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Technical Workshops | July 25/26, 2012

Hydrologic and Hydraulic Modeling with ArcGIS

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Overview

- Core GIS tools for surface water analysis
- DEM data and processing
  - Demo
- Application tools for Hydrologic and Hydraulic Modeling
- Q&A

Water Resources Issues

- Not enough (droughts)
- Too much (floods)
- Of wrong kind (water quality)
- In a wrong place (spatial distribution)
- At the wrong time (temporal distribution)

Focus on Surface Water Quantity

- How much water is there?
  - *Hydrologic modeling* (precipitation-runoff modeling), determines for a given storm on a landscape, how much water will become runoff.

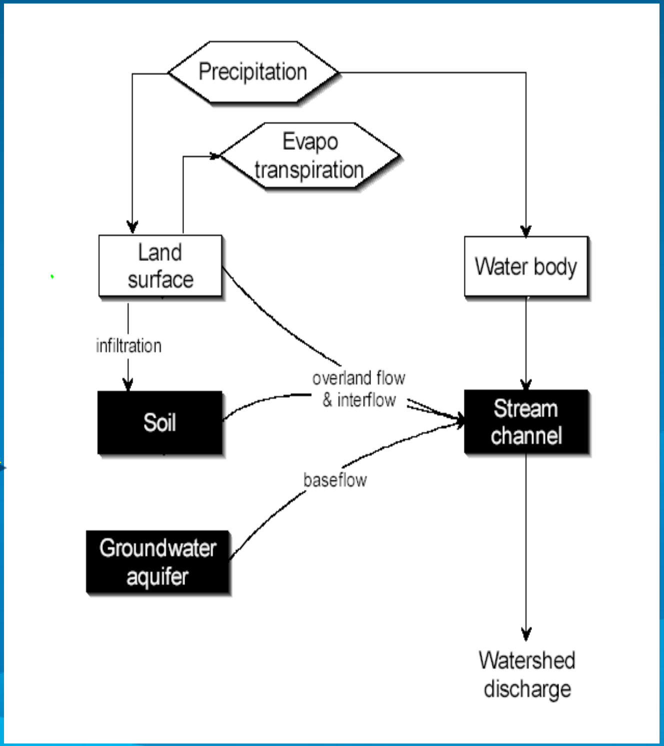
- Where will it go?
  - *Hydraulic modeling* takes the quantity of water and the shape of the landscape and stream channel and determines how deep and fast the water will be, and what area it will cover in the event of a flood.

Hydrologic Modeling

- Goal: **Find stream discharge, Q, at a location for a given precipitation event.**
- **There are many ways to calculate Q.**
  - **Statistical methods**
    - **USGS regression equations (NFF, StreamStats)**
  - **"Physical" modeling (rainfall-runoff models)**
    - **HEC-HMS, SMS, etc.**
- *GIS is used to summarize terrain and hydrologic characteristics of the watershed for input to a model.*

Hydrologic Modeling

- Map natural processes onto software tasks.
- Aggregate landscape characteristics and define the layout.
  - “Lumped parameter model”



Hydraulic Modeling

- Goal: **Predict water surface elevations to create flood inundation maps.**
  - **Also predict velocity, sedimentation, quality**
- Input: **Channel and floodplain geometry with hydraulic characteristics, plus discharge 'Q' and initial water surface level.**
- Output: **Water surface elevation at each cross section and other characteristics.**

- *GIS is used to summarize terrain and hydraulic characteristics of the channel for input to a model and post process hydraulic modeling results (surface determination).*

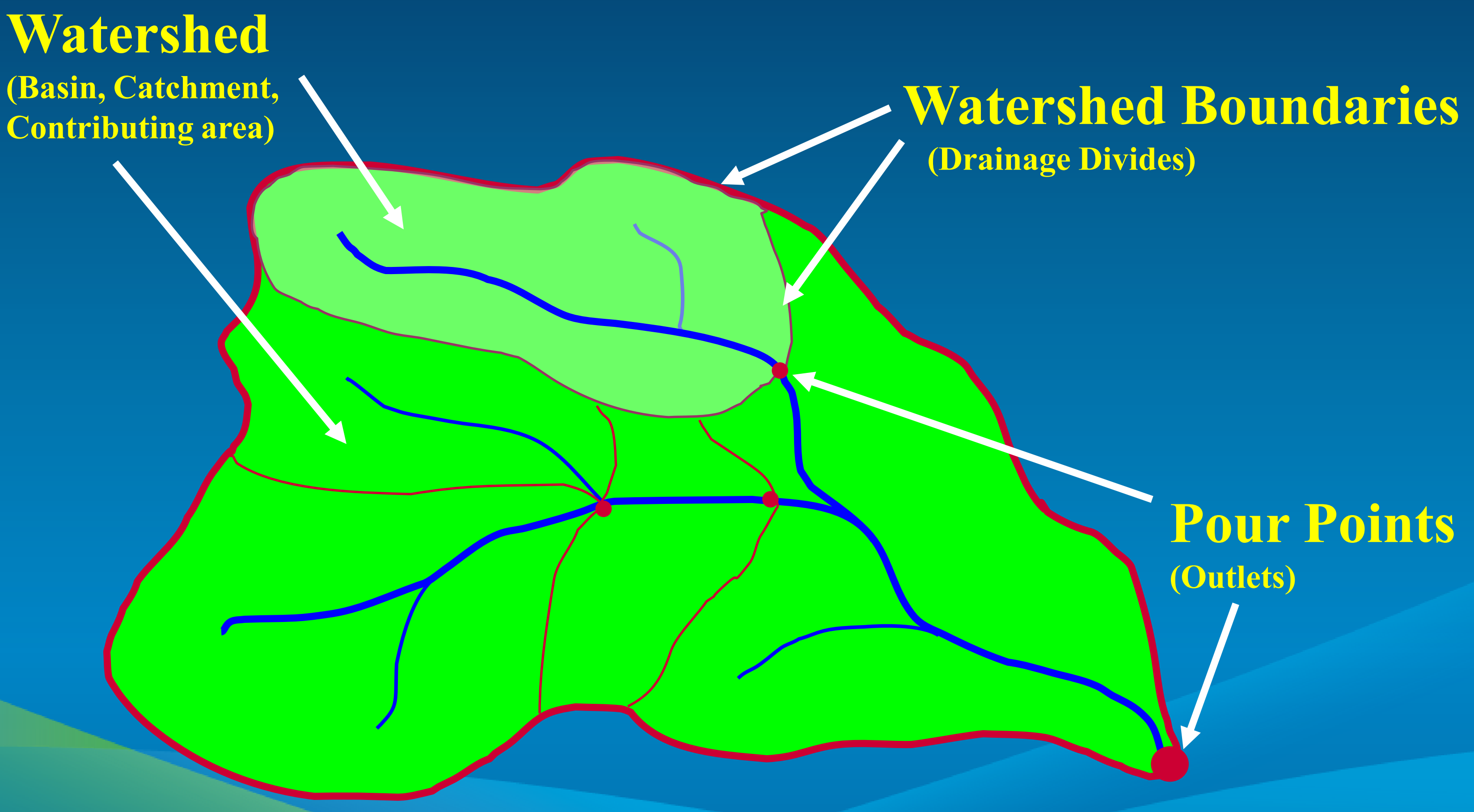
GIS Data for Hydrologic and Hydraulic Modeling

- Digital Elevation Model and land cover
  - http://seamless.usgs.gov/
  - http://edna.usgs.gov/
  - http://www.horizon-systems.com/nhdplus/
- Watershed boundaries
  - http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/
- Hydrography
  - http://nhd.usgs.gov/
- Soils
  - http://www.soils.usda.gov/survey/geography/statsgo/

GIS Data for Hydrologic and Hydraulic Modeling

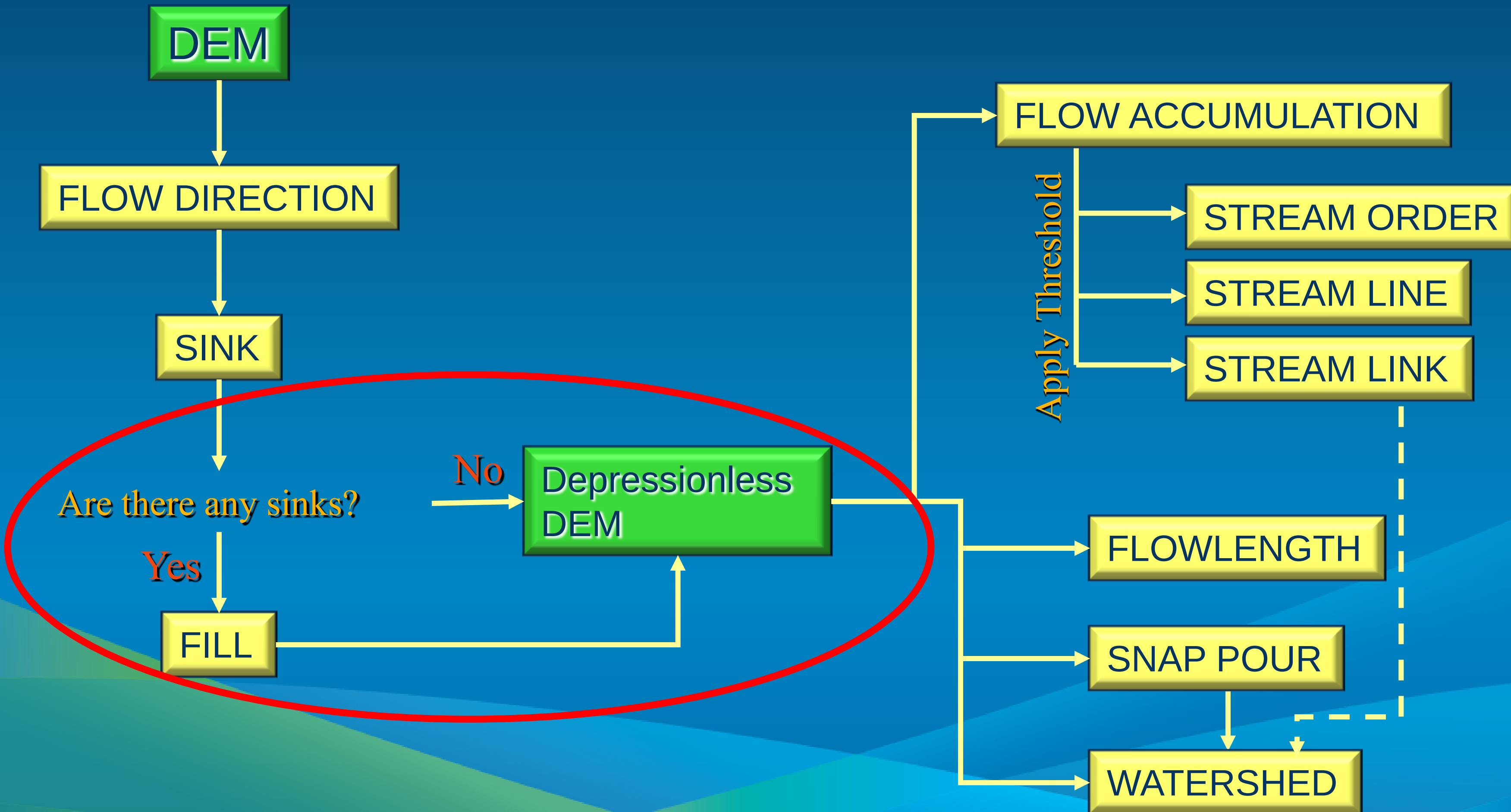
- Current and historic water records
  - http://waterdata.usgs.gov/nwis
  - http://www.epa.gov/STORET/index.html
  - http://his.cuahsi.org/
- Climate and precipitation
  - http://www.weather.gov/gis/
  - http://www.ncdc.noaa.gov/oa/ncdc.html
- Channel geometry (cross sections)

Drainage System



GIS Tools for Describing Surface Water Movement

- **Dendritic morphology – simple process**



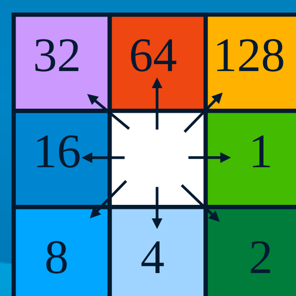
Flow Direction

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Elevation

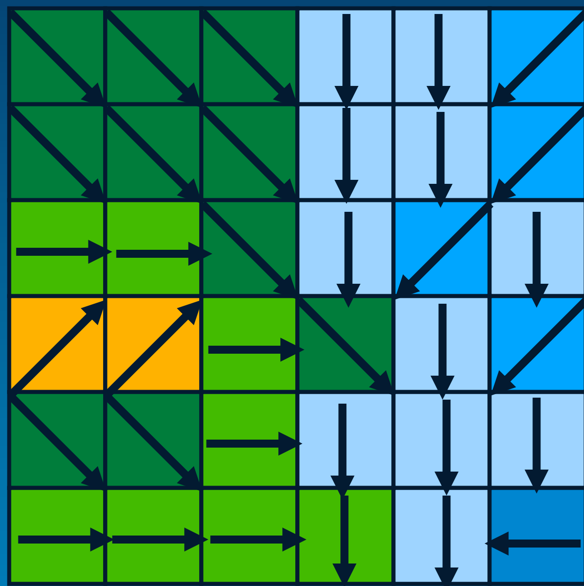
2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

Flow Direction

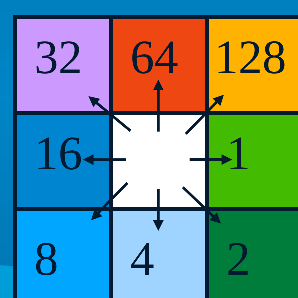


Direction Coding

Flow Accumulation

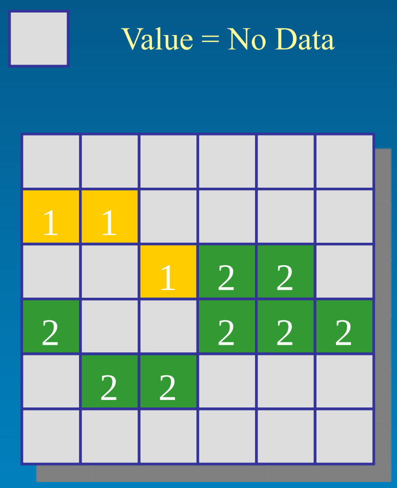


0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

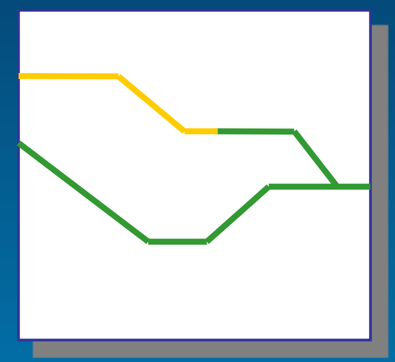


Direction Coding

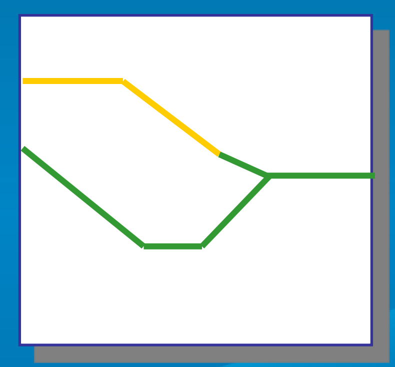
Creating Vector Streams



NET_GRID



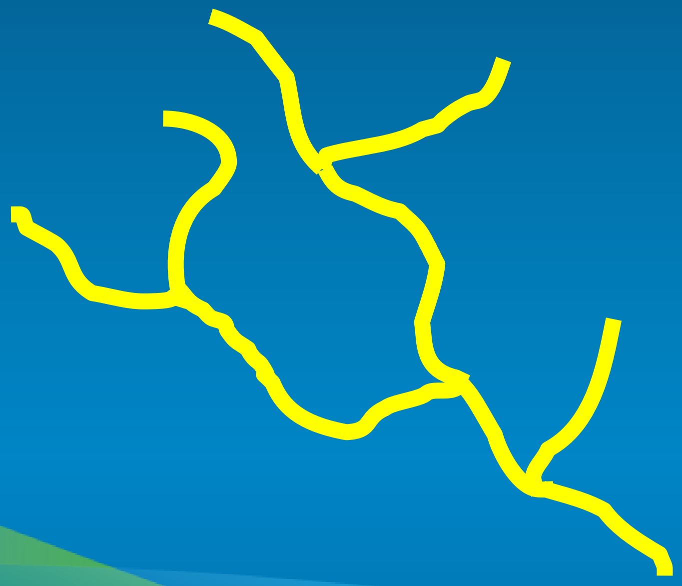
StreamToFeature



RasterToFeature

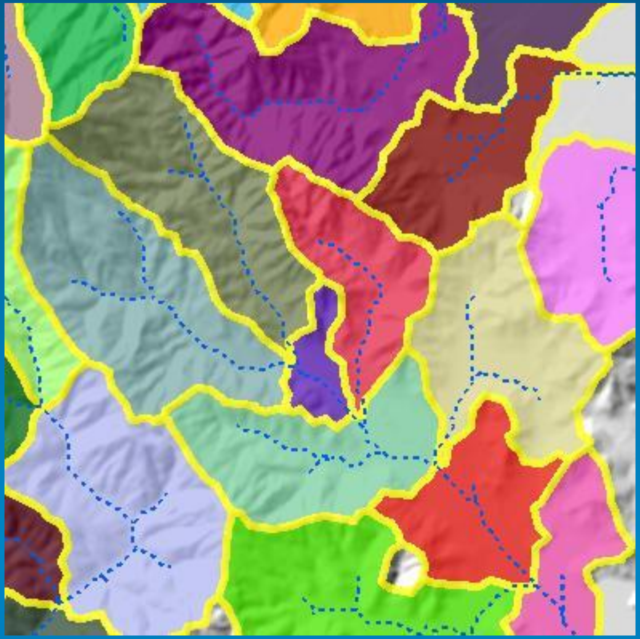
Stream Link

- **Assign a unique value to each stream segment.**
  - **Can be used as input to Watershed tool**

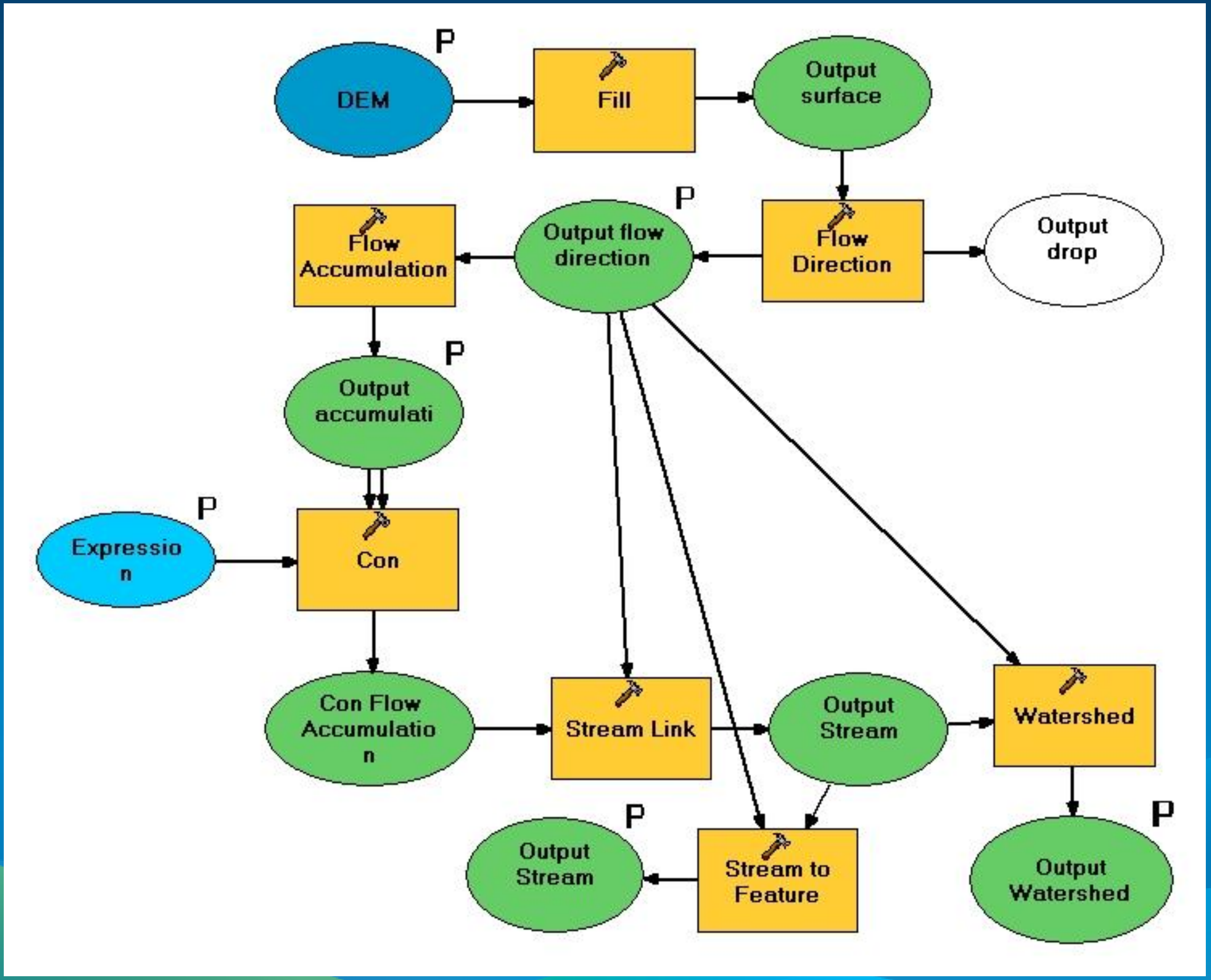


Watershed, subwatershed, drainage area

- Delineate the contributing area to a cell or group of cells.



Using the Tools in Model Builder



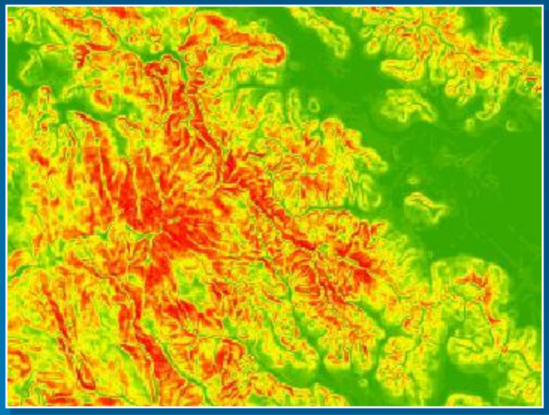
Summarizing Watershed Characteristics

- Use the Zonal Statistics tool.
- A ***"zone"*** is all the areas/cells with the same value.
- Calculate a statistic within the zones for each cell in a raster.
- Input zones can be feature or raster.
- Output as a raster, summary table, or chart.
  - Max. flow length per watershed
  - Average slope per watershed
  - Average curve number per watershed

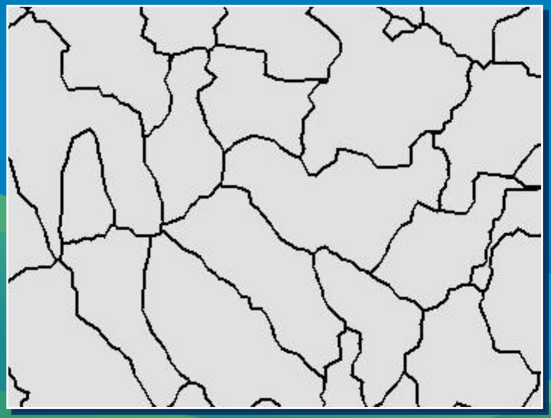
Summarizing Watershed Characteristics

- **Using Zonal Statistics**

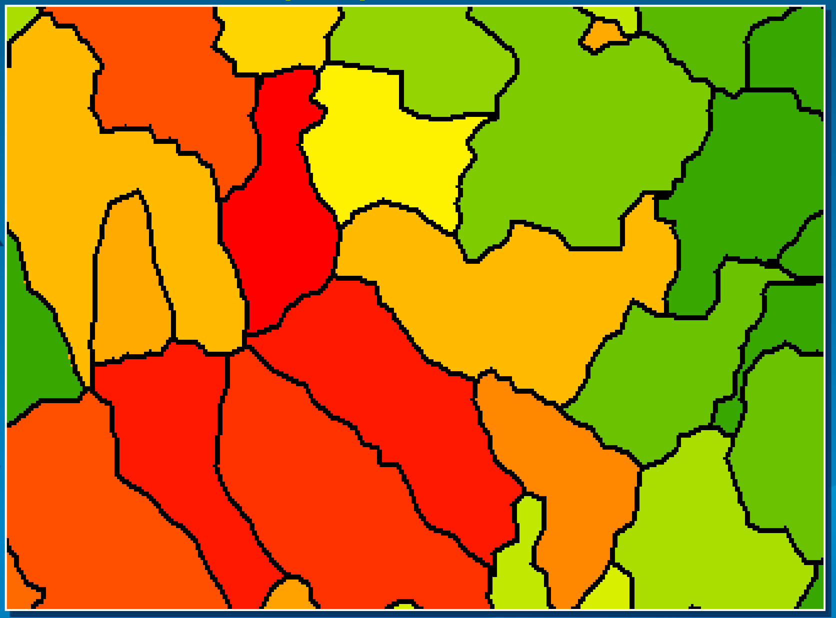
Slope



Watersheds



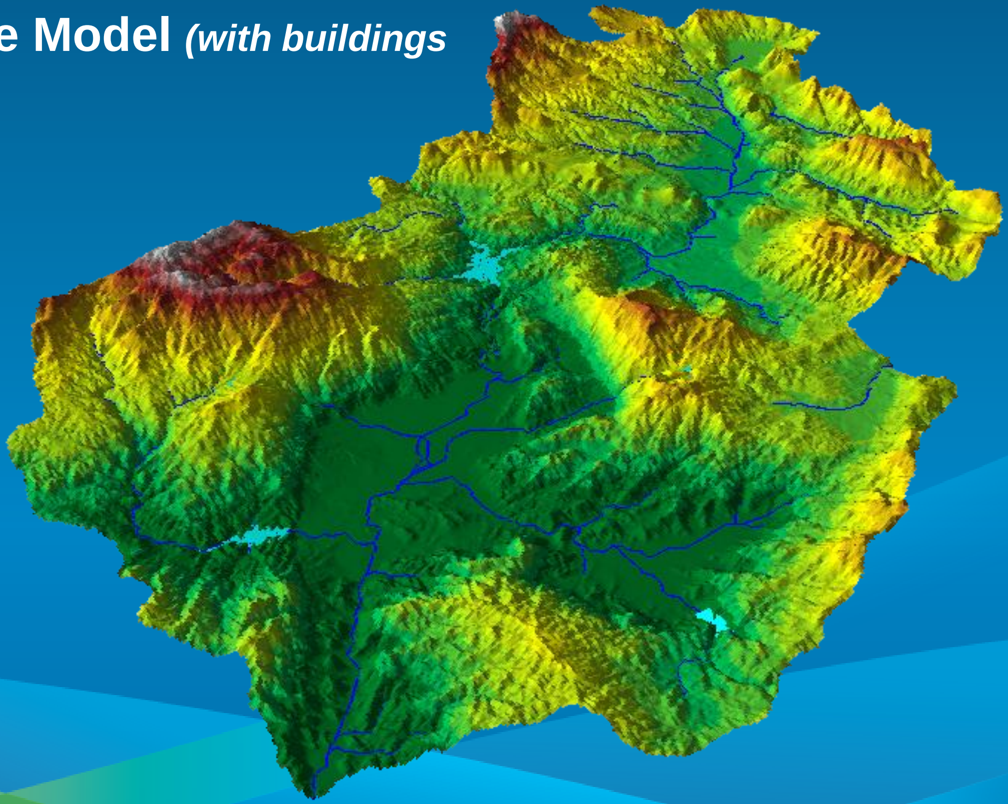
Mean Slope per Watershed



Elevation Data

- **Types**
  - **DEM: Digital Elevation Model** ***(bare Earth)***
  - **DSM: Digital Surface Model** ***(with buildings and trees)***

- **Data Structure**
  - **Raster**
  - **TIN**
  - **Terrain dataset**



Where Do You Get DEM Data?

- Sources
  - Existing data: USGS DEM, NED, DTED, ETOPO30, SRTM
  - LiDAR, IfSAR
  - Generated photogrammetrically
  - Interpolated from points and lines

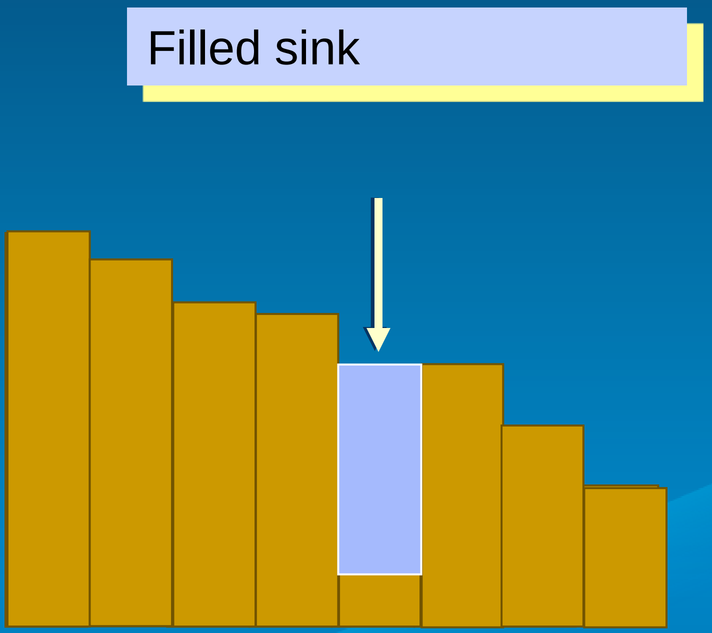
- What cell size and accuracy?
  - Horizontal and Vertical resolution must be appropriate for the landscape and scale being modeled.

DEM Construction Considerations

- Resolution and extent
- Projection (for hydrology – use equal area)
- Source elevation data
- Interpolation techniques
  - For hydrologic applications, use TopoToRaster.
    - Avoids problems with contour input
    - Creates hydrologically correct DEM

DEM Errors – Sinks and Spikes

- Sinks: when sinks are (or are not) sinks – lakes, depressions,…
  - Global fill
  - Dealing with internal basins
  - Selective fill
    - Depth
    - Area
    - Volume
    - “you just know it”



DEM Editing

- Streams: When streams are not where they "should" be
  - Flat areas – Difficulty in determining the flow pattern
  - Barriers (roads) diverting the flow paths
    - How to "model" bridges and culverts in DEM
    - How to model dams
  - Imposing the flow pattern - to burn or not to burn (beware of the scale issues and artifacts – Saunders, 2000.)
    - Simple burn
    - AGREE
    - OMNR

DEM Editing (cont.)

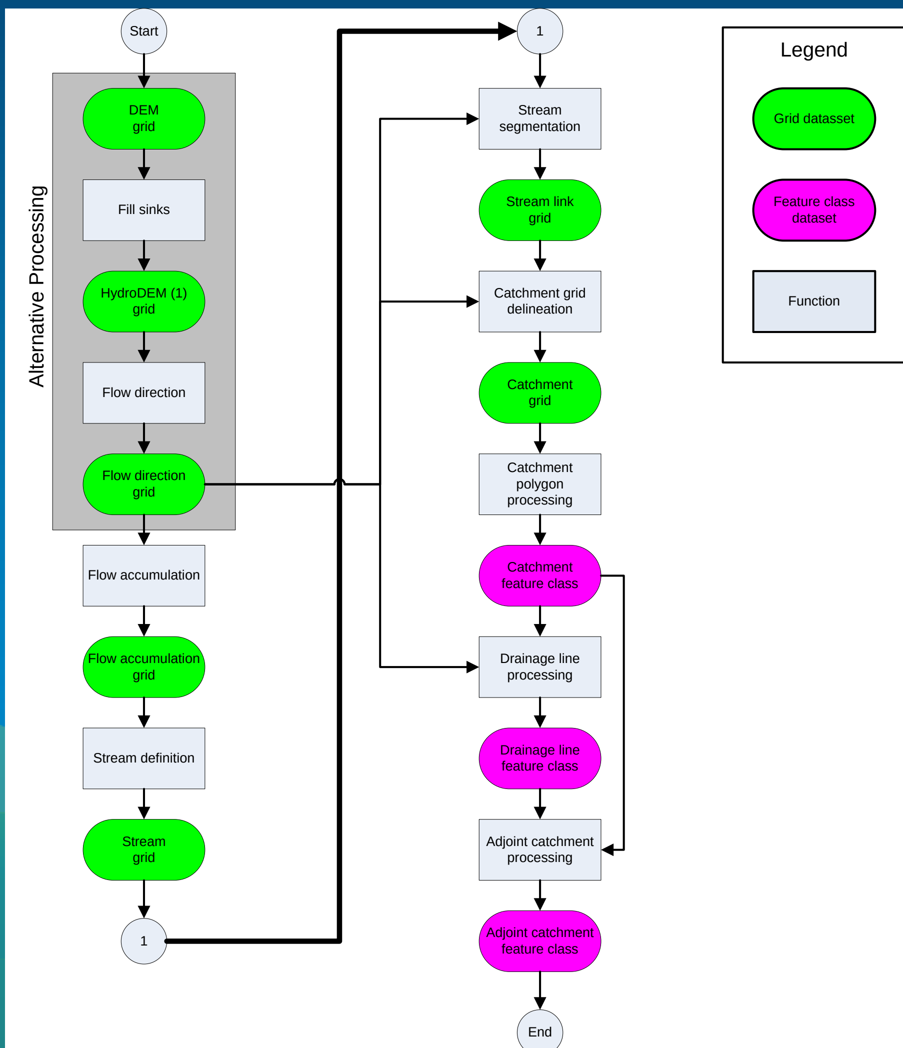
- Watersheds—When watershed boundaries are not where they “should” be
  - To fence or not to fence
  - Ineffective flow areas

What If You Do Not Have Dendritic Morphology?

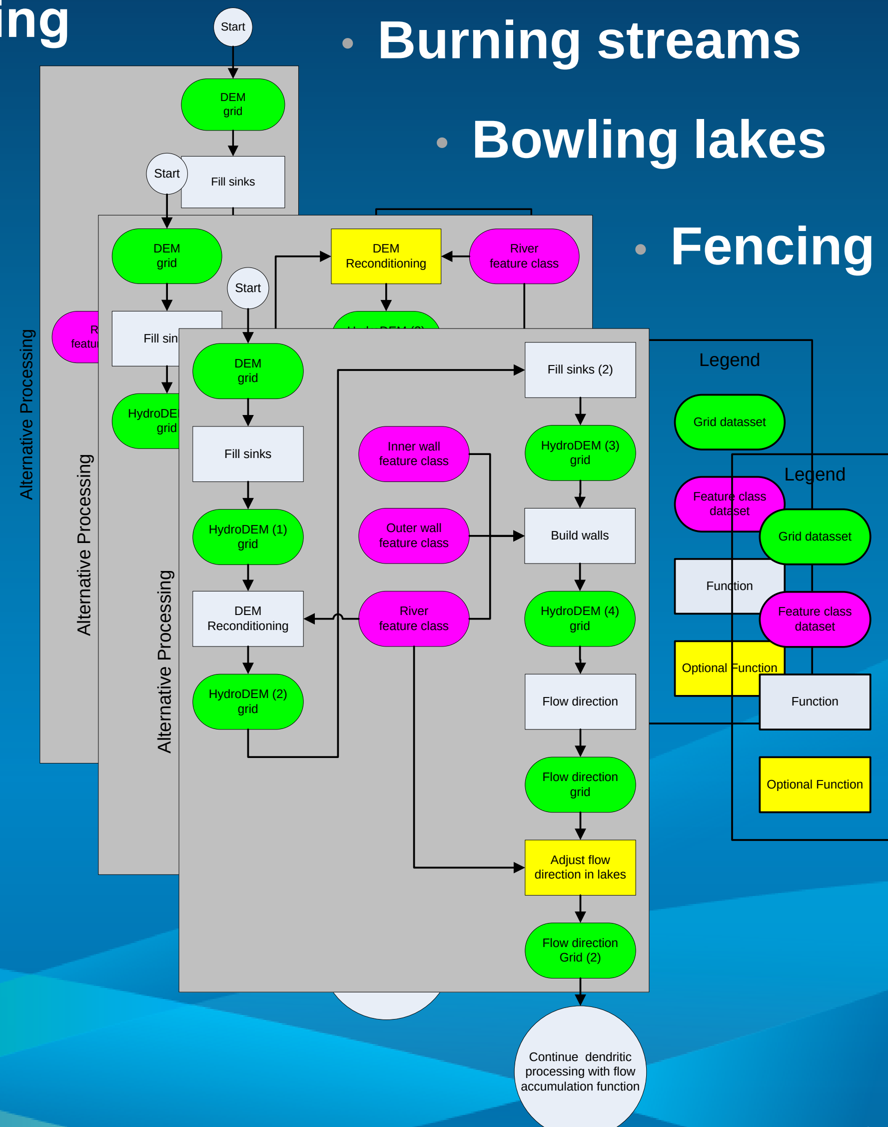
- Arc Hydro tools for terrain preprocessing:
  - Modified dendritic process
    - Burning streams
    - Fencing boundaries
    - Bowling lakes
    - Flow splits
  - Deranged terrains
    - Selective filling of sinks
    - Streams draining into sinks
  - Combined dendritic/deranged

Workflows, Workflows, Workflows

- “Basic” dendritic preprocessing



- Burning streams
- Bowling lakes
- Fencing



Where is this functionality?

- ArcGIS Spatial Analyst
  - Tools in the Spatial Analyst Toolbox
  - Sample Toolbar on ArcObjects Online
  - HydrologyOp containing ArcObjects methods
  - *Example ModelBuilder model on the Geoprocessing Center Web site*

- Arc Hydro
  - Tools in the Arc Hydro Toolbox
  - Arc Hydro Toolbar

Arc Hydro

Arc Hydro

- Extension of geodatabase model for support of water resources applications (template data model)
- Culmination of a three-year process (1999–2002) led by D. R. Maidment through GIS in Water Resources Consortium (Arc Hydro book)
- Collection of tools for support of Arc Hydro geodatabase design and basic water resources functions
- Starting point for water resources database and application development

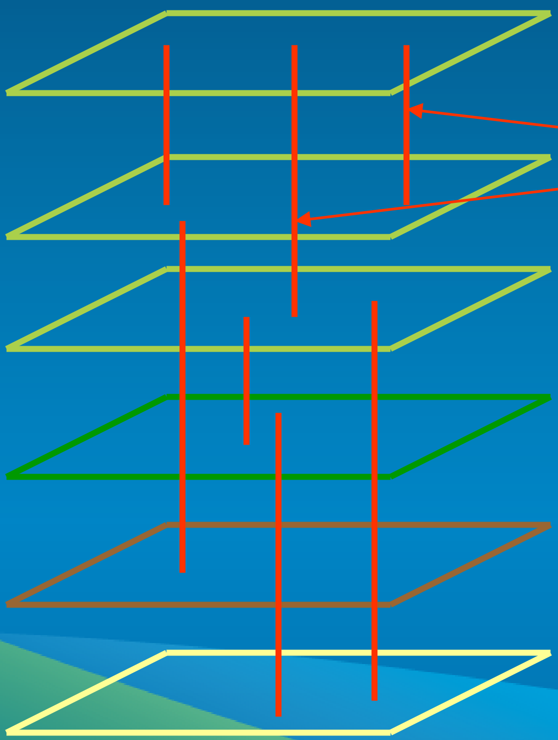
Data Model Purpose

- Target audience: Water resources (surface) community interested in quick start in ArcGIS implementati
- Starting point for project model design
- Not a “do all” design
- Not implementation/application specific, but provides the key components to develop on top of
  - The user needs to add additional data structures for their specific requirements – there’s still work to be done!

What makes Arc Hydro different?

ArcGIS: All features are labeled with a unique ObjectID within a feature layer.

Arc Hydro: All features are labeled with a unique HydroID across the geodatabase.

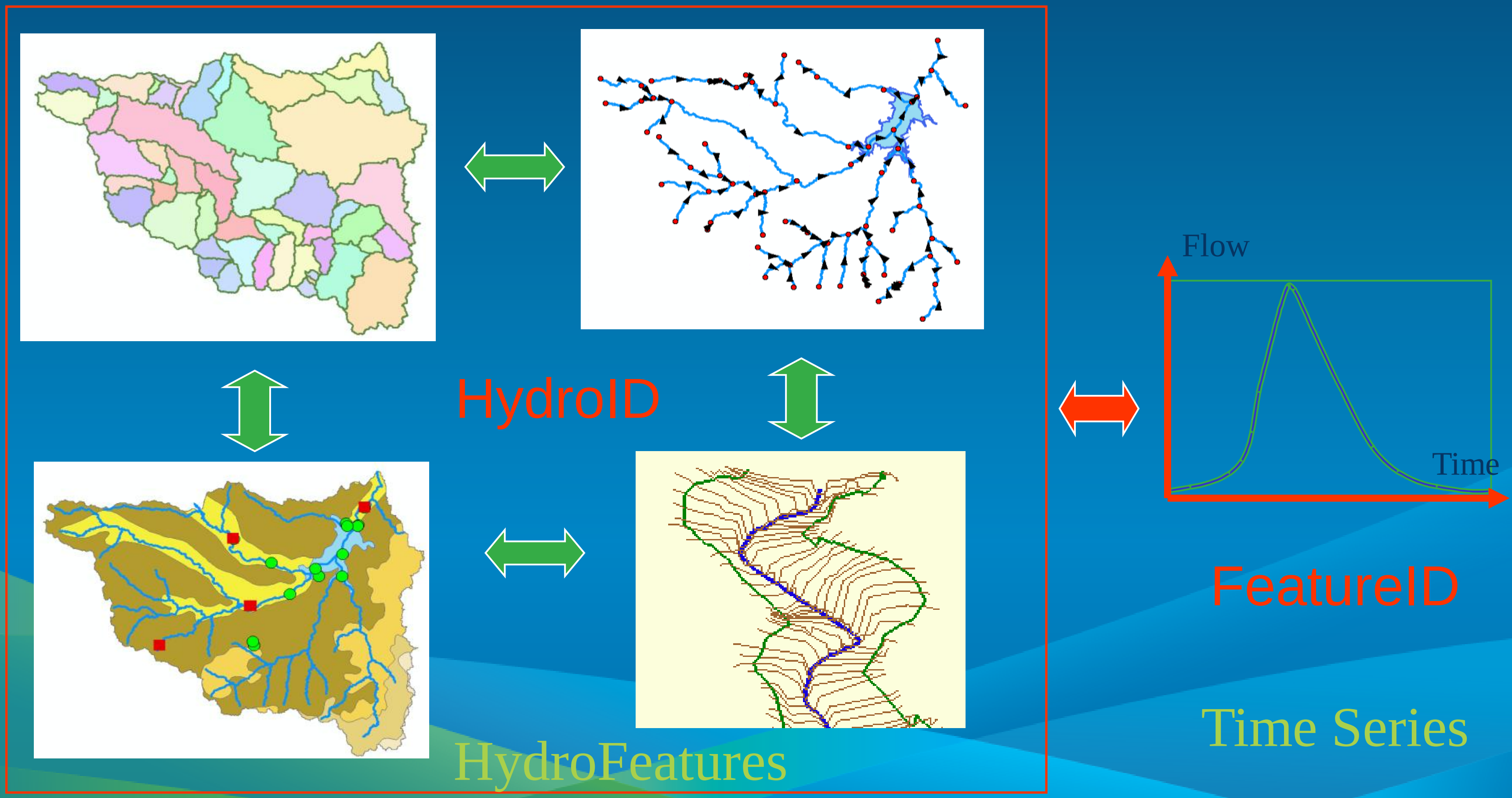


HydroID to ID relationships link neighboring features and help to trace water movement.

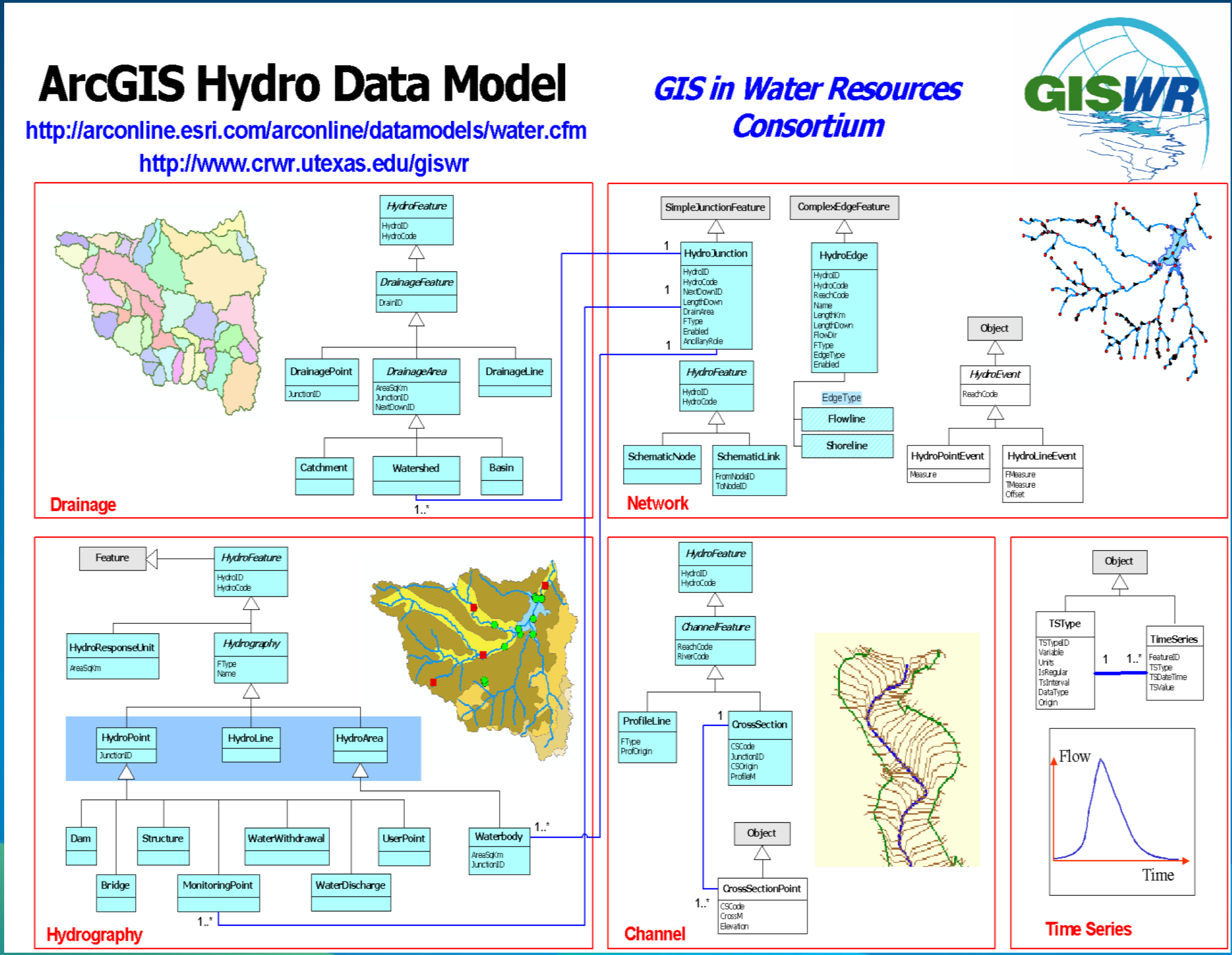
Arc Hydro is a unique "flavor" or style of doing GIS.

What makes Arc Hydro different?

Arc Hydro connects space and time:
HydroFeatures are linked to time series.

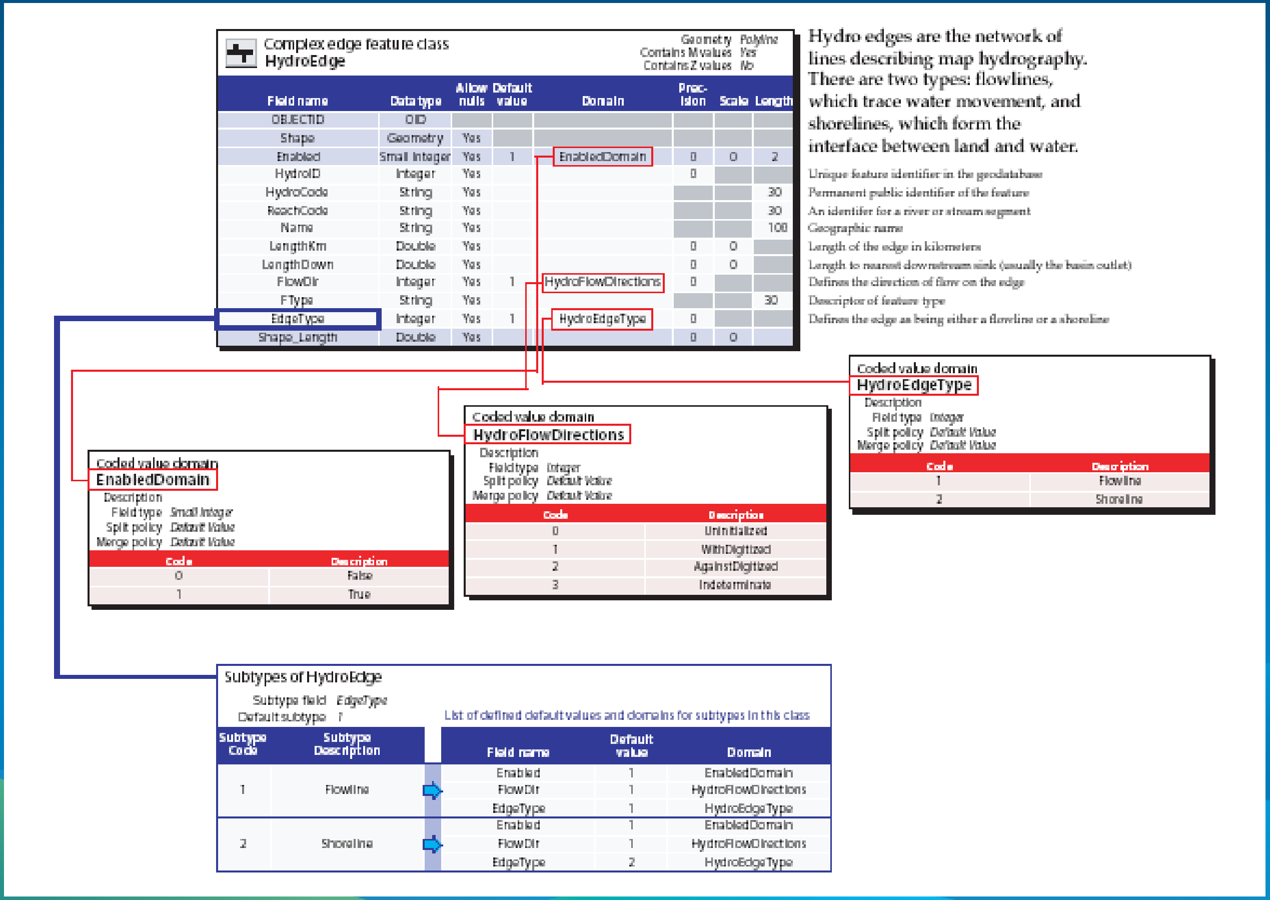


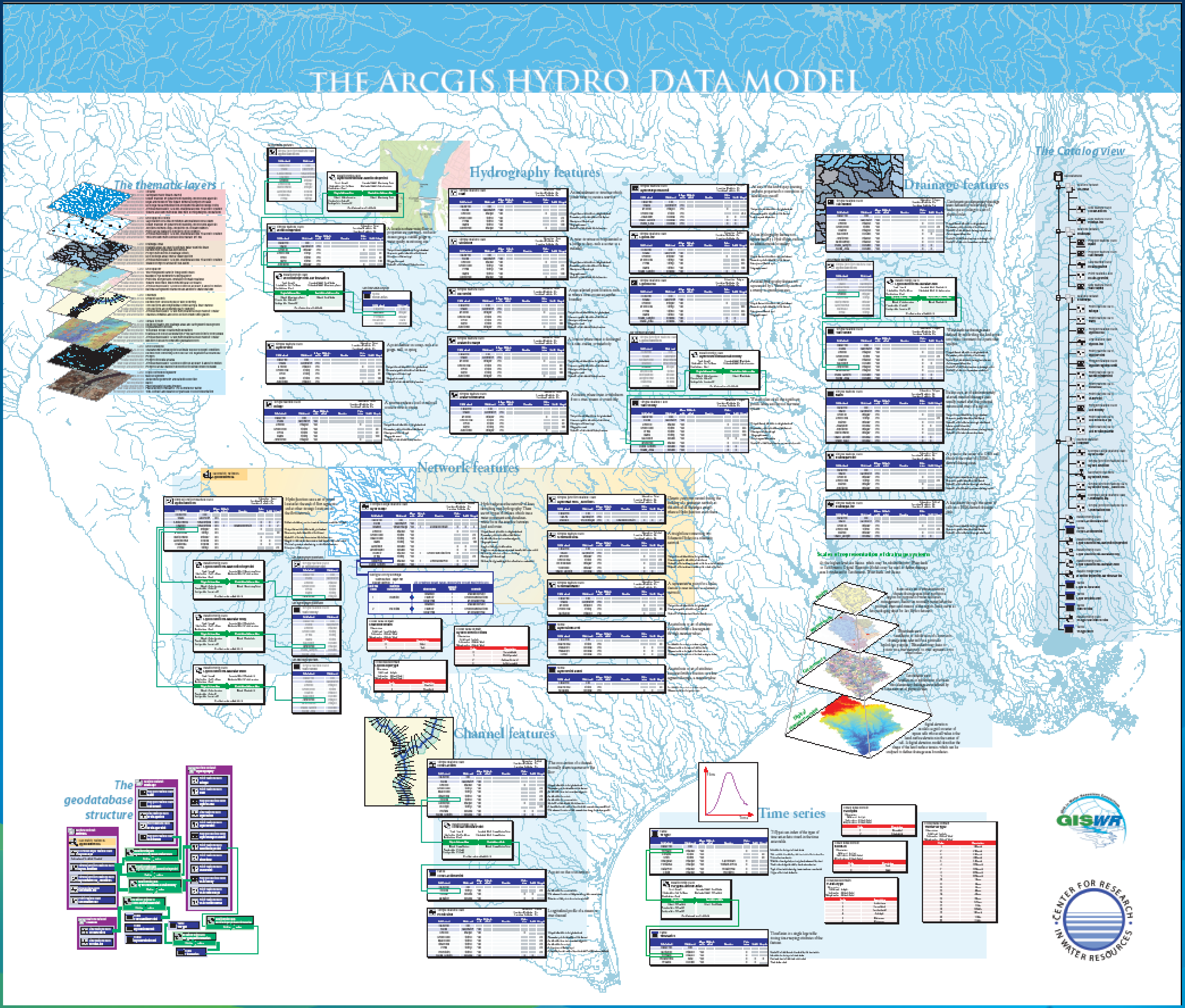
Arc Hydro Data Model



Arc Hydro Data Model Details

- **Detailed representation at the end of corresponding chapters in the book (e.g., p. 51)**

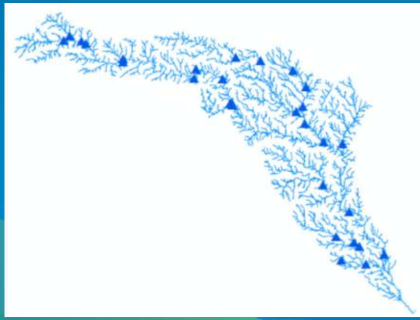


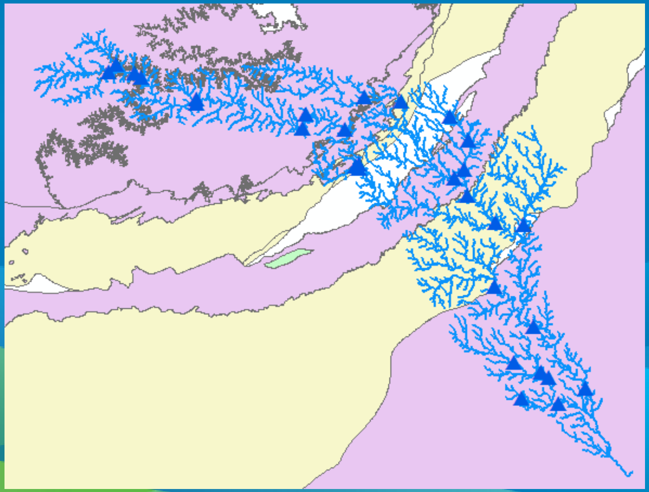

THE ARCGIS HYDRO DATA MODEL
The thematic layers
Hydrography features
Drainage features
The Catalog view
Network features
Channel features
Time series
The geodatabase structure
GISWR
CENTER FOR RESEARCH IN WATER RESOURCES

Integration of Surface Water and Groundwater Data

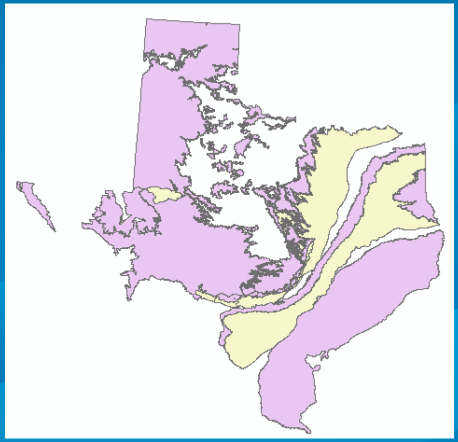
- Describe the relationship between surface water features (e.g., streams and water bodies) with groundwater features (aquifers, wells).
- Enable the connection with the surface water data model.
- Groundwater data model and tools developed and maintained by AQUAVEO.

Hydro network





Aquifers



What are Arc Hydro Tools?

- A set of freely available ArcMap-based tools that are a companion to the Arc Hydro data model
- Developed and maintained by ESRI Water Resources Team (not a core product or a sample)
- Hundred (150) + tools organized in one main and several supporting toolbars in ArcMap
  - Geoprocessing (toolbox) implementation of most of the existing tools. All new tools are developed in gp environment.

What do Arc Hydro Tools do?

- “Exercise” Arc Hydro data model (manage key identifiers—HydroID, JunctionID, Next DownID, etc.)
- Provide functionality common to water resources analyses
  - Terrain analysis
  - Watershed delineation and characterization
  - Tracing and accumulation through networks
  - Schema (node-link) development
  - Specialized data I/O (XML, Excel, etc.)
    - Customizable

“Why Should I Care” about Arc Hydro Tools?

- Economy of development
  - Why reinvent the wheel?
  - Established configuration methodology
  - Established development framework
- Industry “standard”
  - Established techniques rolled into a publicly available utility
- Training and support
- Free maintenance – ESRI’s commitment to the water resources community
  - Bug fixes
  - Performance optimization
  - Release updates

Arc Hydro Tools Documentation

- Online help
- Tutorial
- Various how-to documents
- Instructor-led training

Arc Hydro Demo

Hydrologic and Hydraulic Modeling Support with GIS

How "Things" Build Up

- Database design
- Data preparation
- Terrain preparation
- "Watershed" delineation
- "Watershed" characterization

Generic

- Parameterization

Semigeneric

- Model pre- and postprocessing

Model Specific

Section Overview

- Stream statistics
- Hydrologic modeling (HEC-HMS, GeoHMS)
- Hydraulic modeling (HEC-RAS, GeoRAS)
- H&H integration considerations

Hydrology: Stream Statistics

Regression Equations

- Used to estimate streamflow statistics, both high and low flows, for ungaged sites (in uncontrolled flow environment)
- Relate streamflow statistics to measured basin characteristics
- Developed by all 48 USGS districts on a state-by-state basis through the cooperative program (usually sponsored by DOT)
- Often not used because of large efforts needed to determine basin characteristics
- Users often measure basin characteristics inaccurately.

Example Regression Equation

- Regression equations take the form:

$$Q_{100} = 0.471A^{0.715}E^{0.827}SH^{0.472}$$

- Where

A	is drainage area, in square miles
E	is mean basin elevation, in feet
SH	is a shape factor, dimensionless

Basin Characteristics Used for Peak Flows

Basin characteristic	# of States using this (including PR)
Drainage area or contributing drainage area (square miles)	51
Main-channel slope (feet per mile)	27
Mean annual precipitation (inches)	19
Surface water storage (Lakes, ponds, swamps)	16
Rainfall amount for a given duration (inches)	14
Elevation of watershed	13
Forest cover (percent)	8
Channel length (miles)	6
Minimum mean January temperature (degrees F)	4
Basin shape ((length)^2 per drainage area)	4
Soils characteristics	3
Mean basin slope (feet per foot or feet per mile)	2
Mean annual snowfall (inches)	2
Area of stratified drift (percent)	1
Runoff coefficient	1
Drainage frequency (number of first order streams per sq. mi.)	1
Mean annual runoff (inches)	1
Normal daily May-March temp (degrees F)	1
Impervious Cover (percent)	1
Annual PET (inches)	1

. . . and many others

Role of GIS

- **Speed up the process (instead of hours, minutes).**
- **Provide a common (single) access to the methodology (for users and maintenance).**
- **Systematize methodology and datasets used in the process (repeatability).**
- **Provide better tools for deriving characteristics for regression equation determination.**
- **Provide a map-based user interface.**
- **Web and desktop implementation are based on Arc Hydro.**

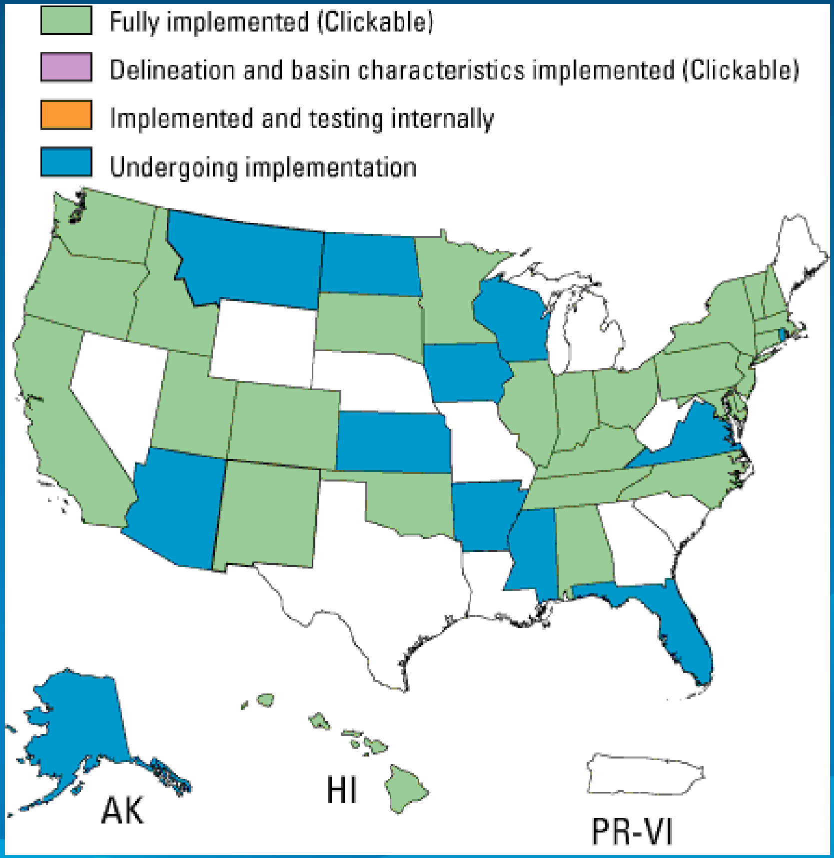
Arc Hydro Tools Role

- StreamStats fully implemented within Arc Hydro environment
  - Terrain preprocessing
  - Local and global watershed delineation
  - Extracting local characteristics
  - Assembly of global characteristics
- Characteristics developed for StreamStats available to wider audience (e.g., hydrologic modeling support)
- Desktop and Web implementations

StreamStats Implementation Activities

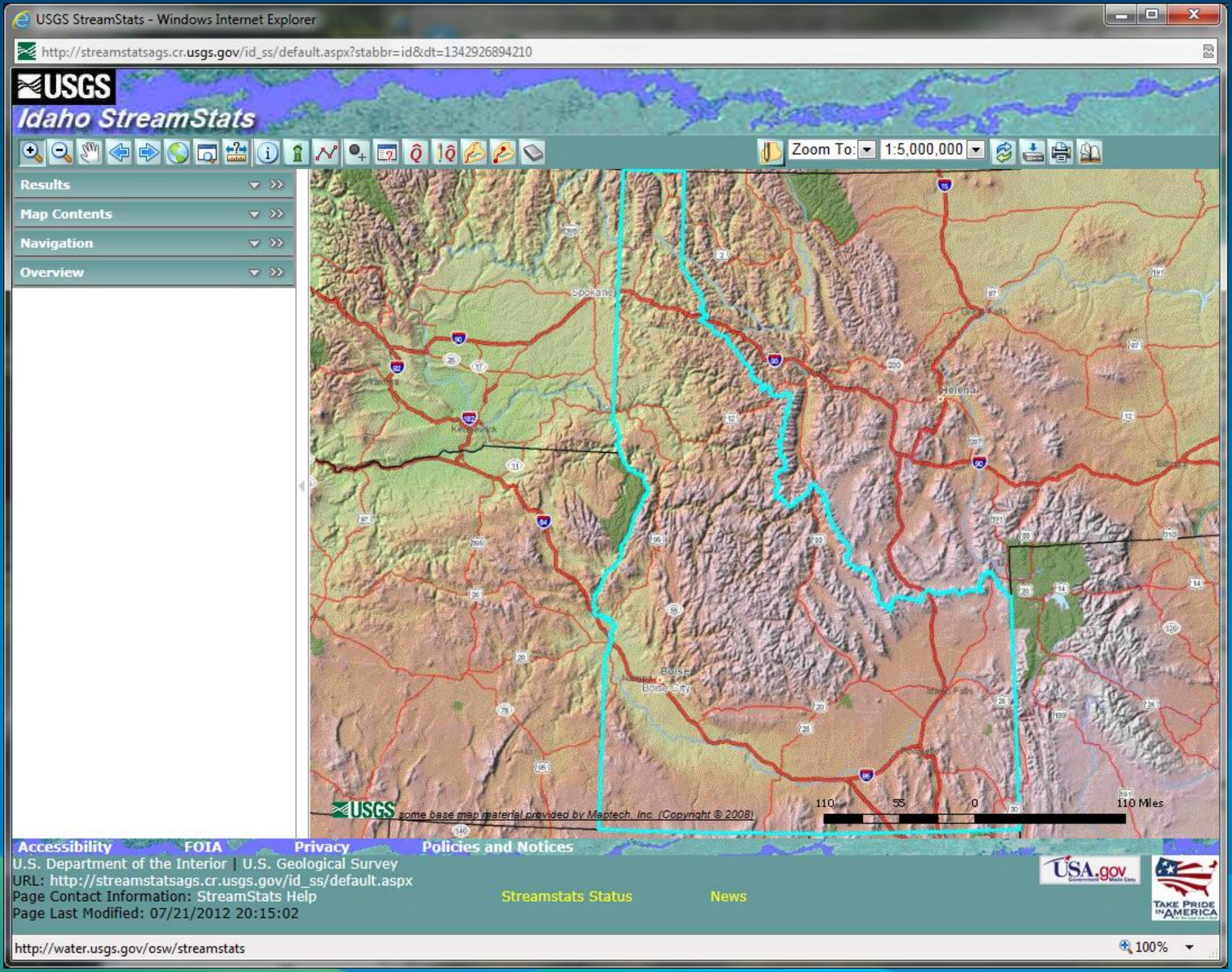
July 2012

- USGS lead effort
- State-based
- ArcGIS Server technology
- Hosted in Denver
- Extended functionality

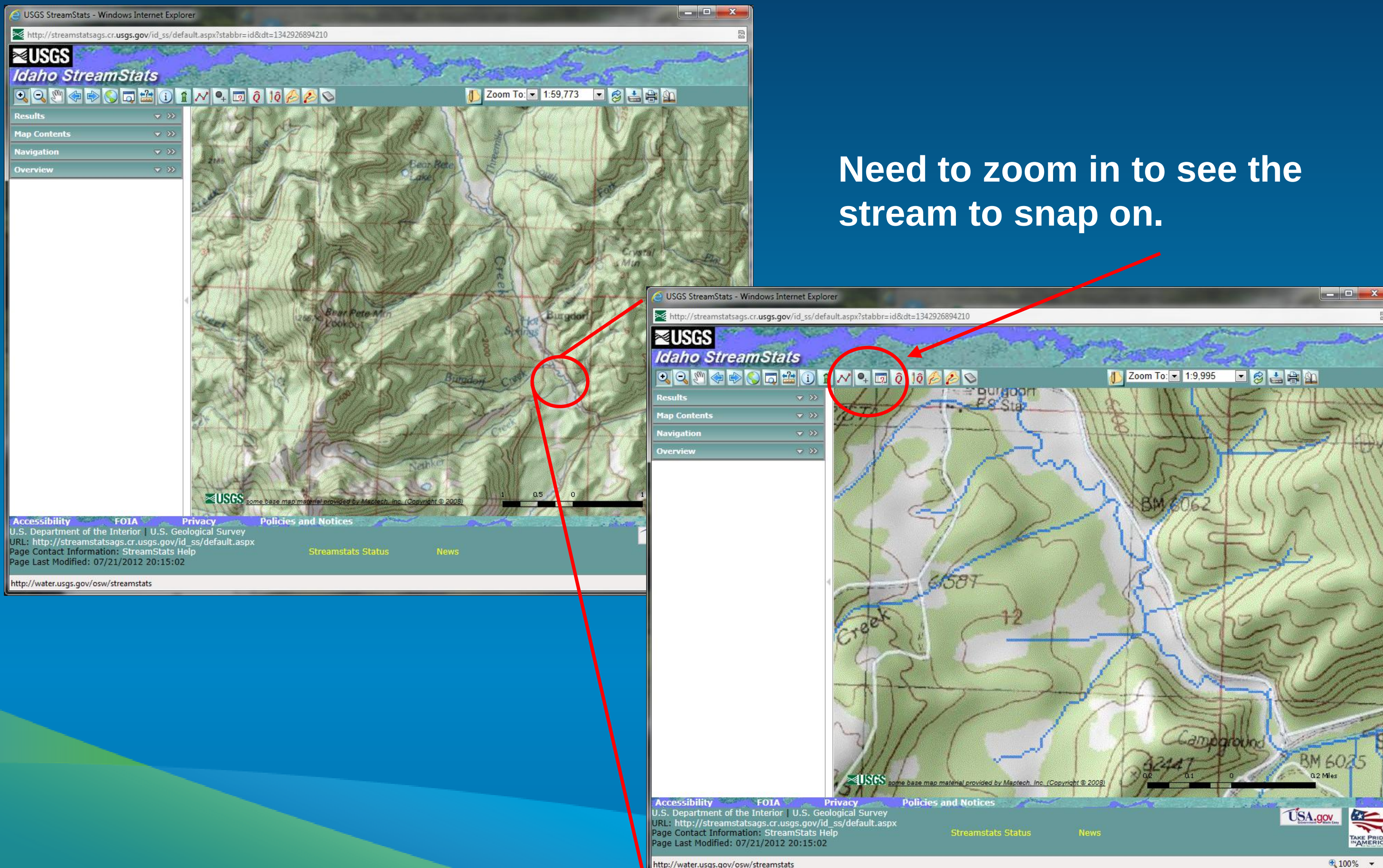


Source: http://water.usgs.gov/osw/streamstats/ssonline.html

State Site (ID)

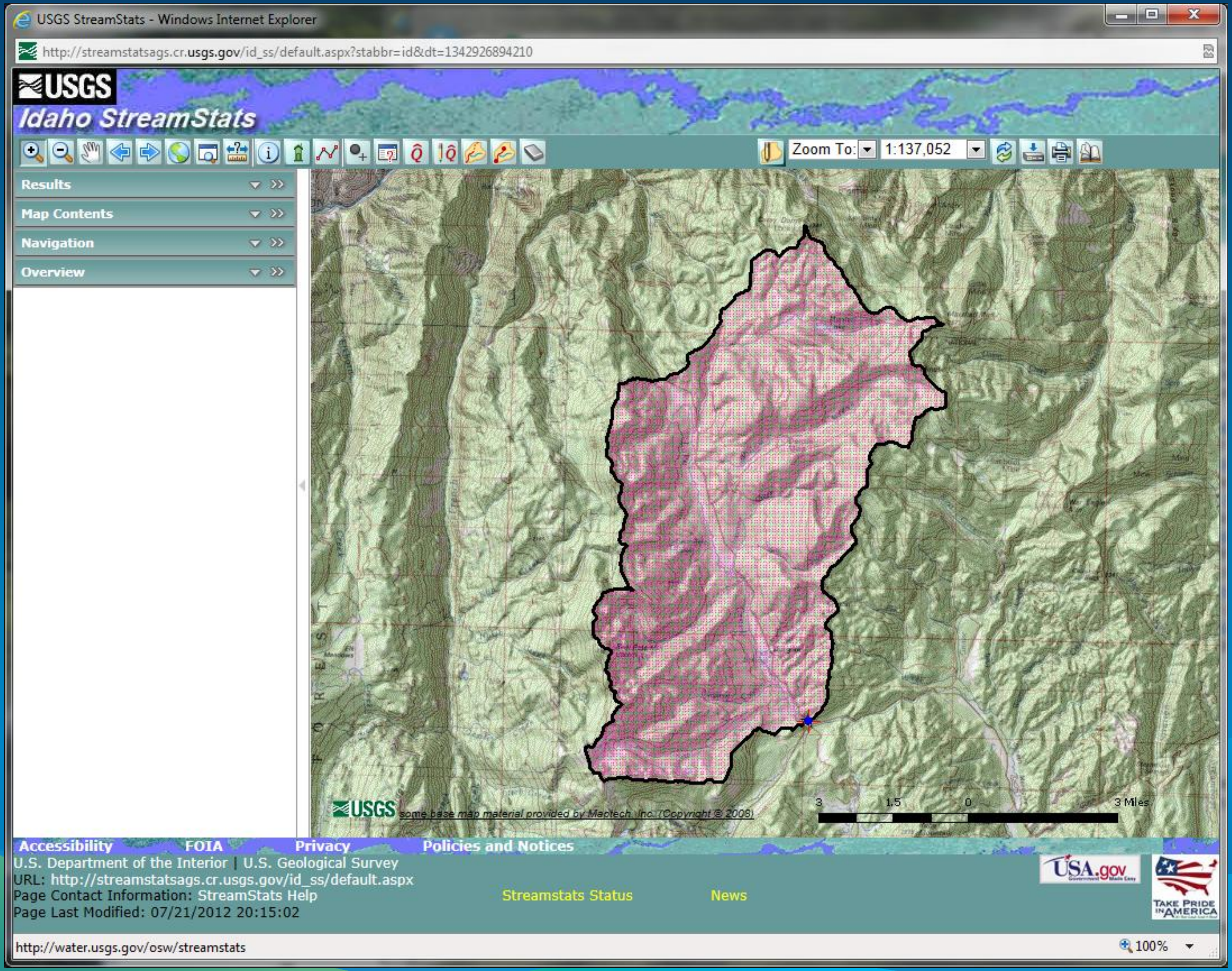


Main Site - Navigation



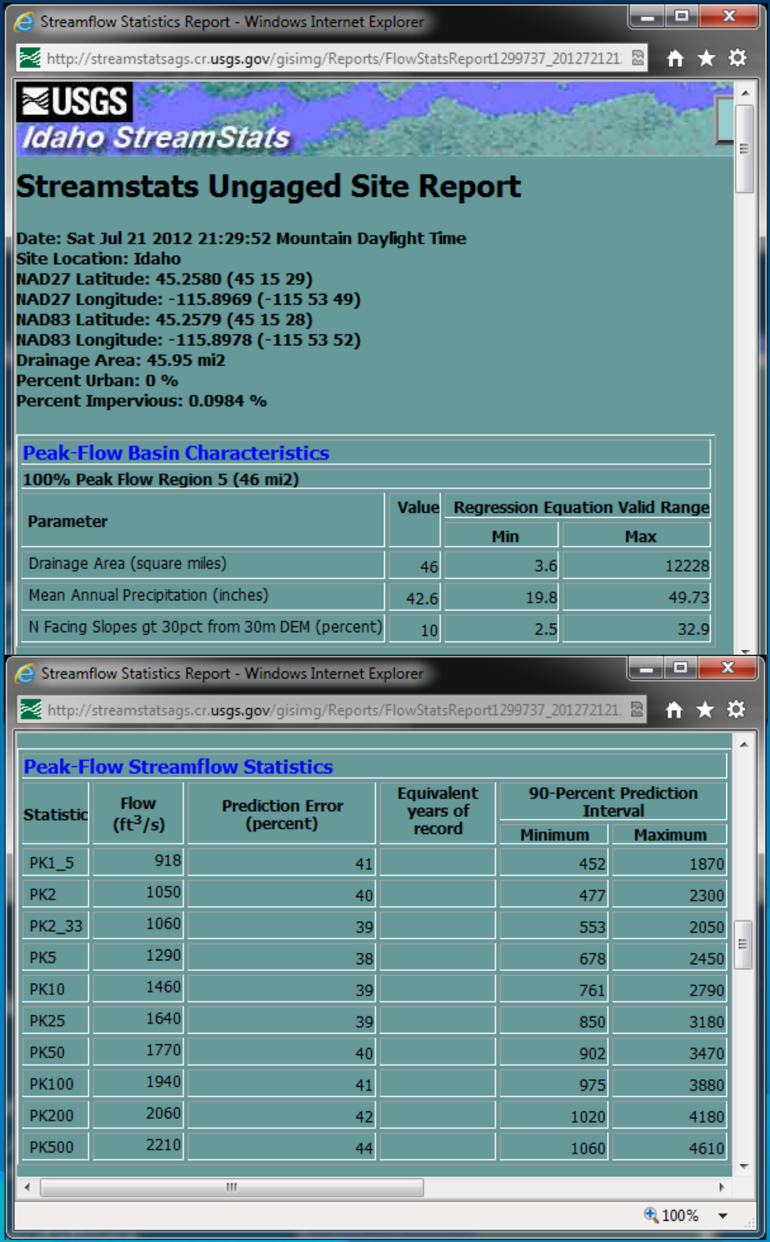
Need to zoom in to see the stream to snap on.

Watershed Delineation - Web



Results - Web

- **Watershed delineation**
  - 20-30 seconds, not much difference with respect to size of the watershed
- **Parameter computations**
  - 10s – 1 minute, depends on the region (what parameters to get) and somewhat on the size



Streamstats Ungaged Site Report

Date: Sat Jul 21 2012 21:29:52 Mountain Daylight Time
Site Location: Idaho
NAD27 Latitude: 45.2580 (45 15 29)
NAD27 Longitude: -115.8969 (-115 53 49)
NAD83 Latitude: 45.2579 (45 15 28)
NAD83 Longitude: -115.8978 (-115 53 52)
Drainage Area: 45.95 mi2
Percent Urban: 0 %
Percent Impervious: 0.0984 %

Peak-Flow Basin Characteristics

100% Peak Flow Region 5 (46 mi2)

Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	46	3.6	12228
Mean Annual Precipitation (inches)	42.6	19.8	49.73
N Facing Slopes gt 30pct from 30m DEM (percent)	10	2.5	32.9

Peak-Flow Streamflow Statistics

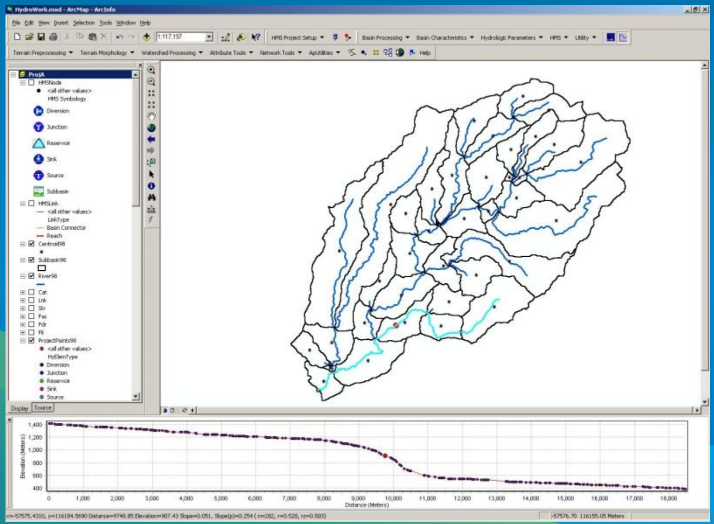
Statistic	Flow (ft^3/s)	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
PK1_5	918	41		452	1870
PK2	1050	40		477	2300
PK2_33	1060	39		553	2050
PK5	1290	38		678	2450
PK10	1460	39		761	2790
PK25	1640	39		850	3180
PK50	1770	40		902	3470
PK100	1940	41		975	3880
PK200	2060	42		1020	4180
PK500	2210	44		1060	4610

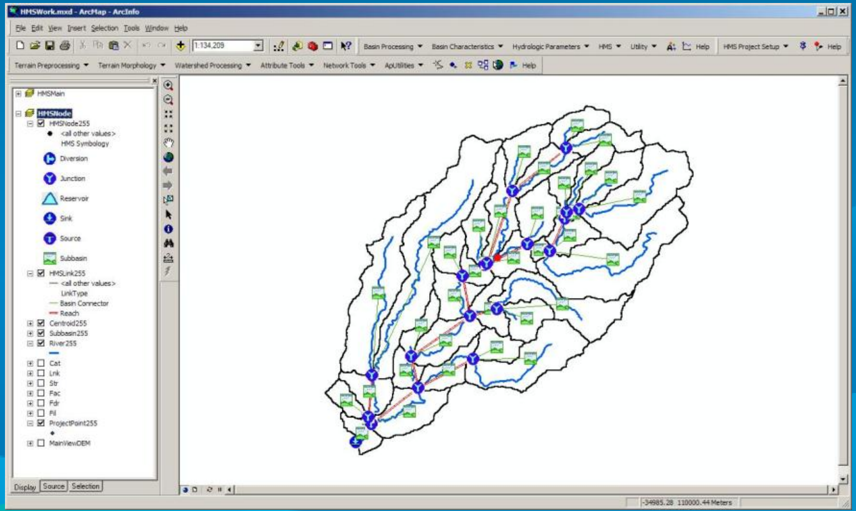
H&H Integration Overview

(HMS-RAS Focus)

HEC-GeoHMS

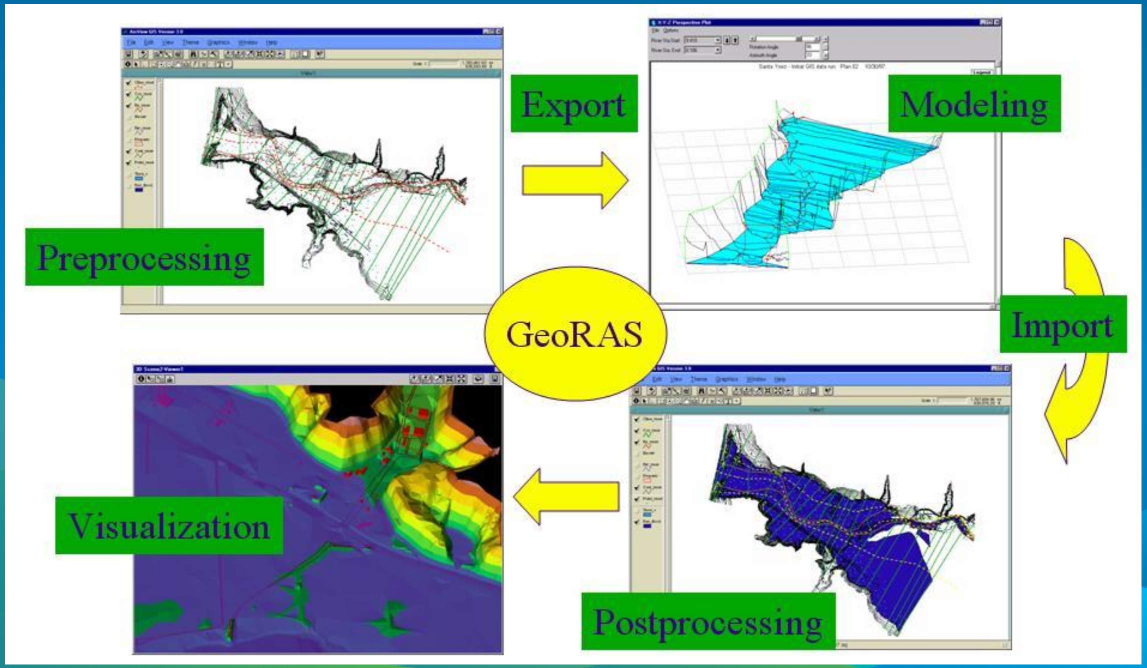
- **HEC-HMS: Hydrologic Engineering Center Hydrologic Modeling System: allows modeling of precipitation – runoff processes.**
- **HEC-GeoHMS:**
  - **ArcGIS preprocessor for HMS**
  - **Transforms the drainage paths and watershed boundaries based on DEM into a hydrologic data structure that can be used to model the watershed response to precipitation**

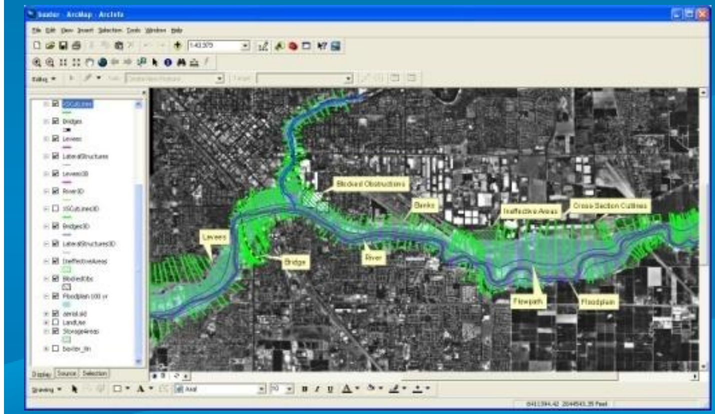




HEC-GeoRAS

- HEC-RAS: Hydrologic Engineering Center River Analysis System: allows performing one-dimensional open channel steady and unsteady flow calculations.
- HEC-GeoRAS:
  - Prepare geometric data for import into HEC-RAS
  - Processes simulation results exported from HEC-RAS





Integration Approach

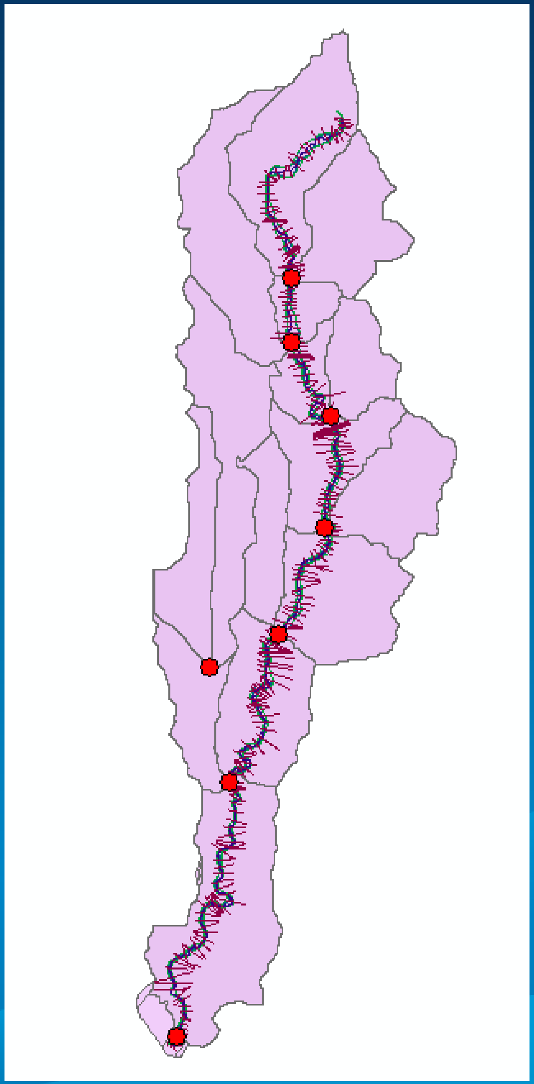
- Mix of planning, GIS, and H&H modeling operations (not a push-button operation)
- Types of integration
  - Modeling support (preparing data for model input)
    - (e.g., land use/soils/CN or rainfall processing – Arc Hydro or general GIS data processing
  - Linked
    - GeoHMS
    - GeoRAS
  - Integrated
    - DSS

Integration Approach (2)

- Key steps
  - Plan (roughly) hydrologic and hydraulic model layouts—flow exchange locations.
    - E.g., location of HMS modeling elements and RAS cross sections
  - Identify sources of precipitation input into the hydrologic model and techniques for their incorporation into the dataset.
    - E.g., Nexrad rainfall
  - Develop the GeoHMS model (and precipitation submodel).
  - Finalize and run the HMS model and generate results (DSS).
  - Develop the GeoRAS model.
  - Finalize and run RAS, taking HMS results as input.
  - Feedback between HMS and RAS is manual.
    - E.g., modification of time of concentration or routing parameters

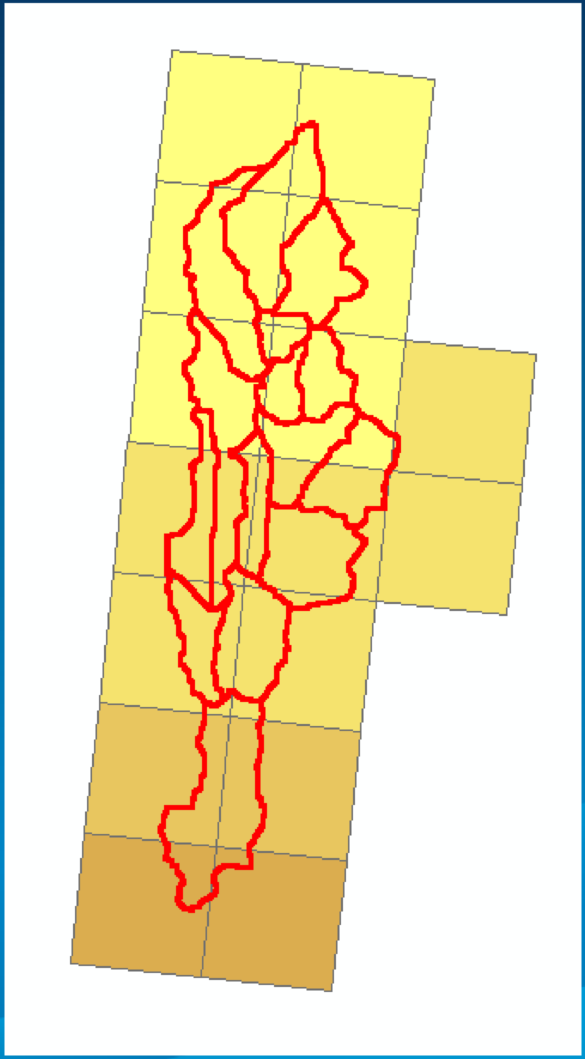
Integration Planning

- Identify where outputs from one model (HMS) become input to the second one (RAS).
  - Place hydrologic elements (subbasins, reaches, junctions) to capture flows at points of interest (confluences, structures).
  - Place hydraulic elements (cross sections) at points of interest.
  - Identify/Specify element-naming conventions between the two models (persistent or transient names).



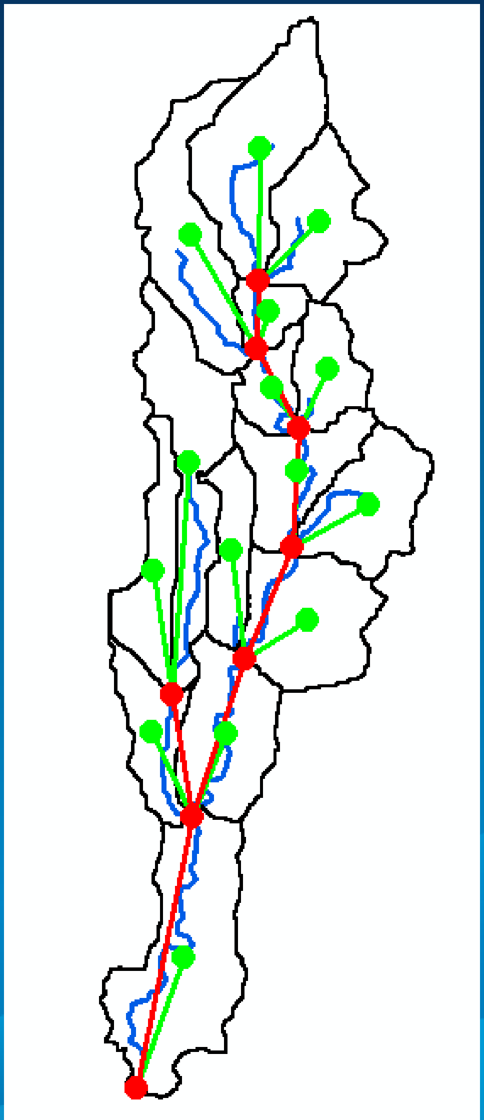
Precipitation Sources

- **Identify sources of precipitation input into the hydrologic model and techniques for their incorporation into the dataset.**
  - **Point (rain gauge)**
  - **Polygon (Nexrad cells)**
  - **Surface (TIN/GRID)**



Develop GeoHMS Model

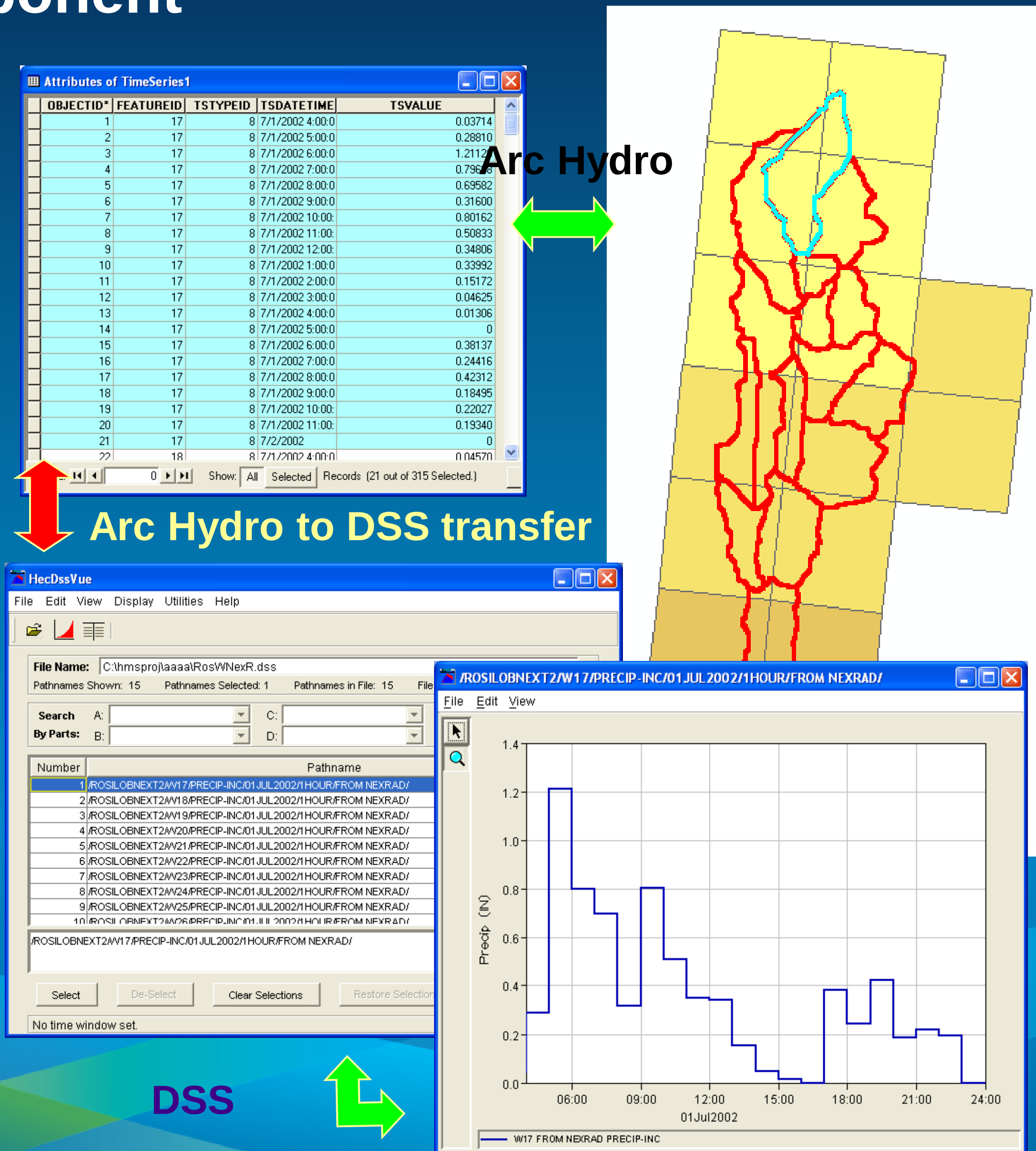
- Follow all principles in development of a hydrologic model.
- In addition, take into consideration integration planning aspects developed earlier.
  - Placement of flow exchange points
  - Naming conventions
- Incorporate precipitation submodel.
  - Develop Arc Hydro time series for the final subbasin delineation and export to DSS.
- Export to HMS.



Meteorological Component

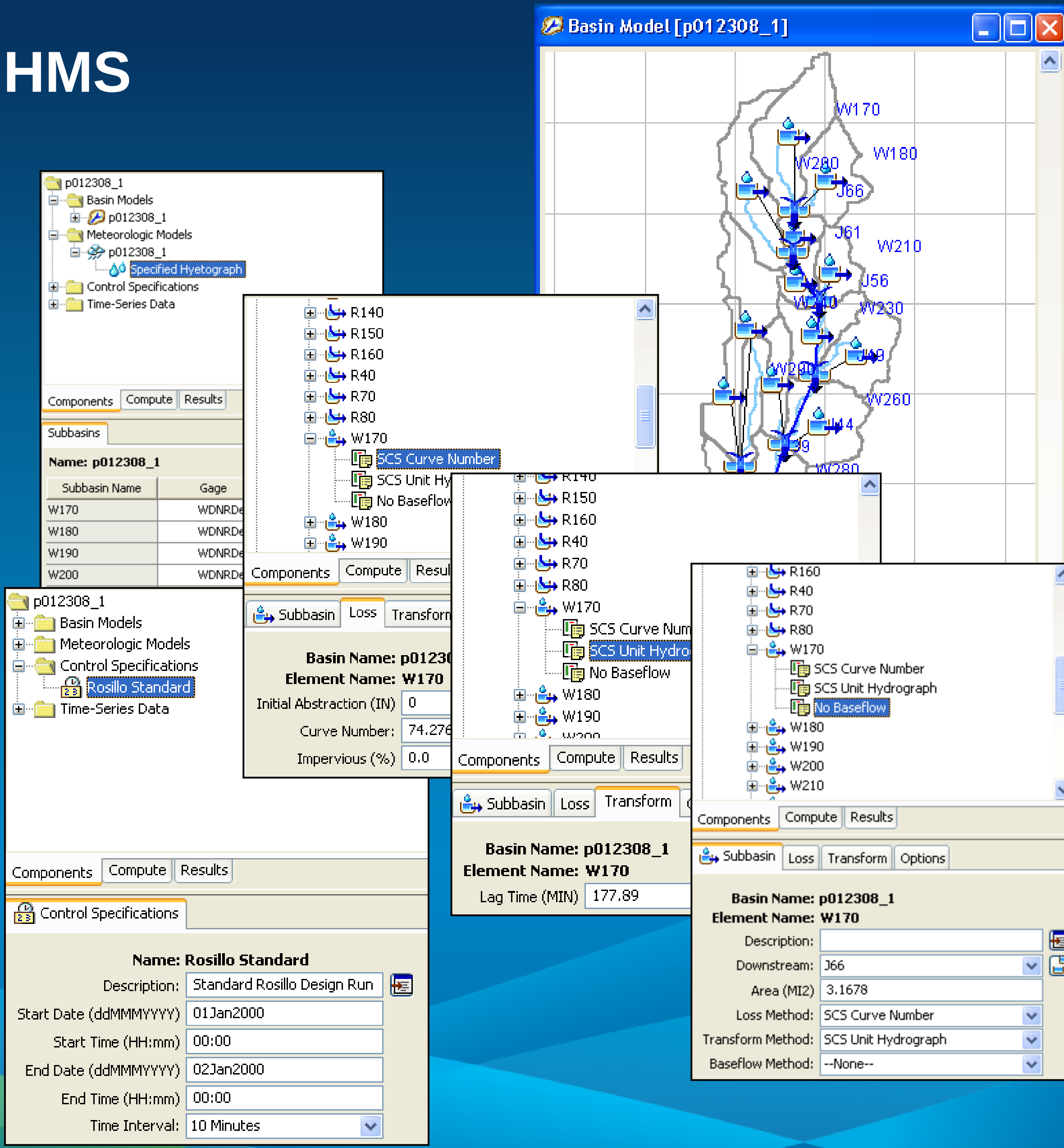
- Develop a custom “gauge” for each subbasin or for each rainfall observation element with corresponding weights for subbasins.

- Export the time series for the subbasin “gauge” from Arc Hydro time series data structure into DSS.



Finalize and Run HMS

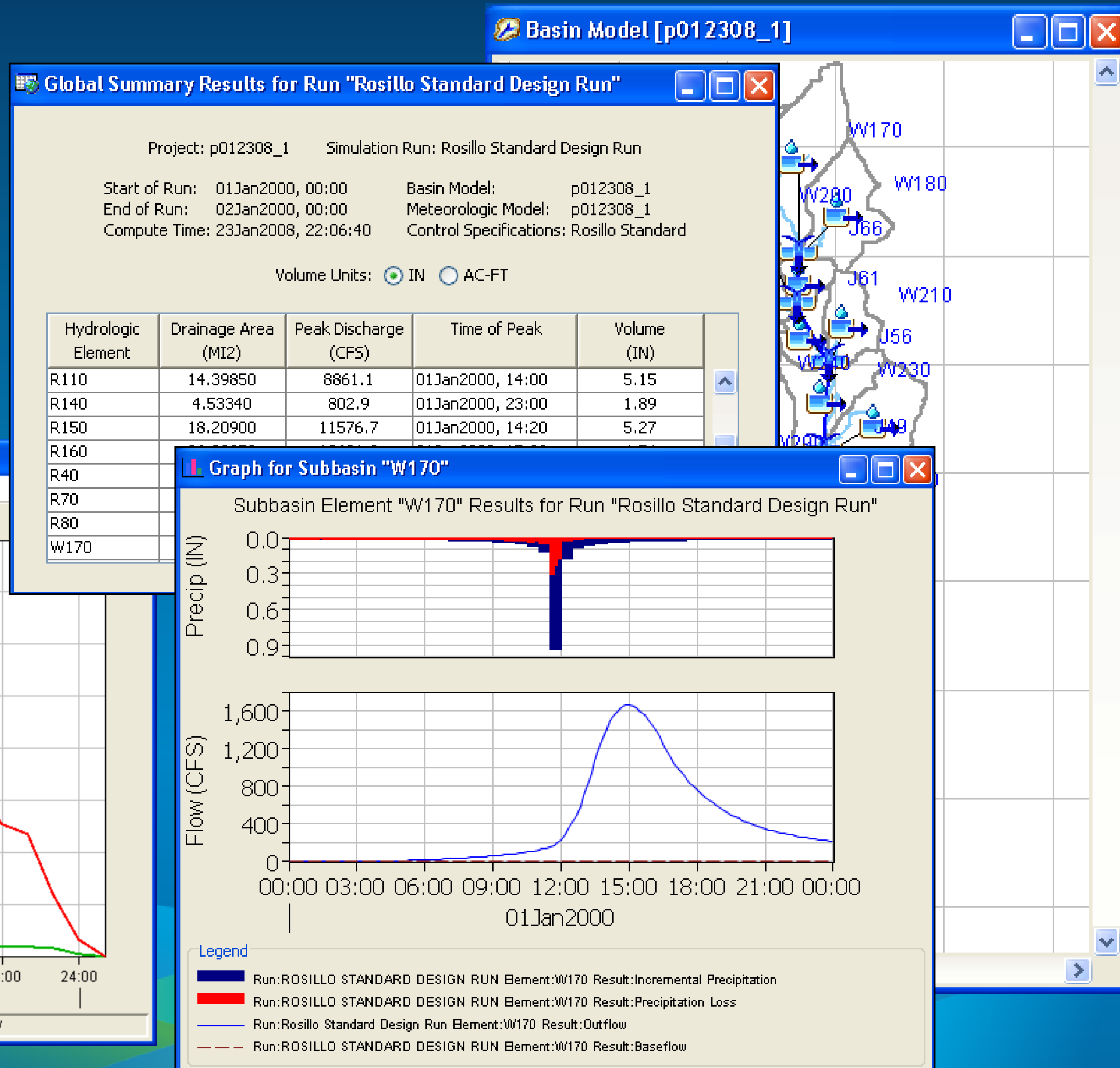
- Complete HMS model with any additional parameters including meteorological model and control specifications.
- Follow all principles in HMS model development (calibration, etc.).



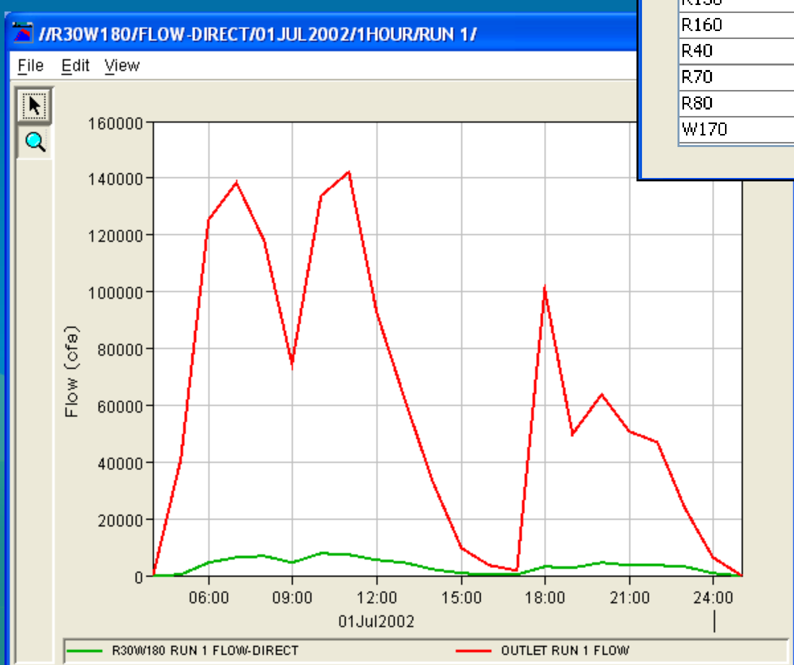
Finalize and Run HMS (2)

- Do the final run and generate results (DSS).

HMS View

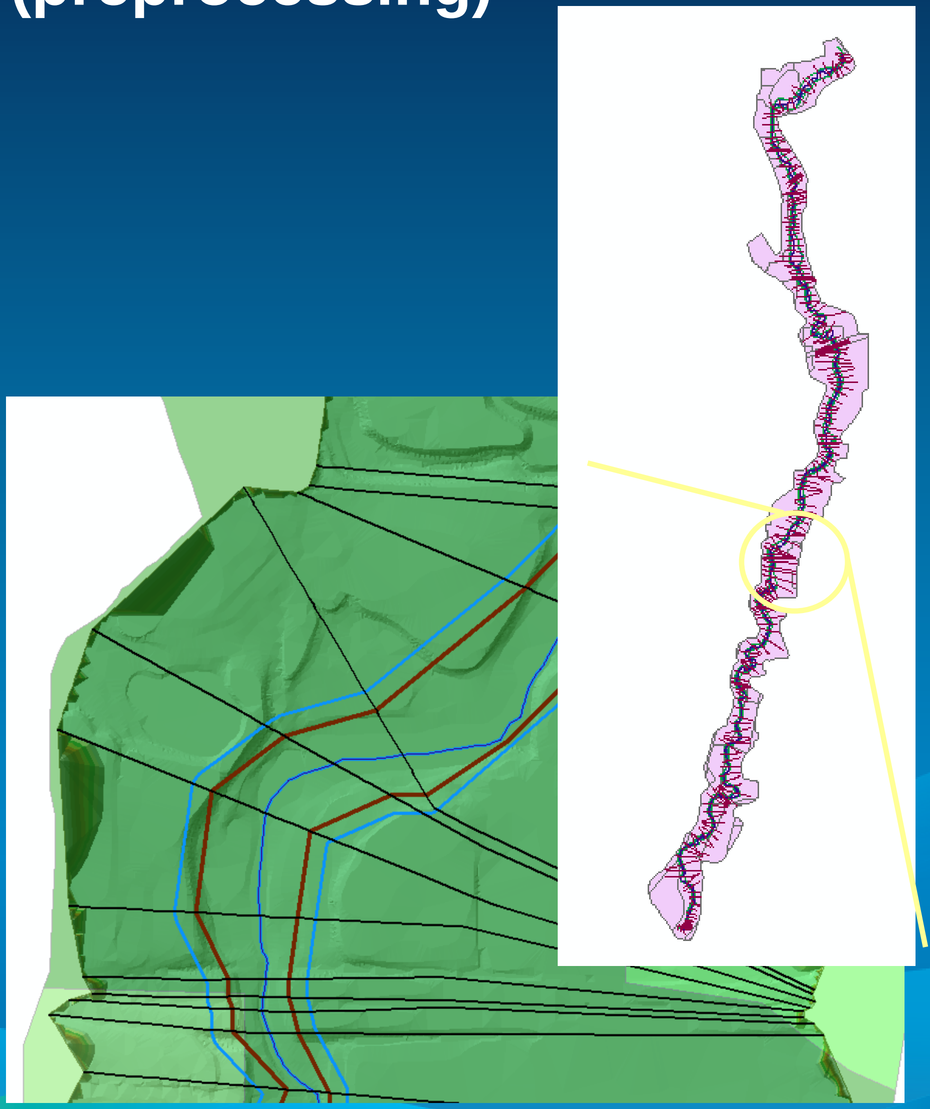


DSS View



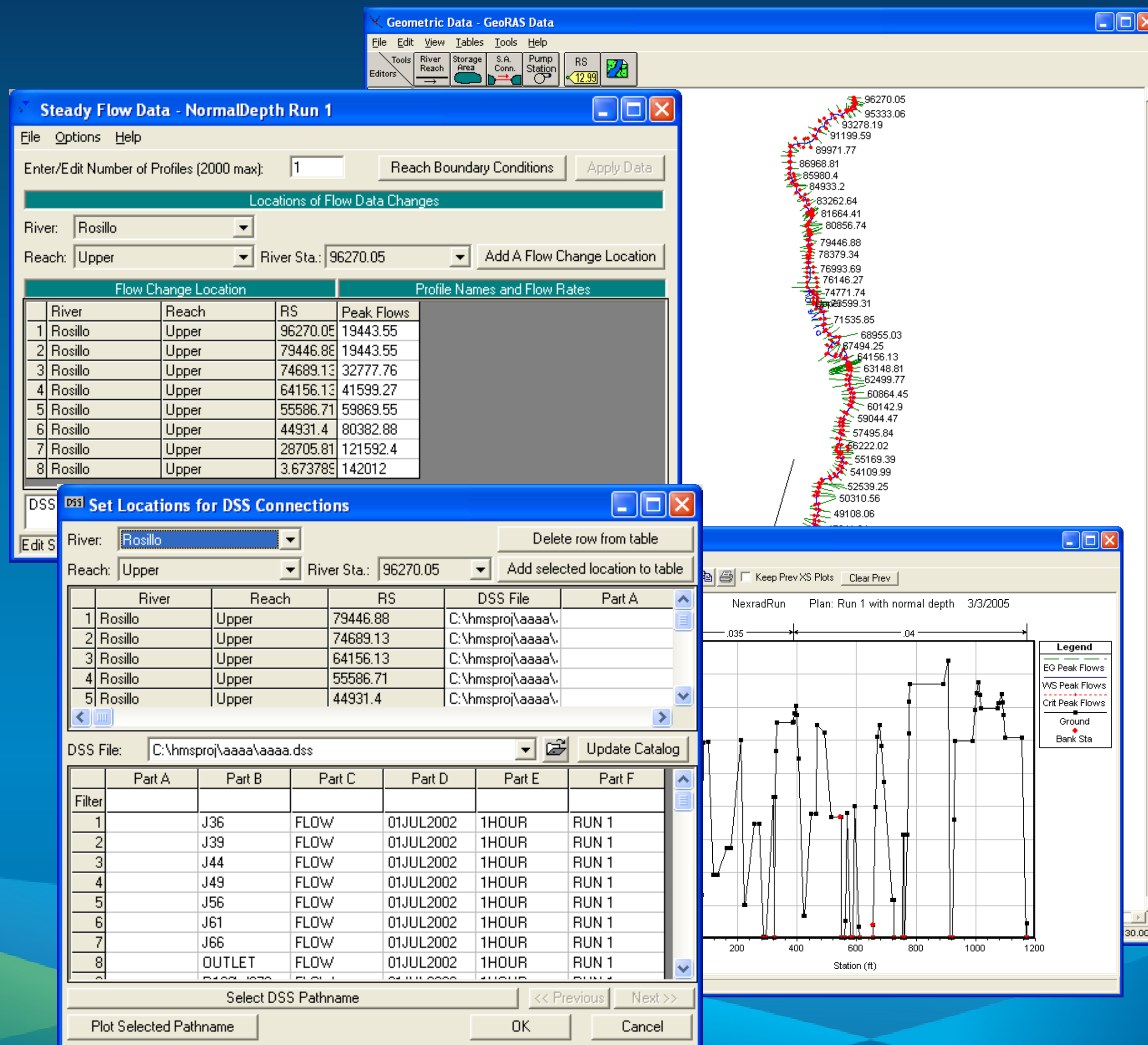
Develop GeoRAS Model (preprocessing)

- Follow all principles in development of a hydraulic model for element placement (confluences, structures, …)
- In addition, take into consideration integration planning aspects developed earlier
  - Naming conventions (add name of the HMS element to the cross-section that will get the element’s flows)
- Export to RAS



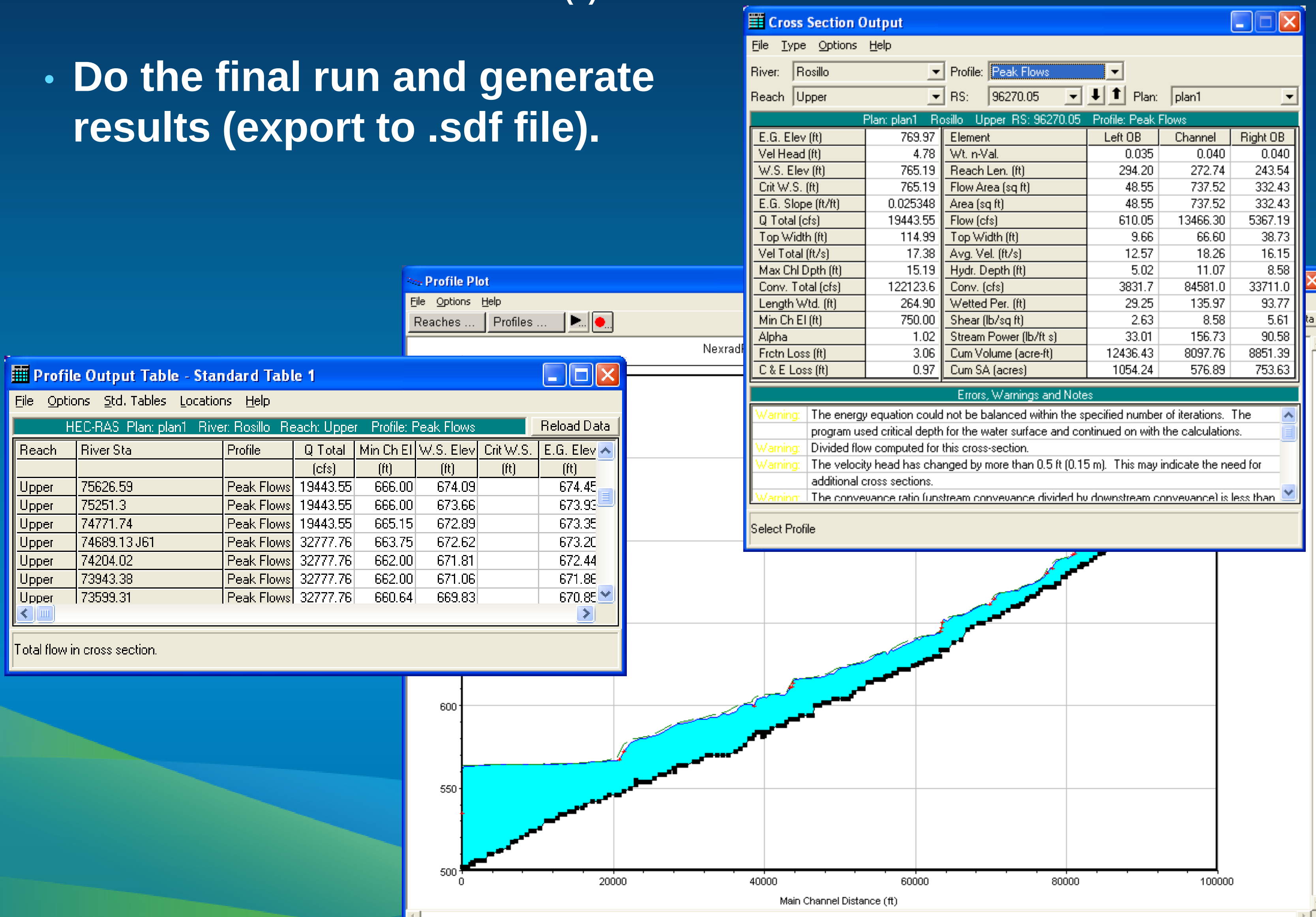
Finalize and Run RAS

- Complete RAS model with any additional parameters including initial and boundary conditions.
- Follow all principles in RAS model development (calibration, etc.).



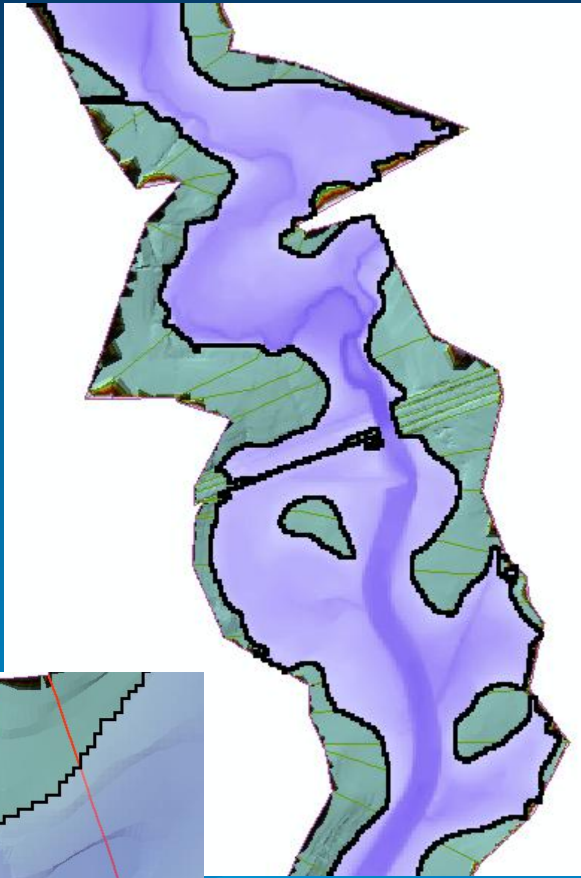
Finalize and Run RAS (2)

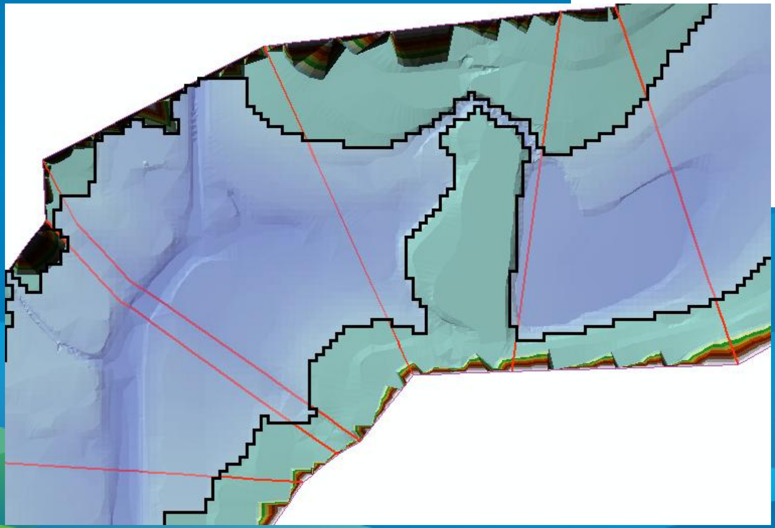
- **Do the final run and generate results (export to .sdf file).**



Process RAS Results in GeoRAS

- **Construct the floodplain based on the results in the .sdf.**
- **Review the results with respect to spatial integrity (extents of cross sections, ineffective flow areas, disconnected flood areas, etc.).**
- **Clean results.**
- **Revisit RAS.**

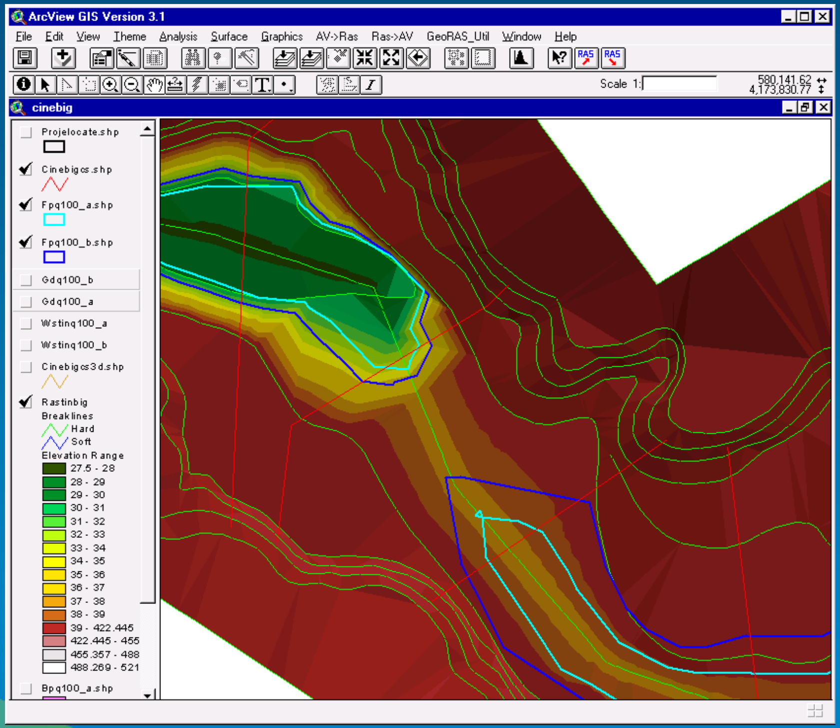


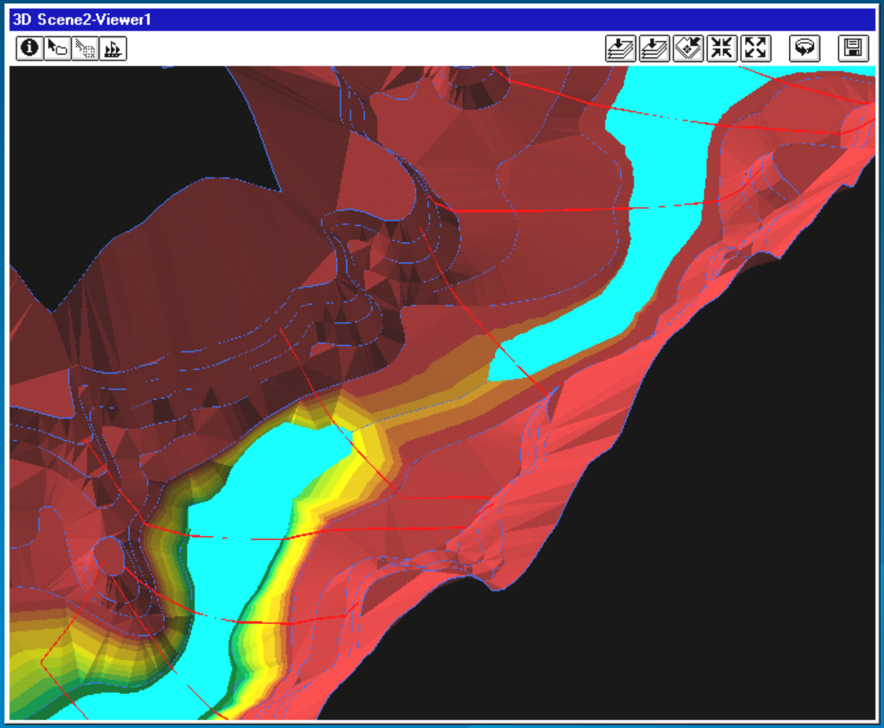


GIS–HMS–RAS Feedback

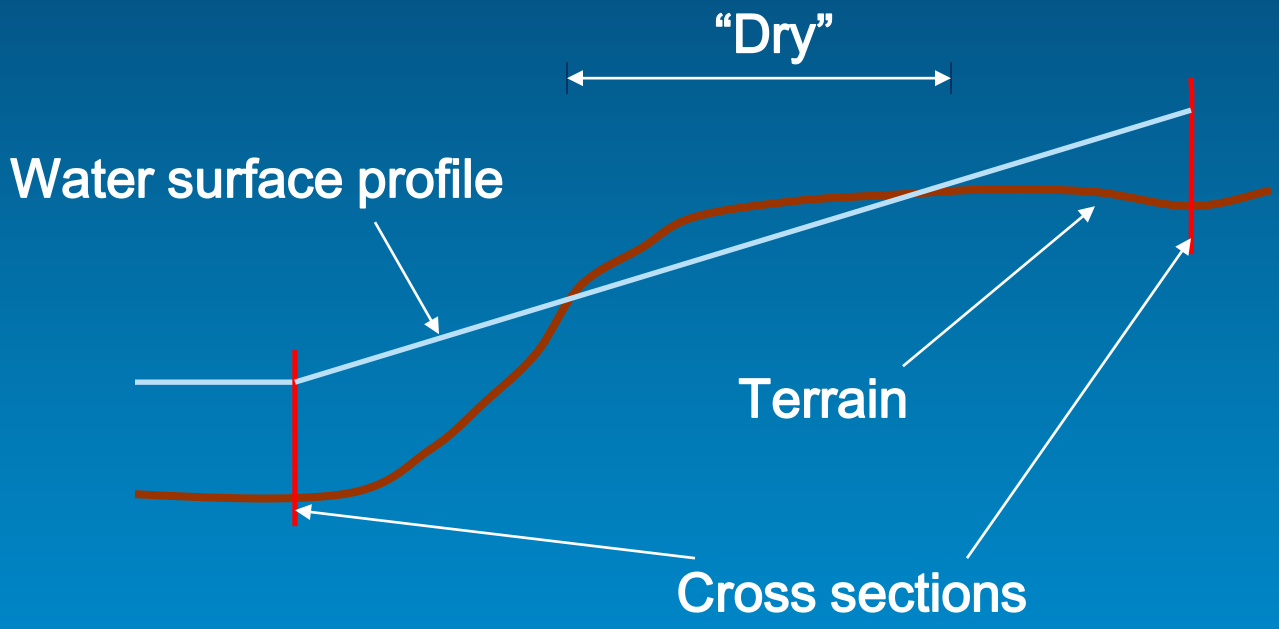
- At present, it is manual and at the discretion of the modeler.
  - GIS–H&H interaction
  - H–H interaction
- Visualization in both pre- and postprocessing is not just a “pretty picture.”
  - Flyover in preprocessing (GeoHMS and GeoRAS)
    - Identification of data problems
    - Modeling element placement
  - Postprocessing (GeoRAS)
    - Validity of element placement

Floodplain Discontinuity

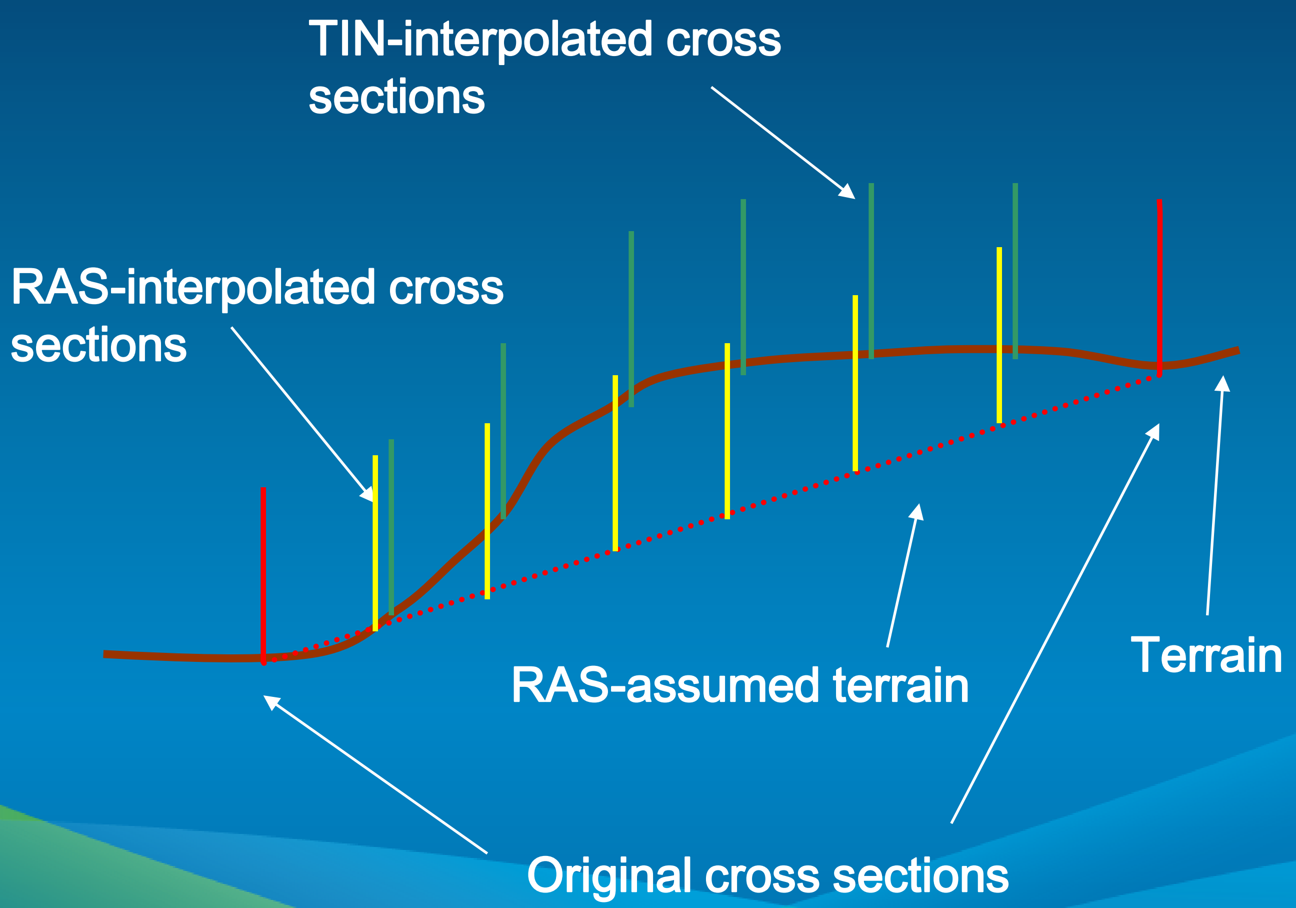




Floodplain Discontinuity (cont.)



Cross-Section Interpolation



Summary

GIS provides many capabilities for support of H&H

- Integrated, multi-purpose database for storage of H&H and related data.
- Consistent methodology for spatial data processing and analytical functionality, such as terrain processing, watershed delineation and characterization.
- Pre- and post-processing for H&H models significantly reduces time for data preparation for modeling support.
- Environment for integrated solution management:
  - Emergency management
  - Design
  - Decision support

- Thank you for attending
- Have fun at UC2012
- Open for Questions

- Please fill out the evaluation:

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