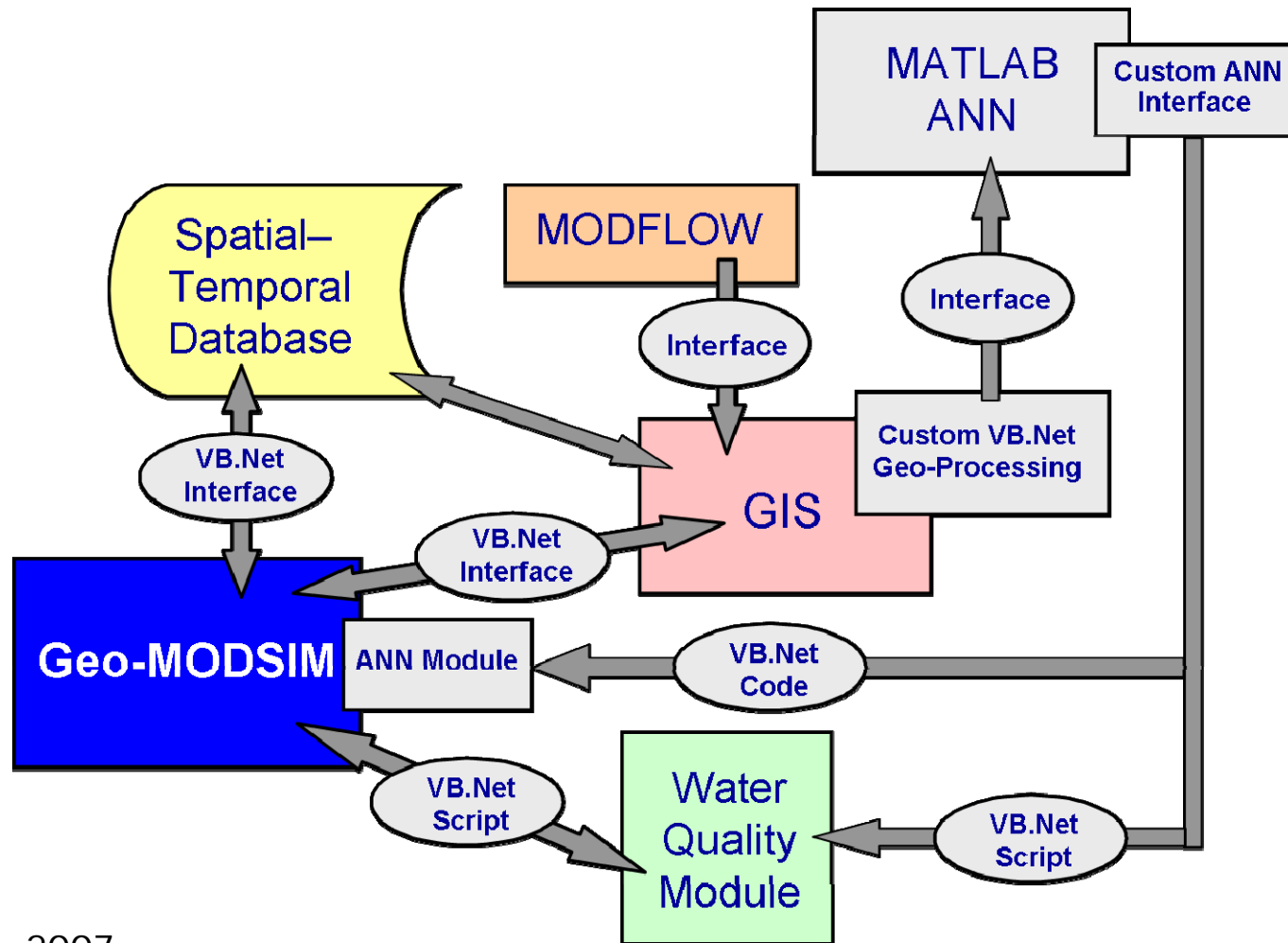 - Interstate compact analysis models

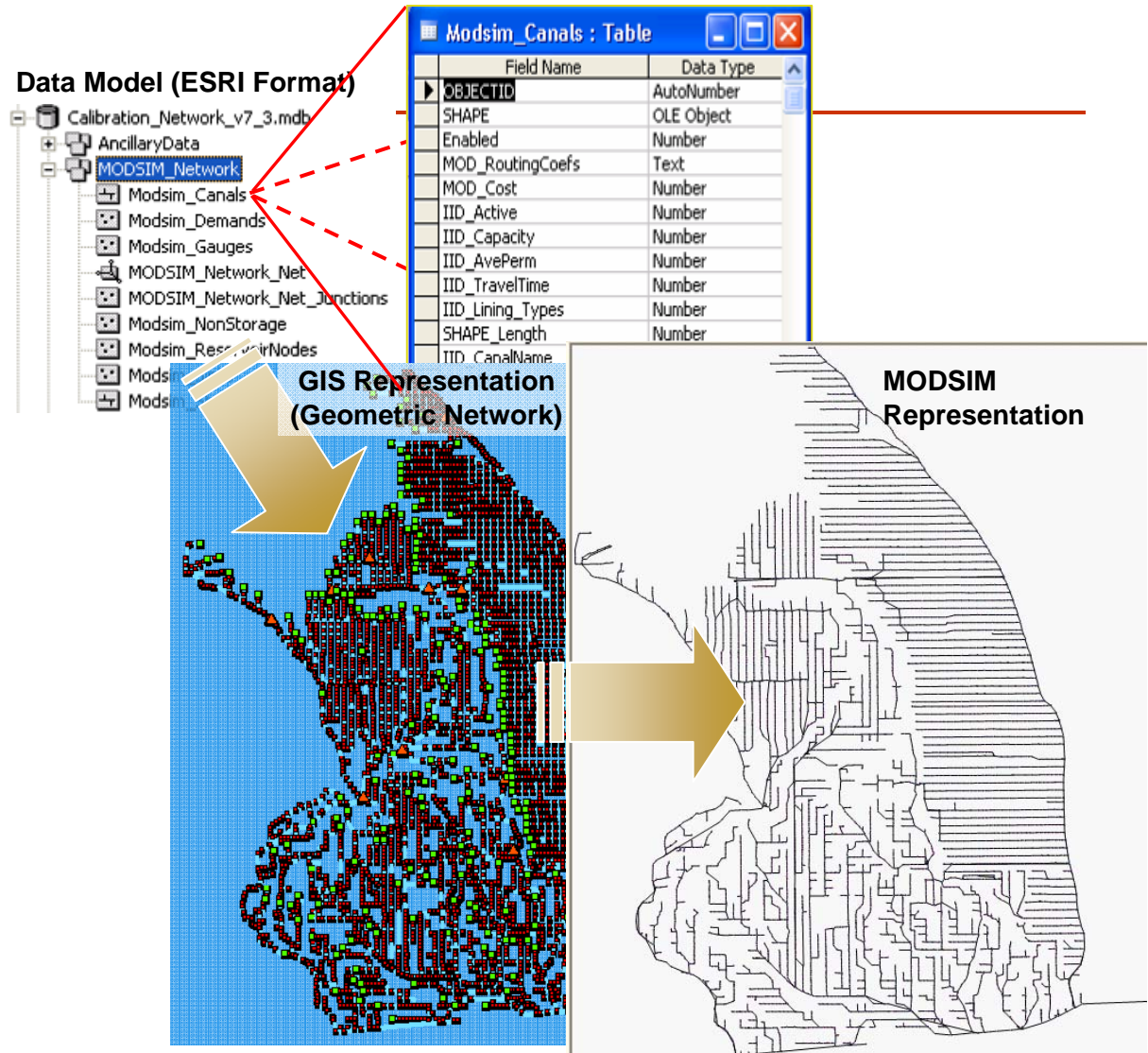http://cdss.state.co.us
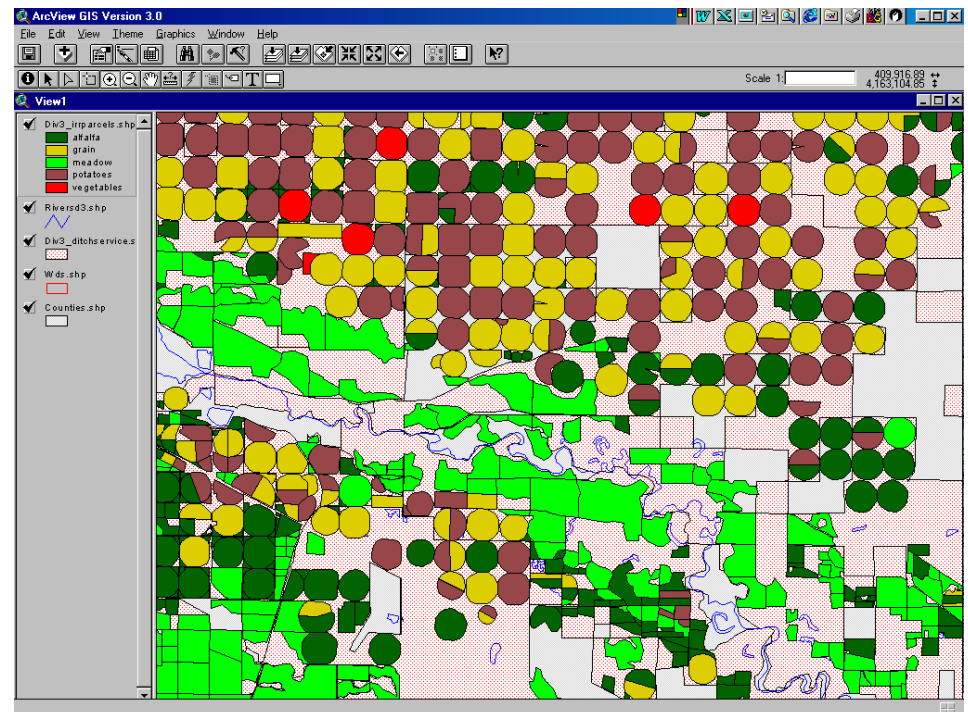
CRDSS Database Schema
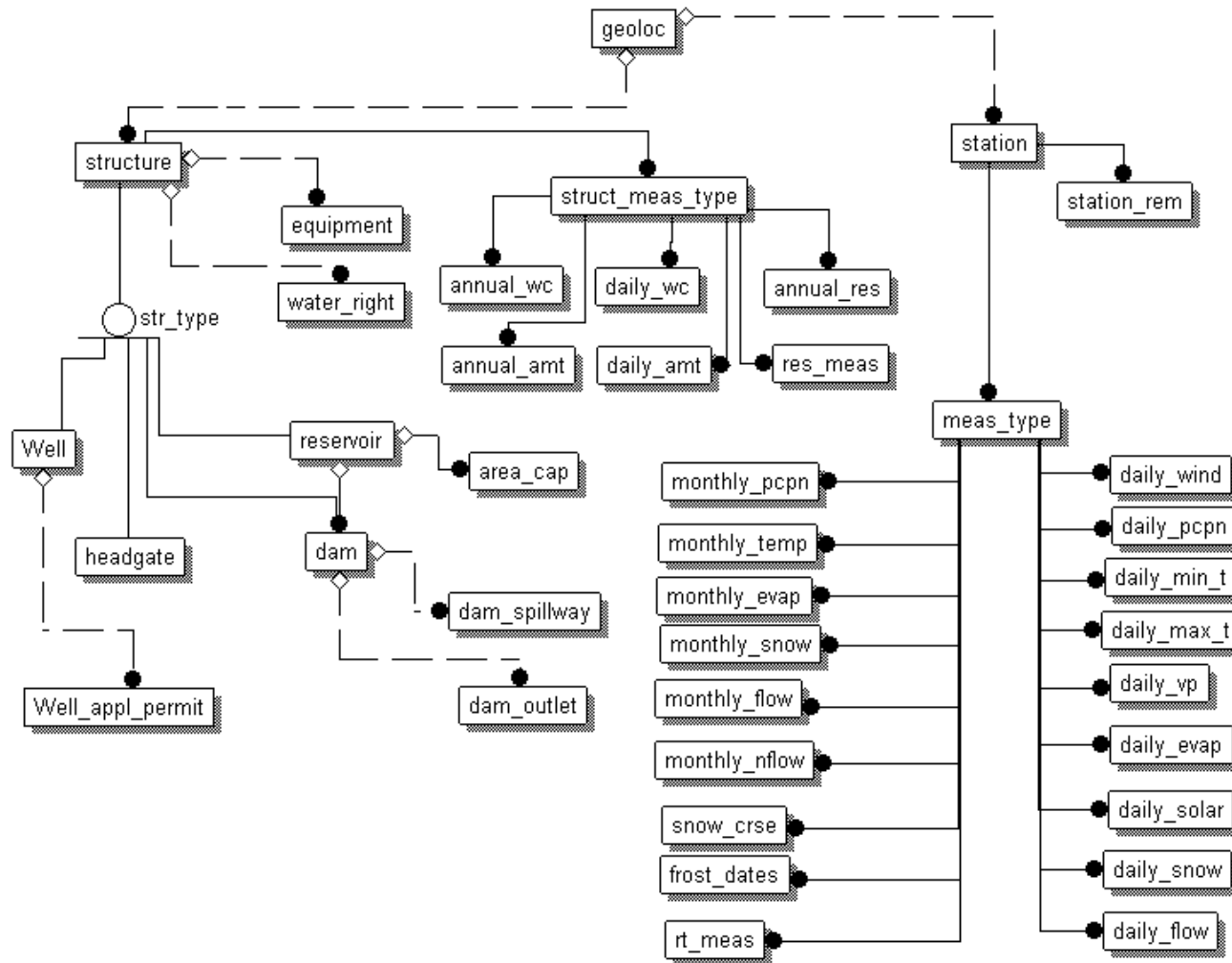
Geo-MODSIM Modules
groundwater, water quality and ANN* for stream-aquifer modeling

Labadie, 2007

*ANN = Artificial Neural Networks

MODSIM Geometric Network

Labadie, 2007

MODSIM network for the Lower Arkansas River basin

RiverWare

- General purpose river basin modeling system
- Basin features as objects
- Capable of modeling
  - Reservoirs & hydropower,
  - river reaches,
  - diversions & distribution canals,
  - consumptive uses,
  - surface-groundwater conjunctive use,
  - Water quality
  - water rights,
  - water accounting transactions
- Goal programming optimization mode
- Applied to:
  - Colorado River
  - TVA
  - Upper Rio Grande
  - San Juan Basin
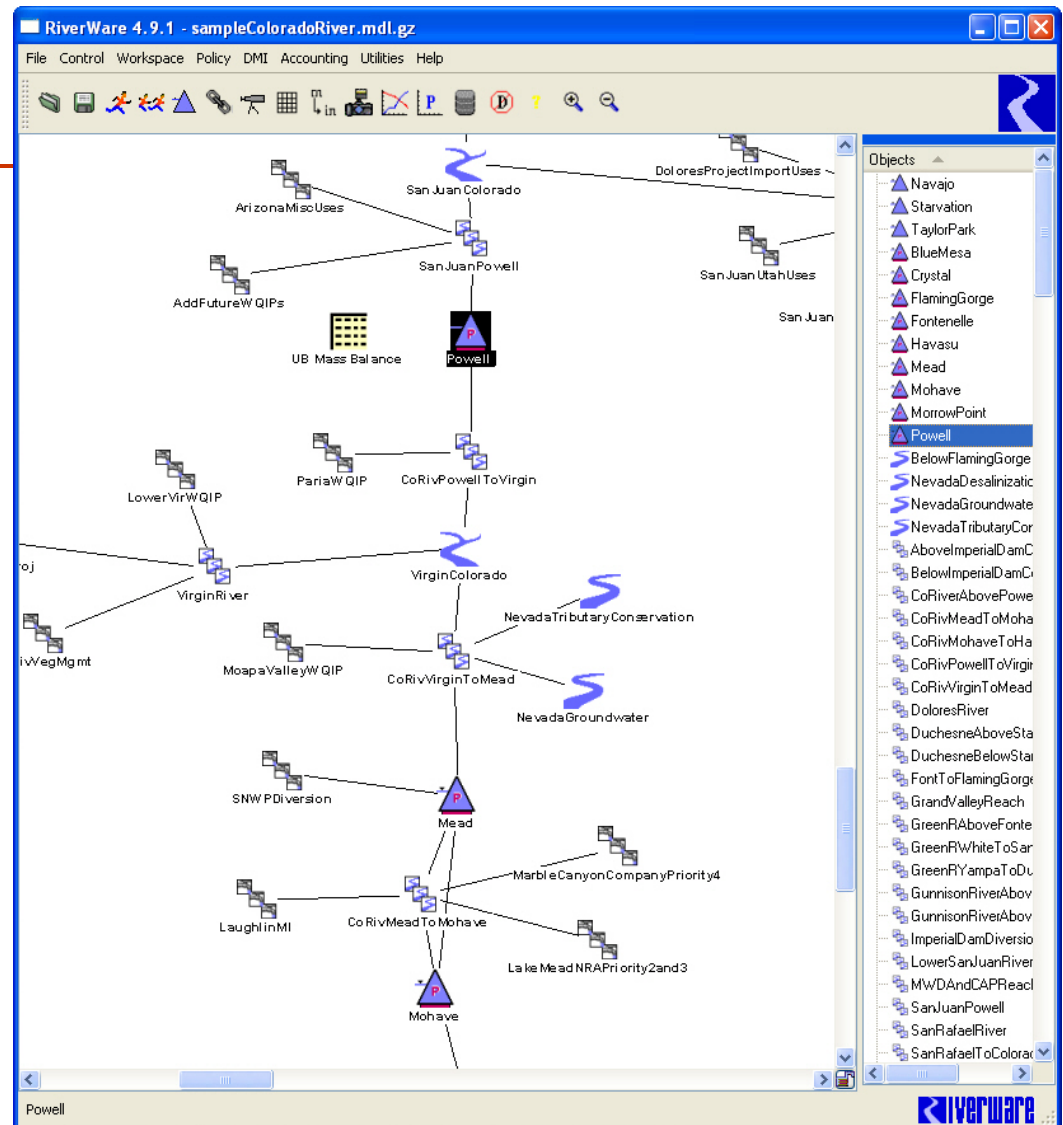
RiverWare model schema for Lower Colorado River

http://cadswes.colorado.edu/riverware/
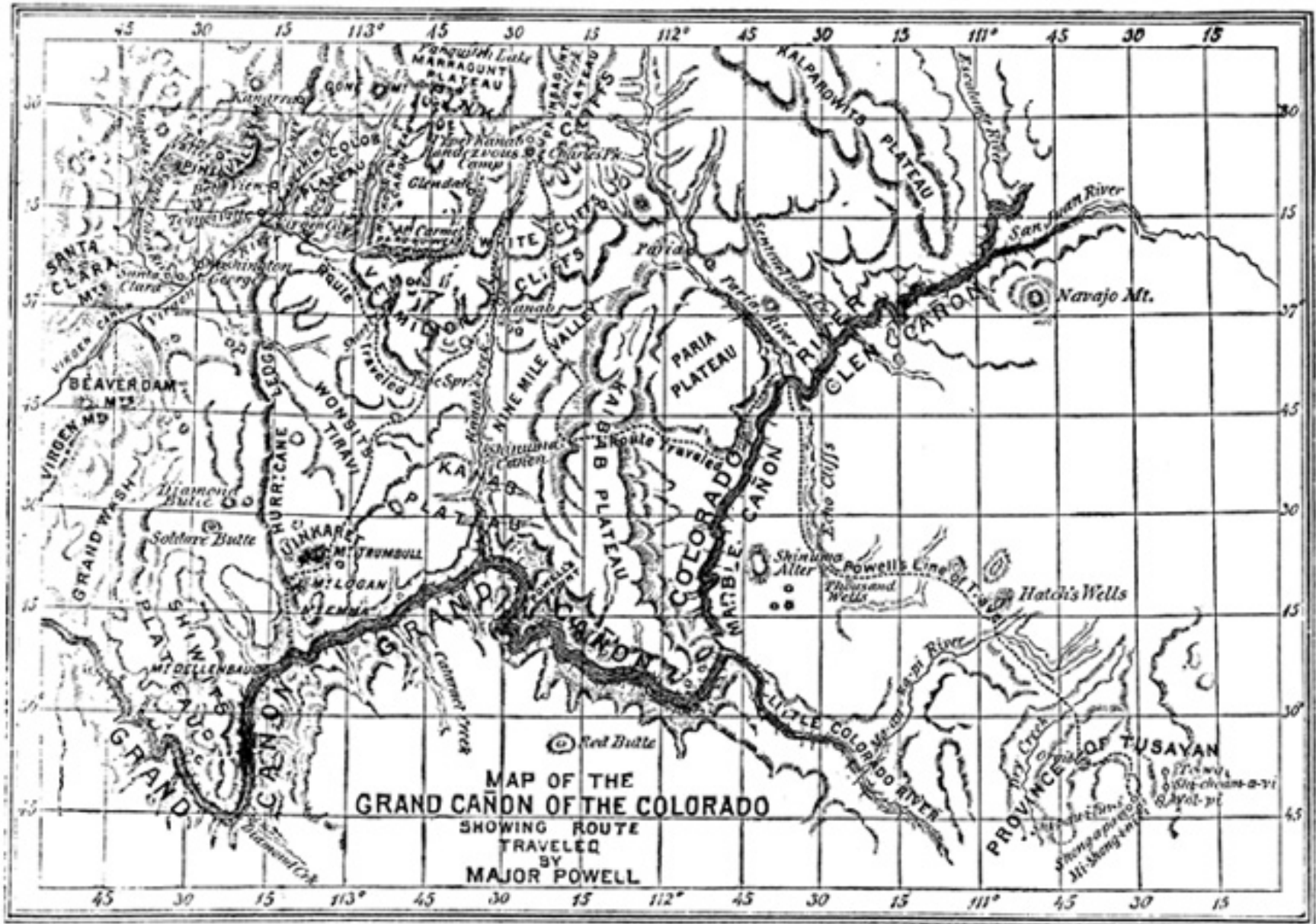
Map of the Grand Canyon of the Colorado showing the route traveled by Powell, 1875.

(NPR, 2002, http://www.npr.org/programs/atc/features/2002/sept/powell/)

GIS in Water Resources Engineering

- Data
  - Conversion to digital
  - Advanced data sensors
- Data Management
  - Data models
  - Enterprise systems
- Water Resources Models
  - Standarization of models
  - GIS interfaces
- Decision Support Systems
  - Integrated databases, models, displays, interactive
  - Web deployment
  - Institutional assimilation

THANKS

Lynn.Johnson@cudenver.edu

MEng-GIS Courses

- CE 5381 Introduction to GIS
- CE 5382 GIS Data Development
- CE 5383 GIS Analyses
- CE 5384 GIS Management
- CE 5385 GIS Relational Databases
- CE 5386 GIS Laboratory
  - ArcGIS
  - Object-Oriented Programming for GIS
- CE 5387 Advanced Remote Sensing
- CE 5388 GIS Web Deployment
- CE 5960 GIS Project

LEJ Background

- Academic
  - BS - Civil Engineering, BA – Geology; Univ. Buffalo
  - MS - Water Resources Management; UW Madison
  - PhD – Water Resources Systems; Cornell
    - Thesis – Derivation of Optimal Reservoir Operating Policies
- Professional
  - USGS stream gager, flood studies, water quality, groundwater
  - Registered Professional Engineer
  - Engineering practice and research
    - Water supply source and distribution design
    - Flood control and damage mitigation
    - River basin management studies
    - Estuary numerical modeling, dredged material for wetlands
    - Water quality modeling and WQ management
- CU Denver
  - Water supply and wastewater systems design
  - Hydrological modeling and forecasting
  - Reservoir operations
  - River basin decision support systems
  - Master of Engineering in GIS (http://www.cudenver.edu/MEngGIS)