Hydrologic and Hydraulic Modeling with ArcGIS

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Content

- Water resources issues
- Core GIS tools for surface water analysis
- DEM data and processing
- Arc Hydro
- Application tools for Hydrologic and Hydraulic Modeling
- Q&A

Water Resources Issues

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.

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.*

Hydraulic Modeling

- Goal: **Predict water surface elevations and velocities for a given discharge.**
- Input: **Terrain geometry with hydraulic characteristics, plus discharge ‘Q’ and initial water surface level.**

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

GIS Data for Hydrologic and Hydraulic Modeling

- **Check out Esri's Living Atlas (AGOL)**
- **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/

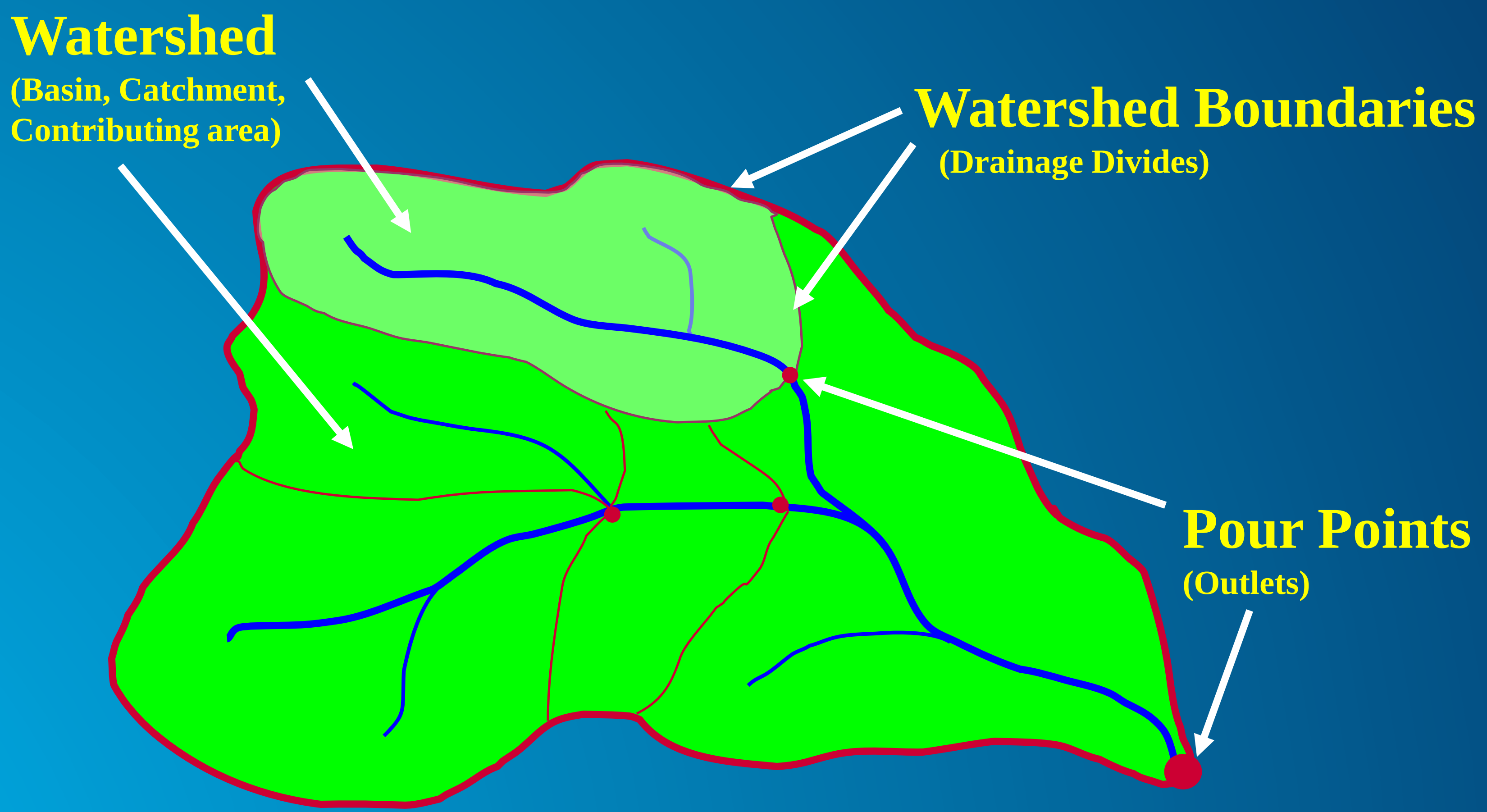
GIS Data for Hydrologic and Hydraulic Modeling

- **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)**

- **H&H data are very "local"**
  - **"You have to be there when it rains!"**

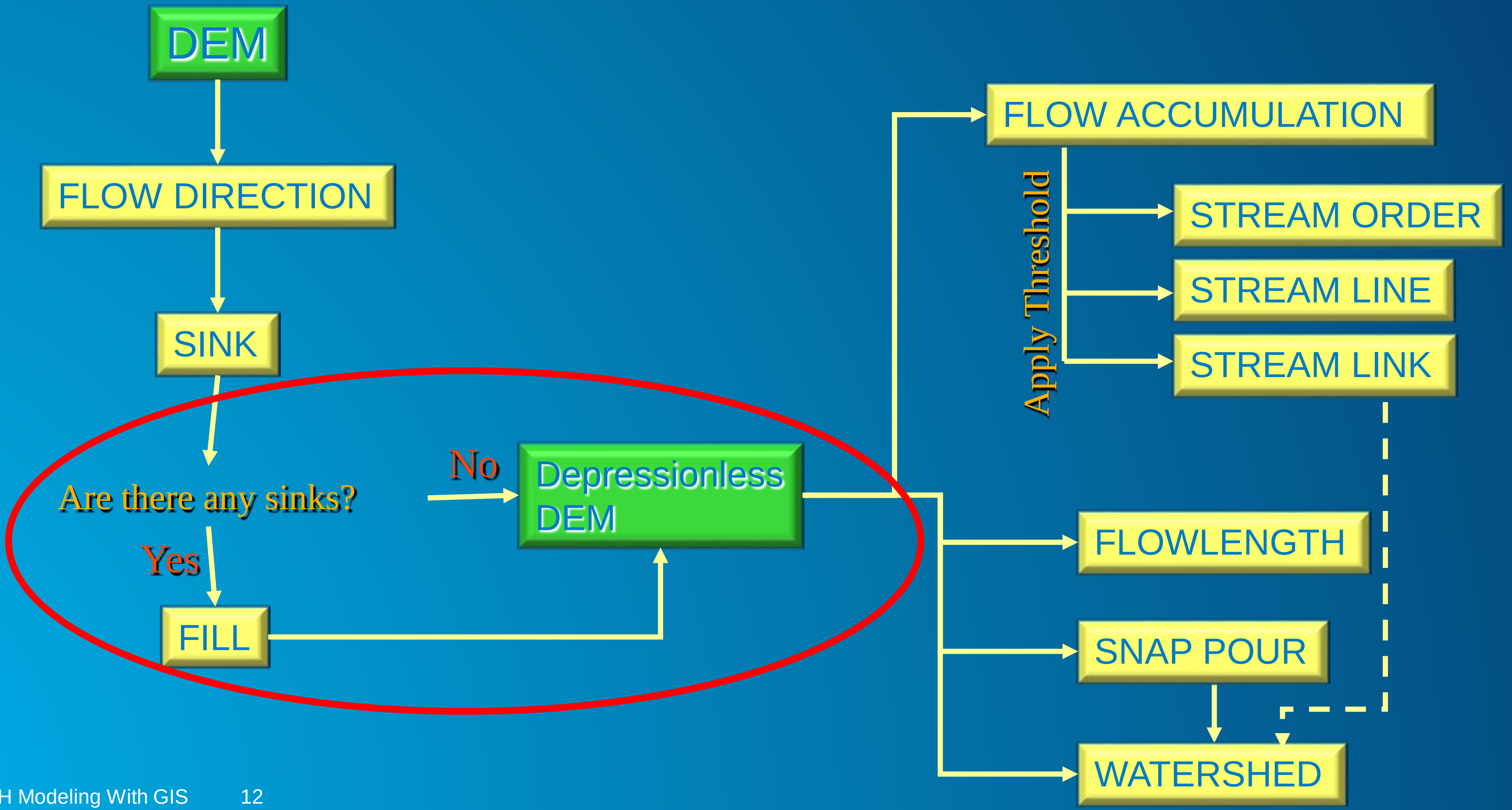
Core GIS Tools for Surface Water Analysis

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

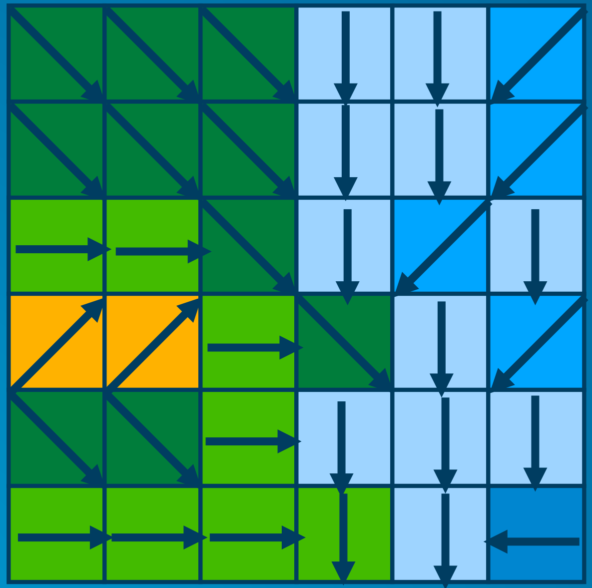
2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

Flow Direction

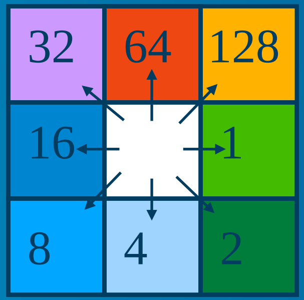
32	64	128
16		1
8	4	2

Direction Coding

Flow Accumulation

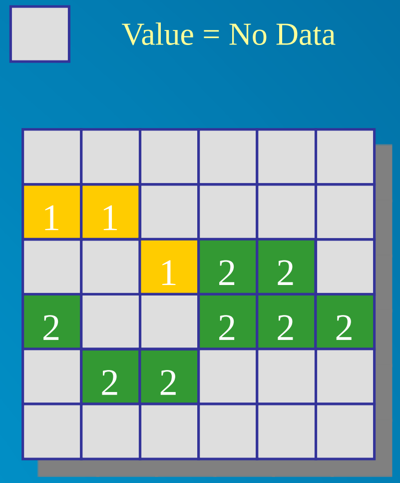


0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

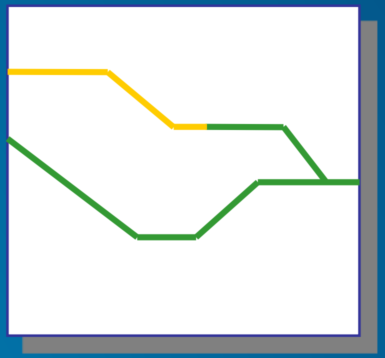


Direction Coding

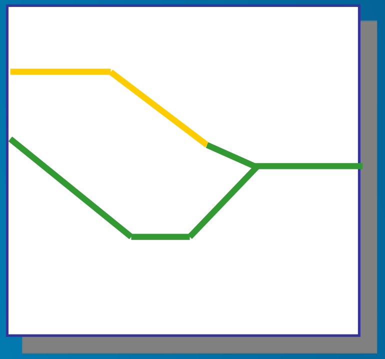
Creating Vector Streams



NET_GRID



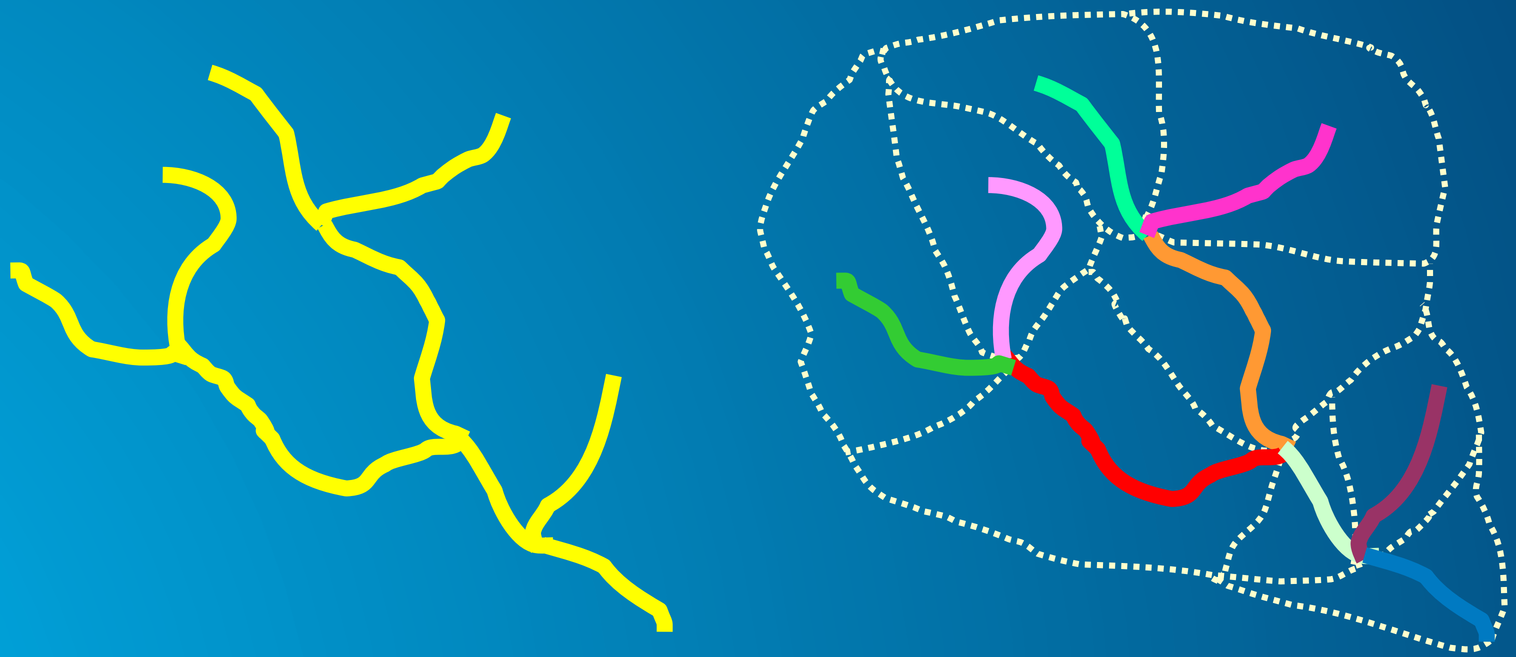
StreamToFeature



RasterToFeature

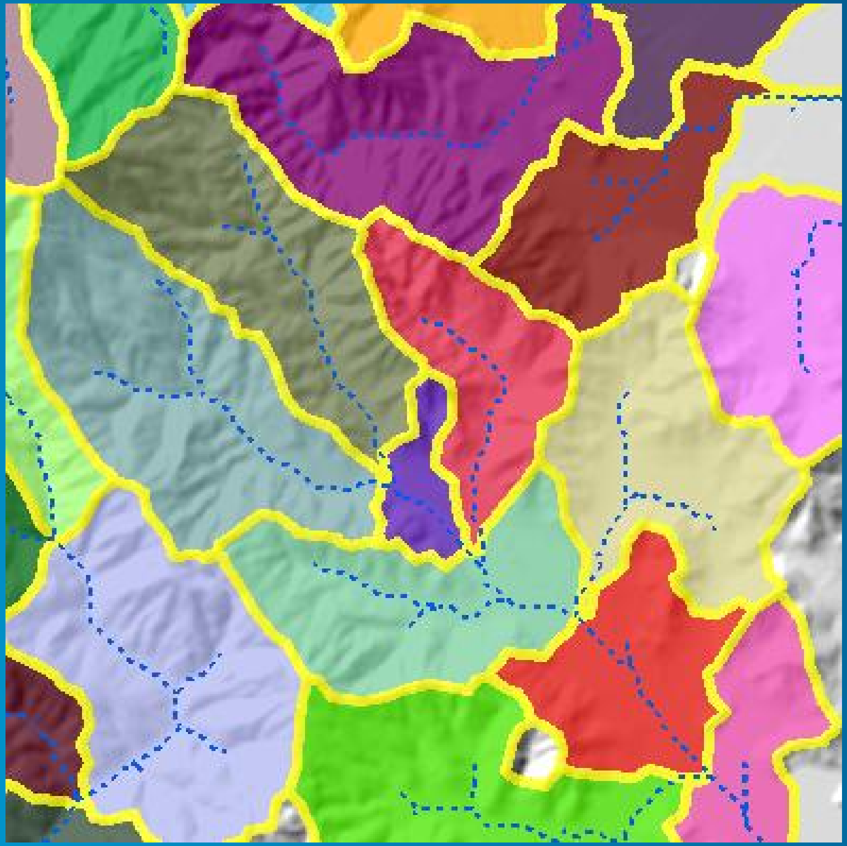
Stream Link

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



Watershed, subwatershed, drainage area

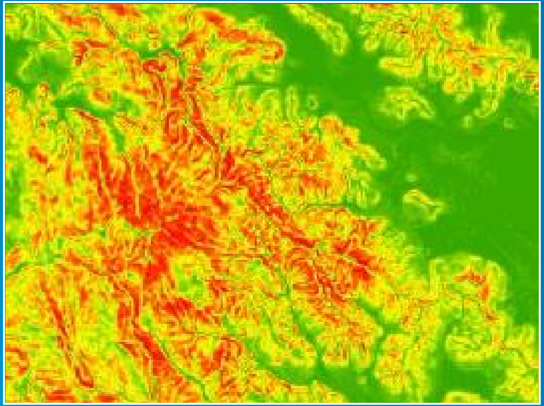
- Delineate the contributing area to a cell or group of cells.



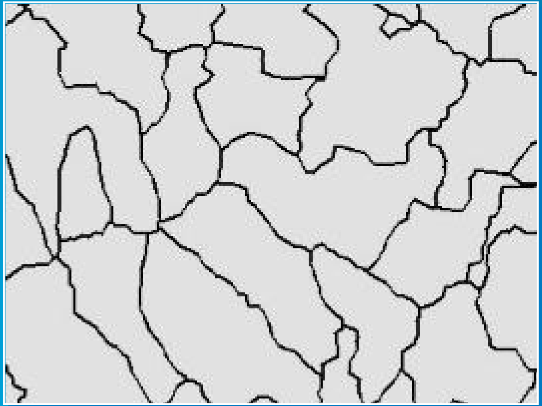
Summarizing Watershed Characteristics

- **Using Zonal Statistics**

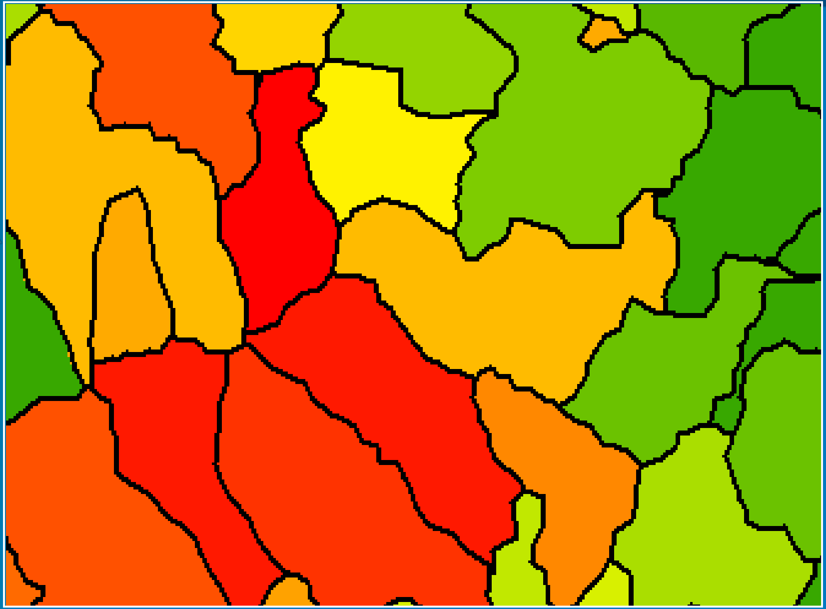
Slope



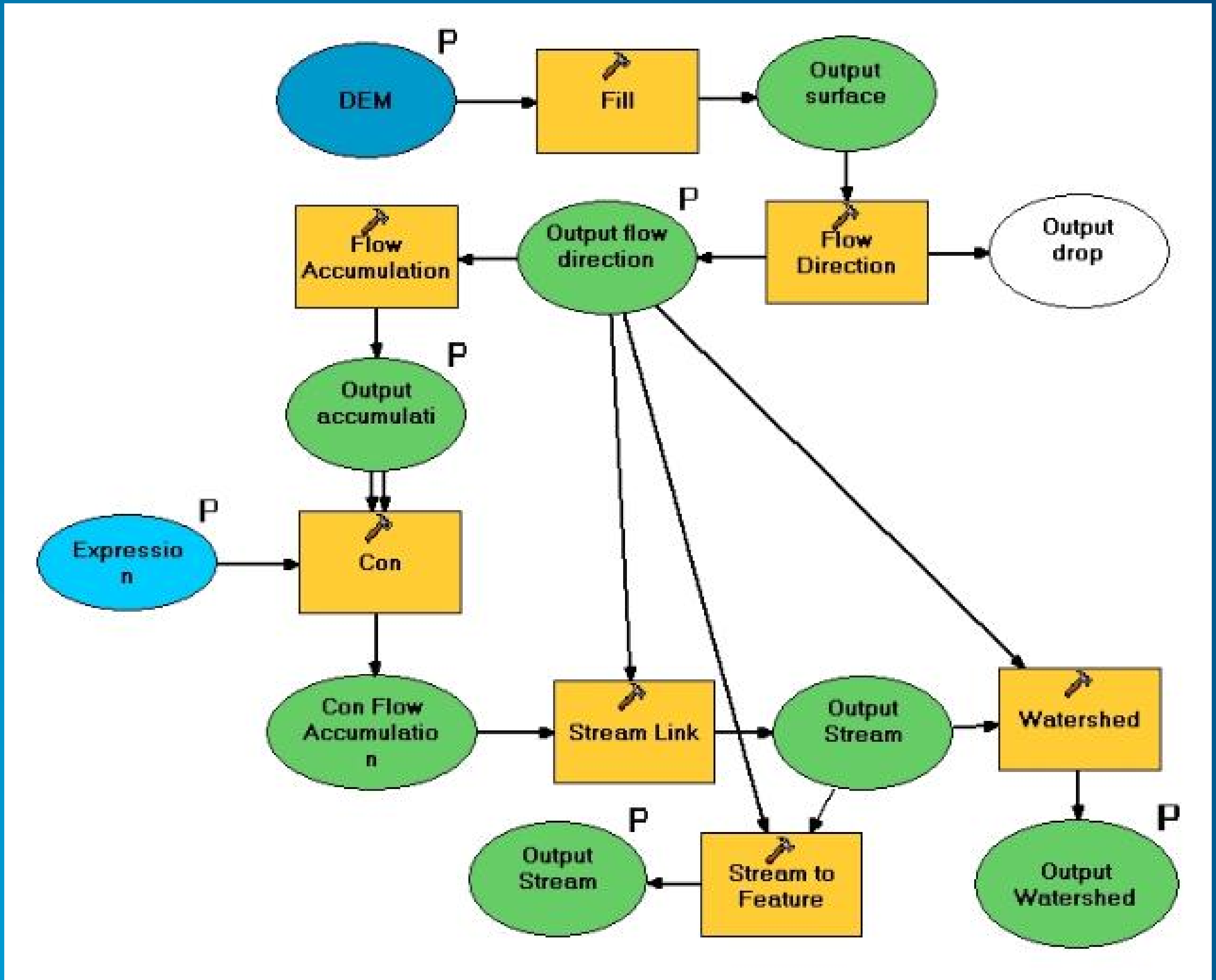
Watersheds



Mean Slope per Watershed



Using the Tools in the Model Builder

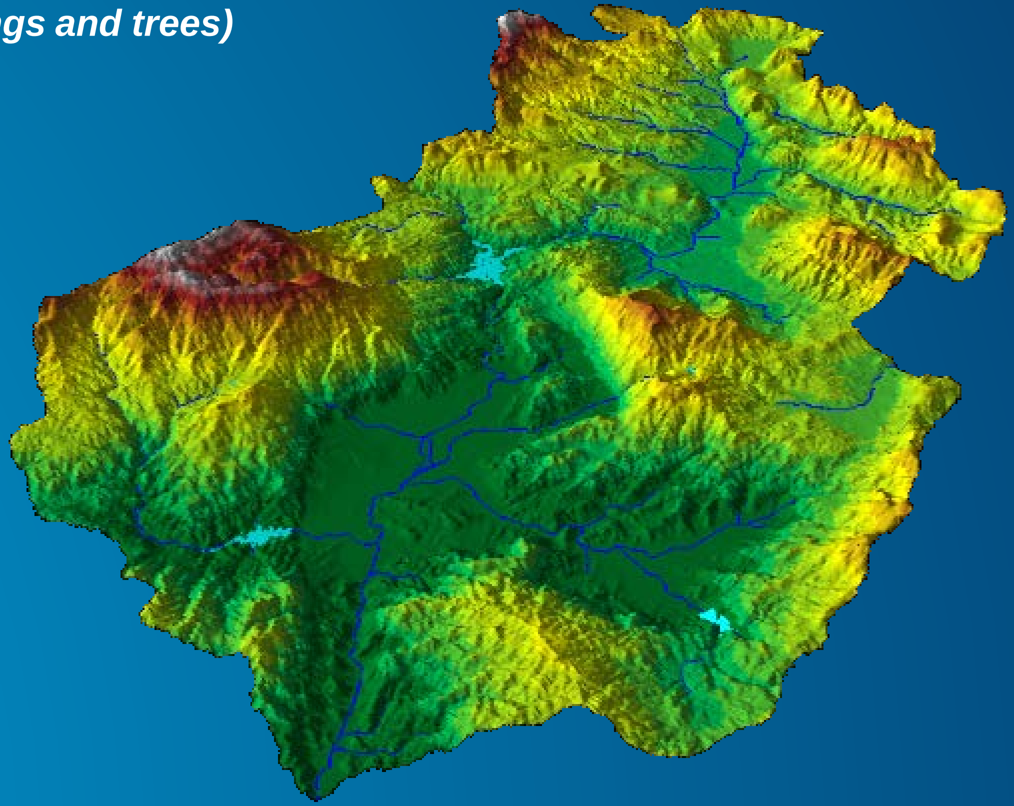


DEM Data and Processing

Elevation Data – Key Dataset

- **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

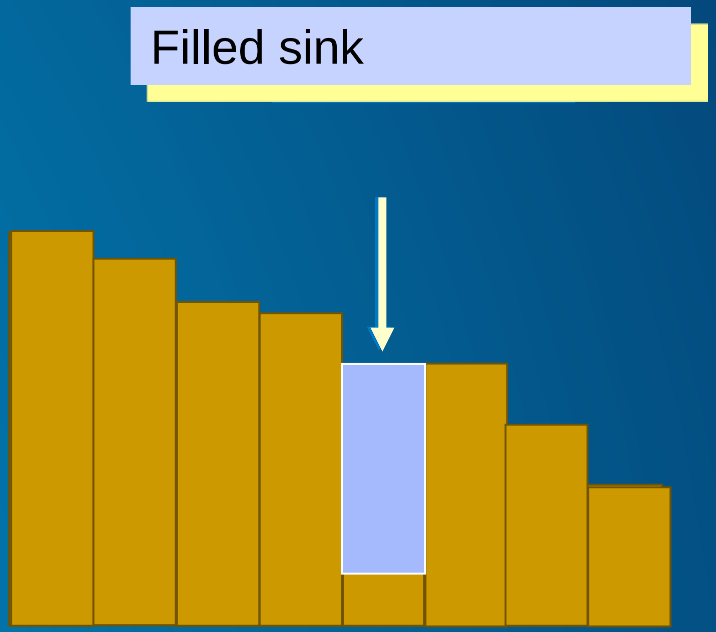
- What cell size and accuracy?
  - Horizontal and Vertical resolution must be appropriate for the landscape and scale being modeled.

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
  - Or specialized packages such as ANUDEM

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.)

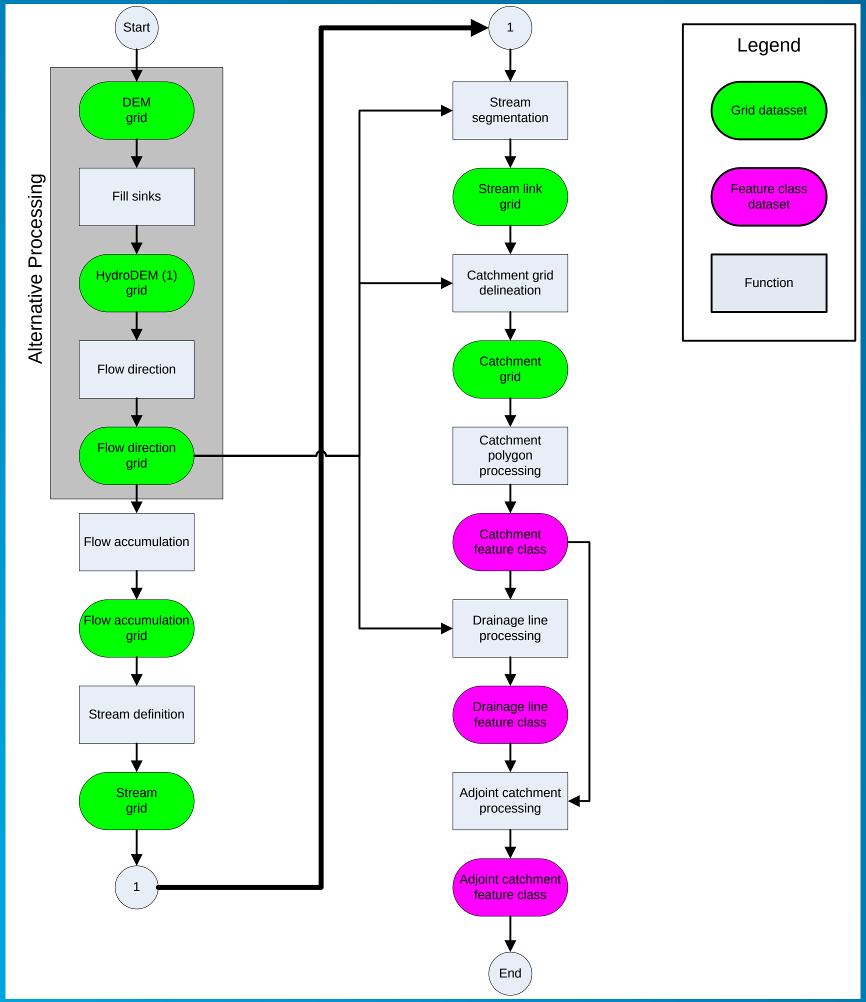
- Watersheds—When watershed boundaries are not where they “should” be
  - To fence or not to fence
  - Ineffective flow areas

What If You Do Not Have Dendritic Morphology?

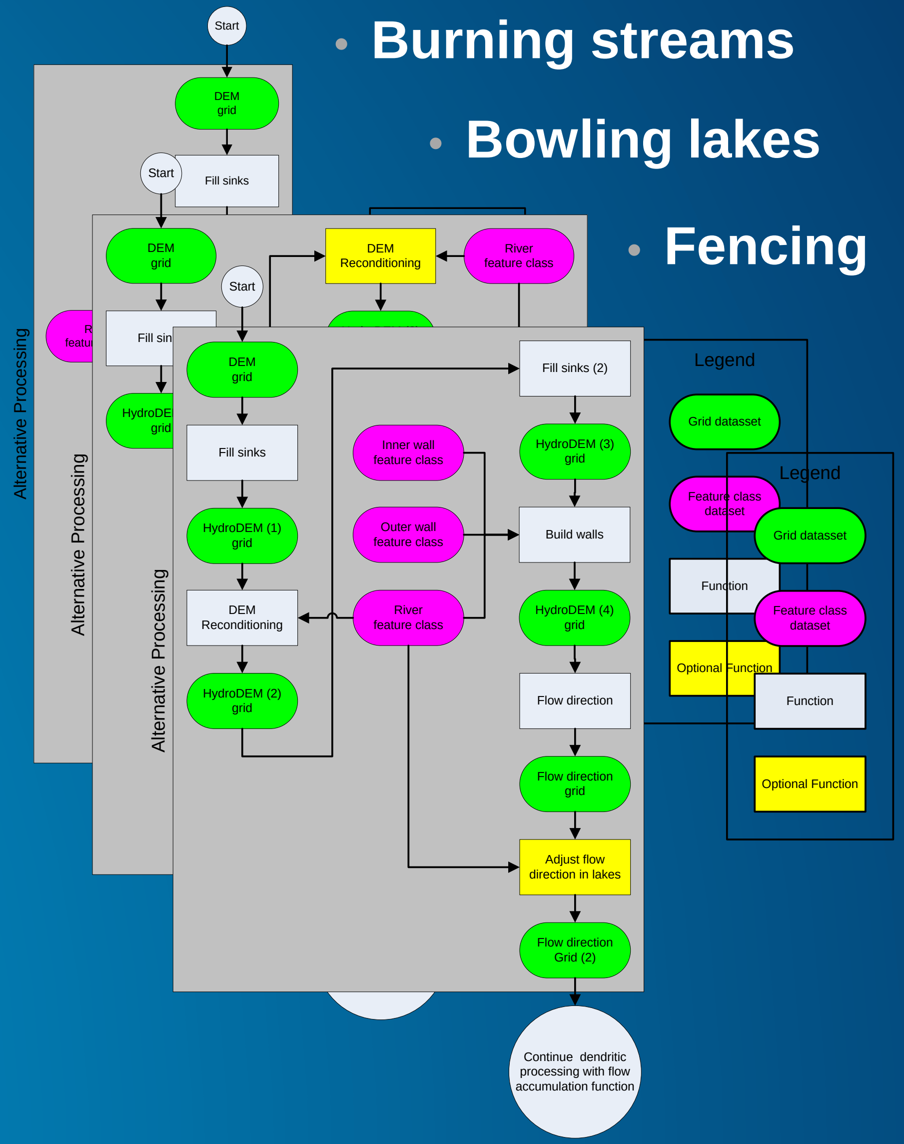
- Arc Hydro tools for terrain preprocessing:
  - Modified dendritic process
    - Burning streams
    - Fencing boundaries
    - Bowling lakes
    - Flow splits
  - Deranged terrains
    - Selective filling of sinks
    - Streams draining into sinks
  - Combined dendritic/deranged

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

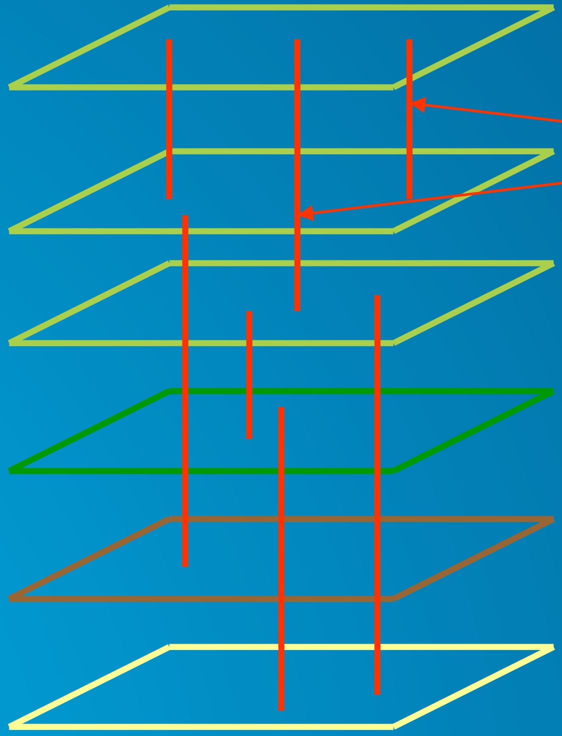
Data Model Purpose

- Target audience: Water resources community interested in quick start in ArcGIS implementation
- 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.

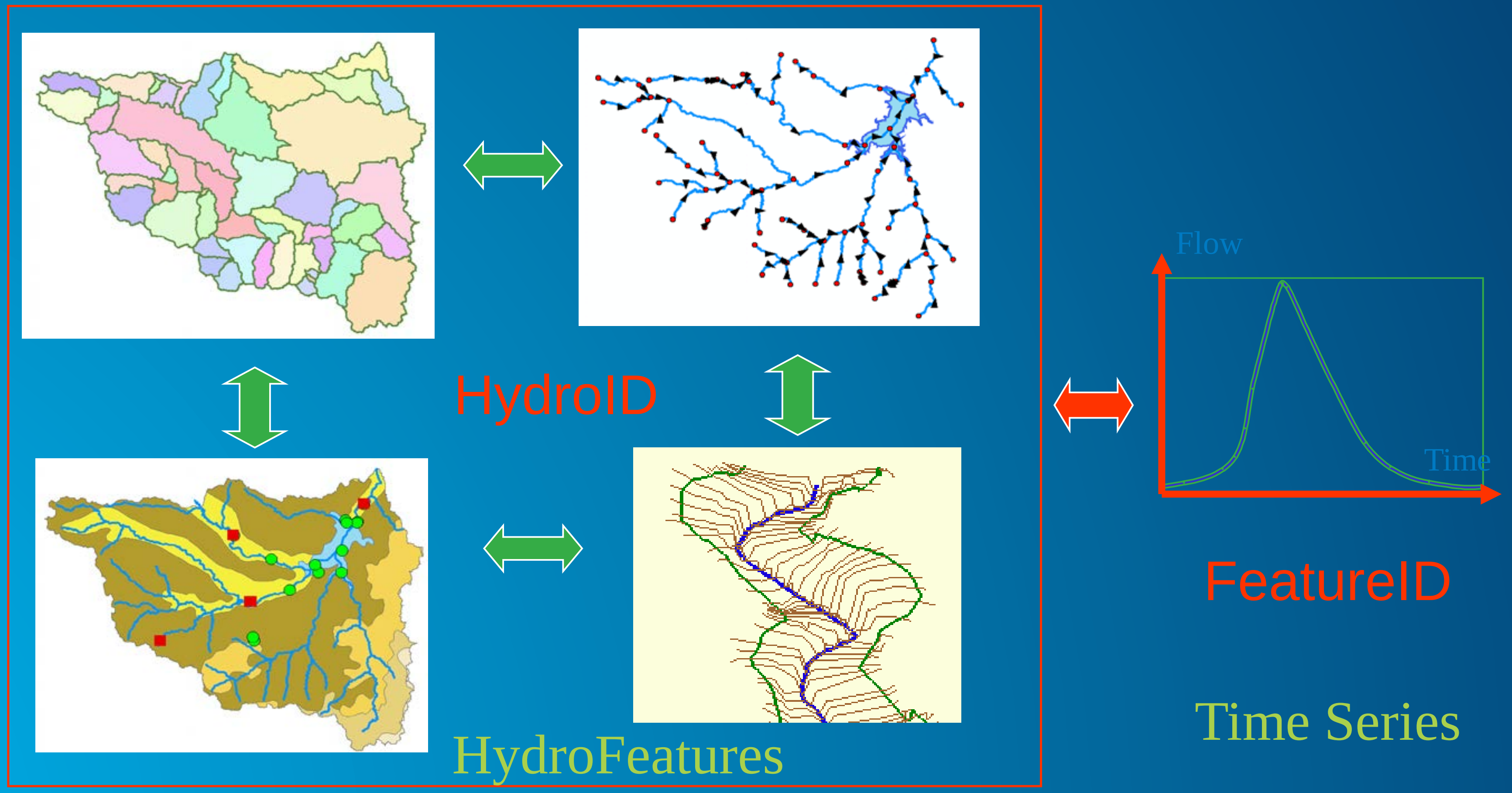


HydroID to ID relationships link neighboring features and help to trace water movement.

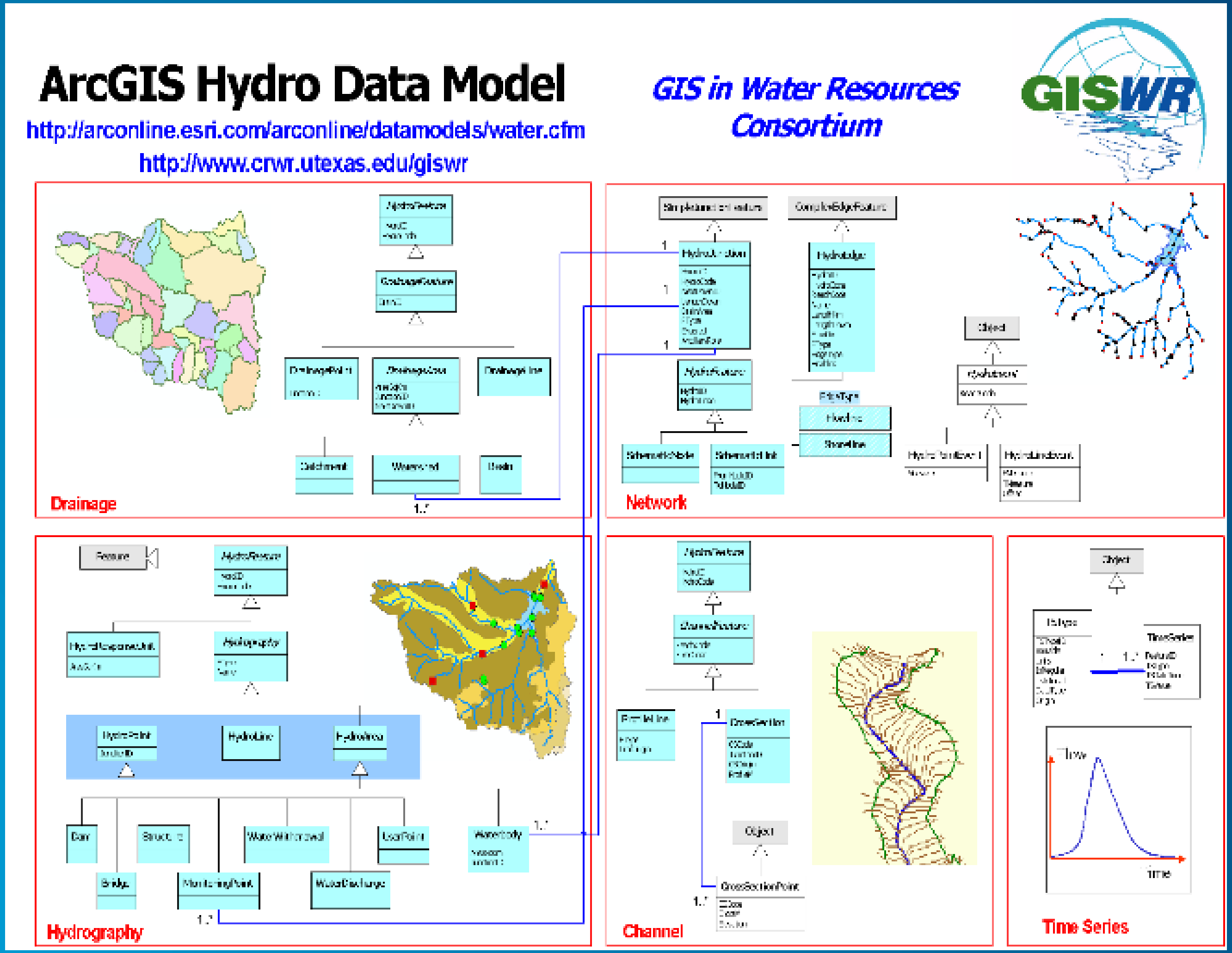
Arc Hydro is a unique "flavor" or style of doing GIS.

What makes Arc Hydro different?

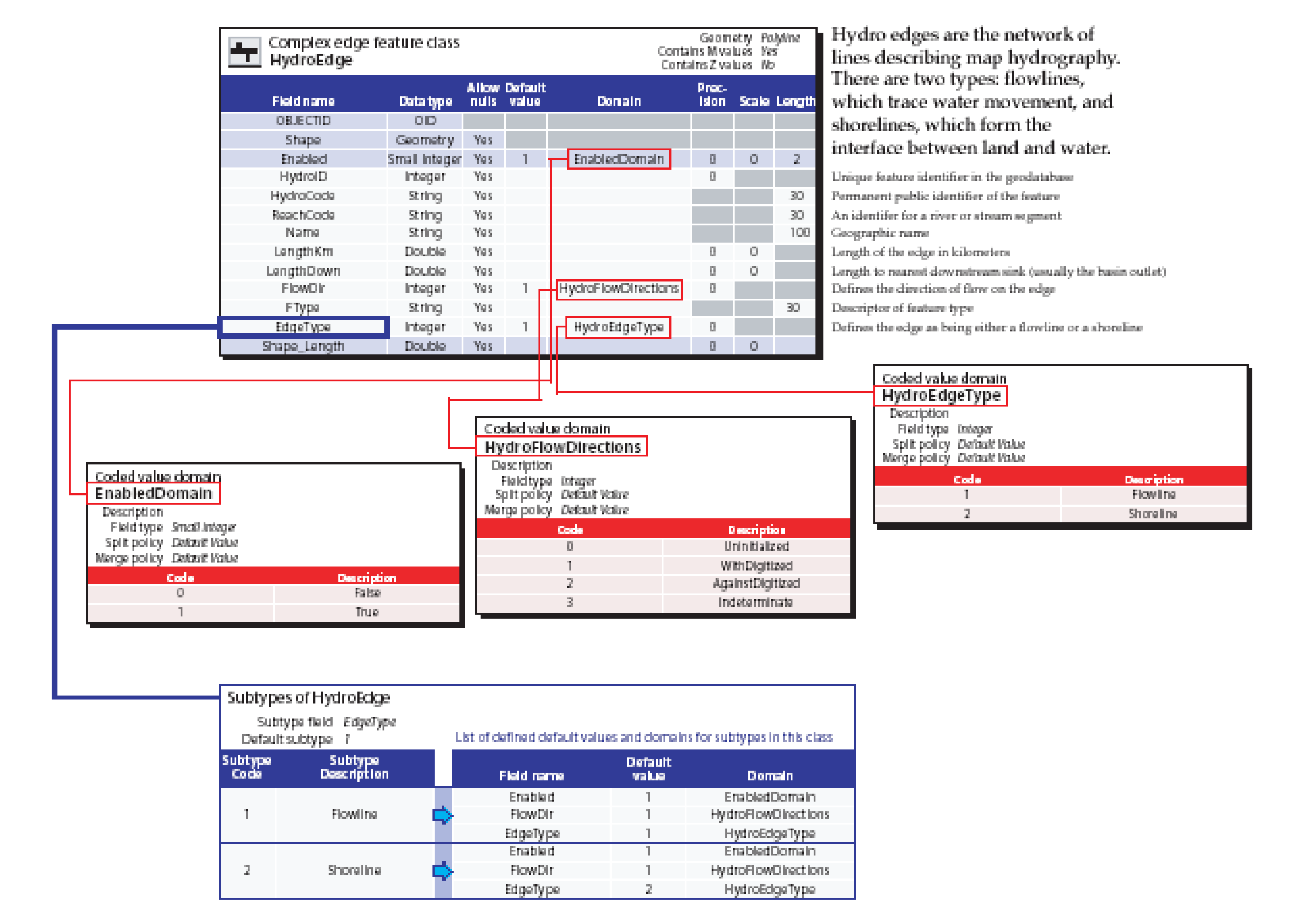
Arc Hydro connects space and time:
HydroFeatures are linked to time series.



Arc Hydro Data Model



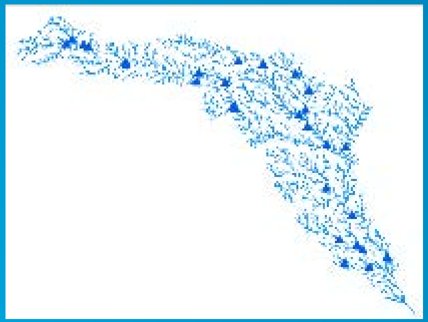
Arc Hydro Data Model Details

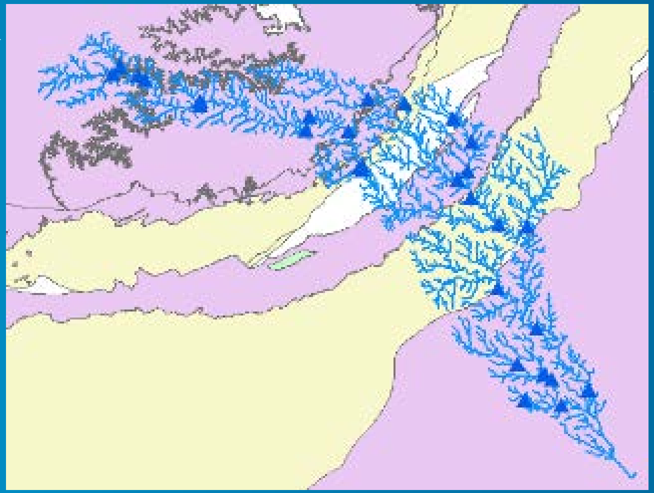


Integration of Surface Water and Groundwater Data

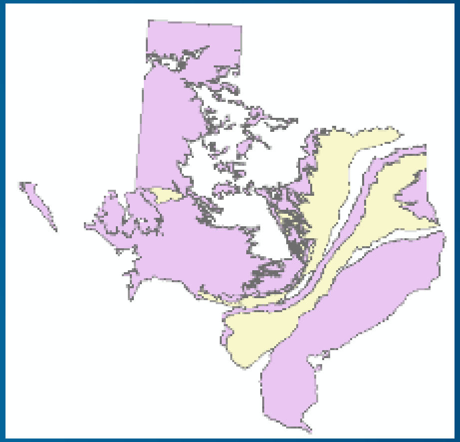
- **Describe the relationship between surface water features (e.g., streams and water bodies) with groundwater features (aquifers, wells).**

Hydro network





Aquifers



What are Arc Hydro Tools?

- A set of freely available 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 (230) + 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?

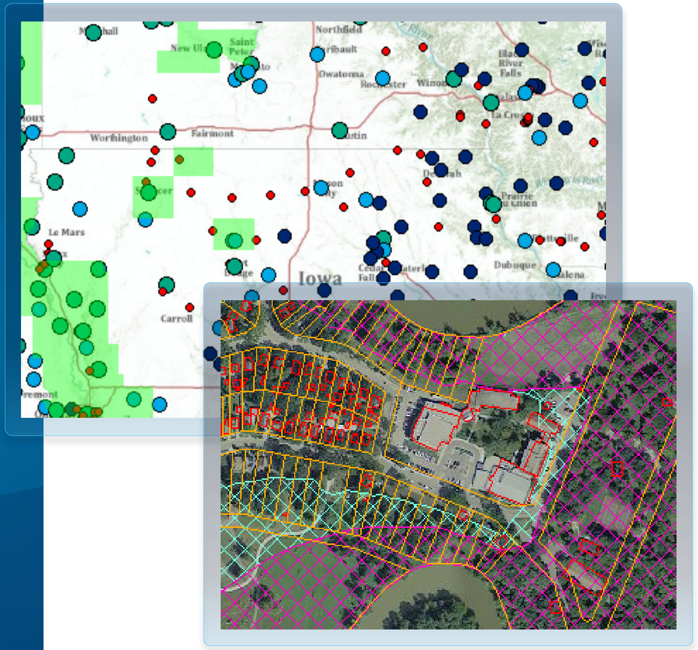
- Economy of development
  - Why reinvent the wheel?
  - Established configuration methodology
  - Established development framework
- Industry “standard”
  - Established techniques rolled into a publicly available utility
- Training and support
- Free maintenance – ESRI’s commitment to the water resources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

Arc Hydro Tools Documentation

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

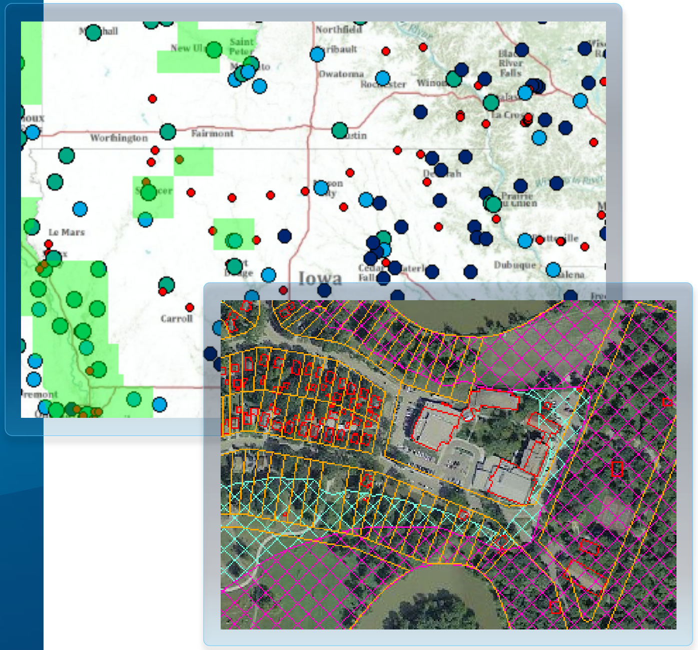
Demo

Arc Hydro



Demo

World Watershed Delineation and Tracing Services



Hydrologic and Hydraulic Modeling Support with GIS

How “Things” Build Up

- Database design
- Data preparation
- Terrain preparation
- “Watershed” delineation
- “Watershed” characterization

Generic

(Arc Hydro)

- Parameterization

Semigeneric

- Model pre- and post- processing

Model Specific

Section Overview

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

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)

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.

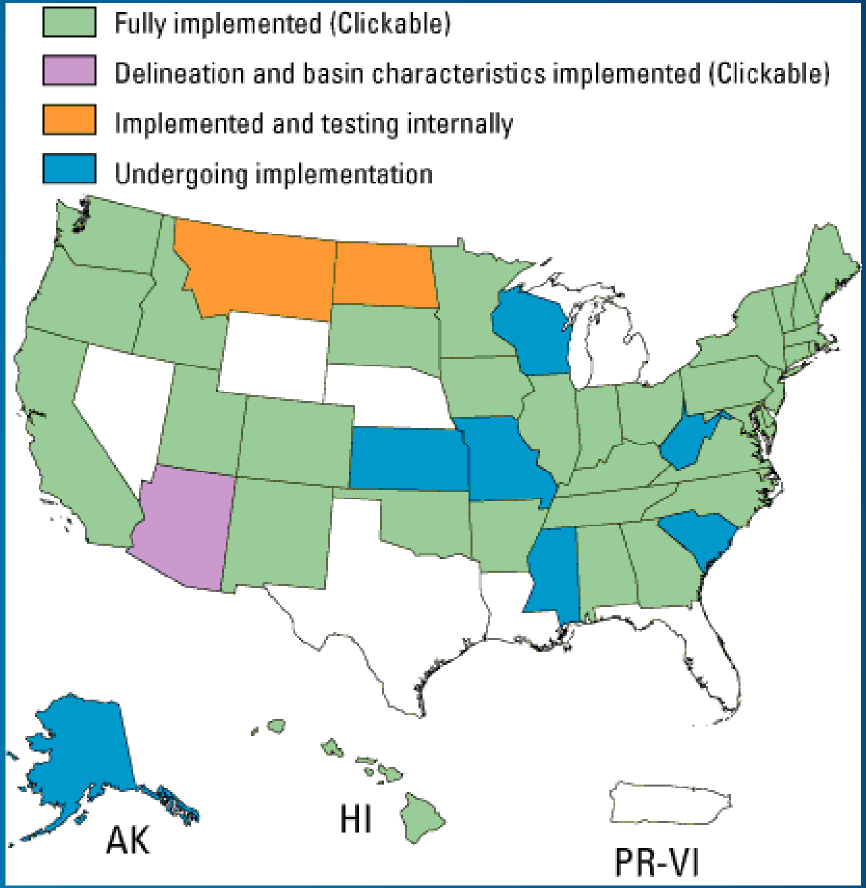
Arc Hydro Tools Role

- 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

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

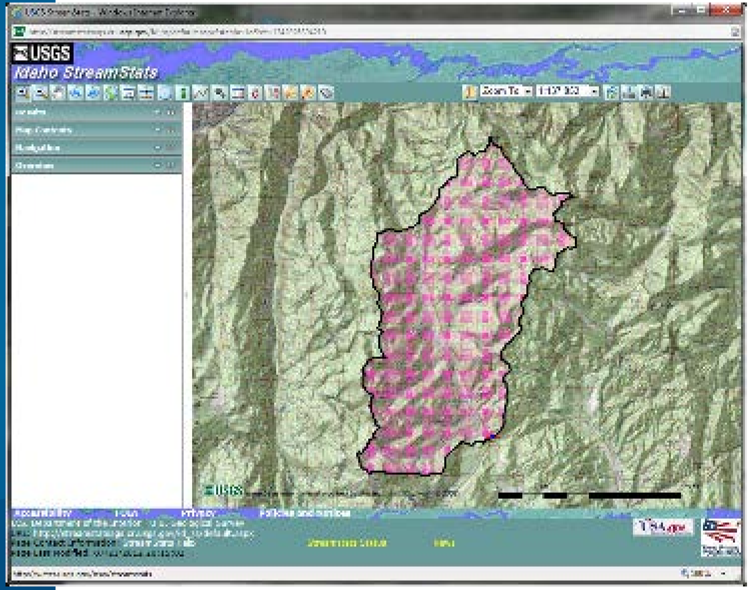
July 2013 July 2014 July 2015



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

Demo

Streamstats



H&H Integration Overview

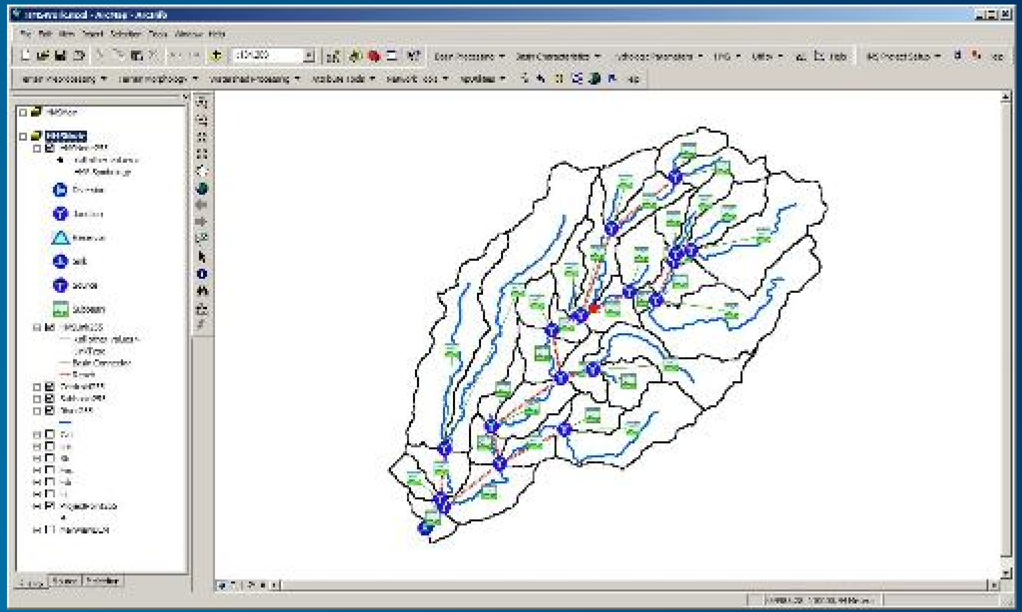
(HMS-RAS Focus)

Role of GIS

- Develop hydrologically correct DEM and derivatives.
- Develop integrated drainage system.
- Summarize terrain and hydrologic characteristics of the watershed for input to a model.
- Summarize terrain and hydraulic characteristics of the channel for input to a model.
- Post process hydraulic modeling results (water surface determination).
- Visualization and mapping.

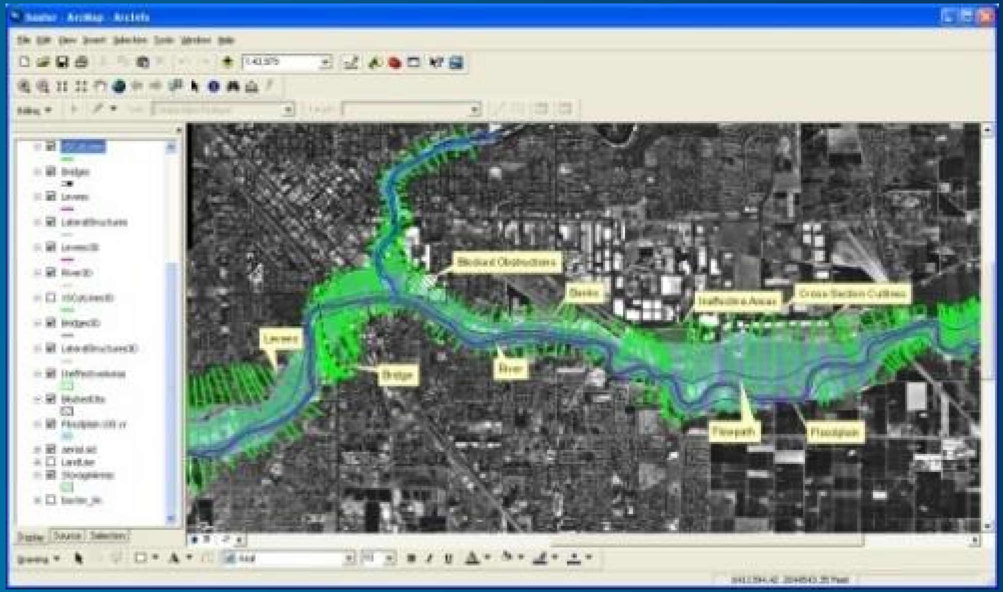
HEC-GeoHMS

- **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

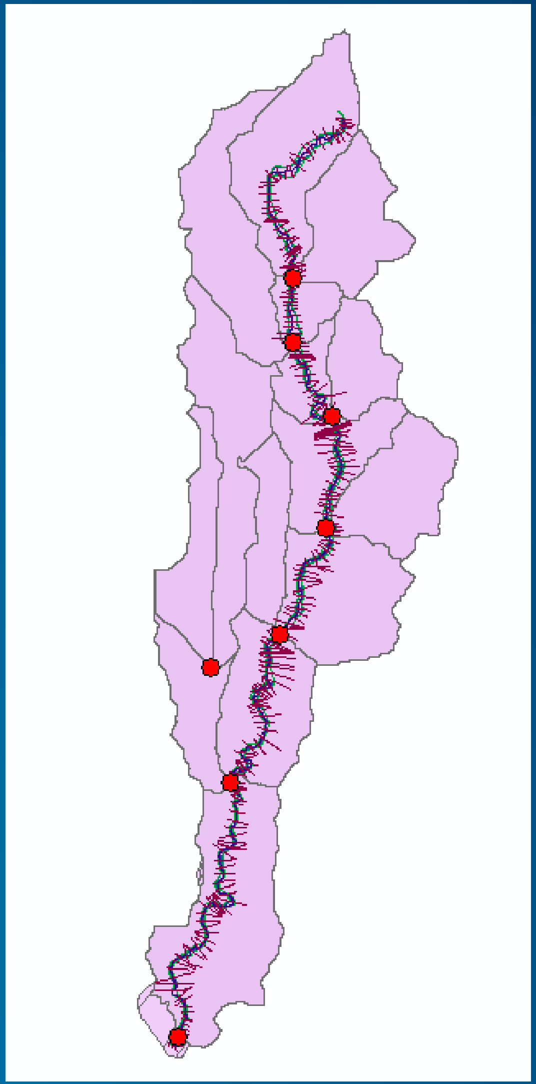


Integration Approach

- 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

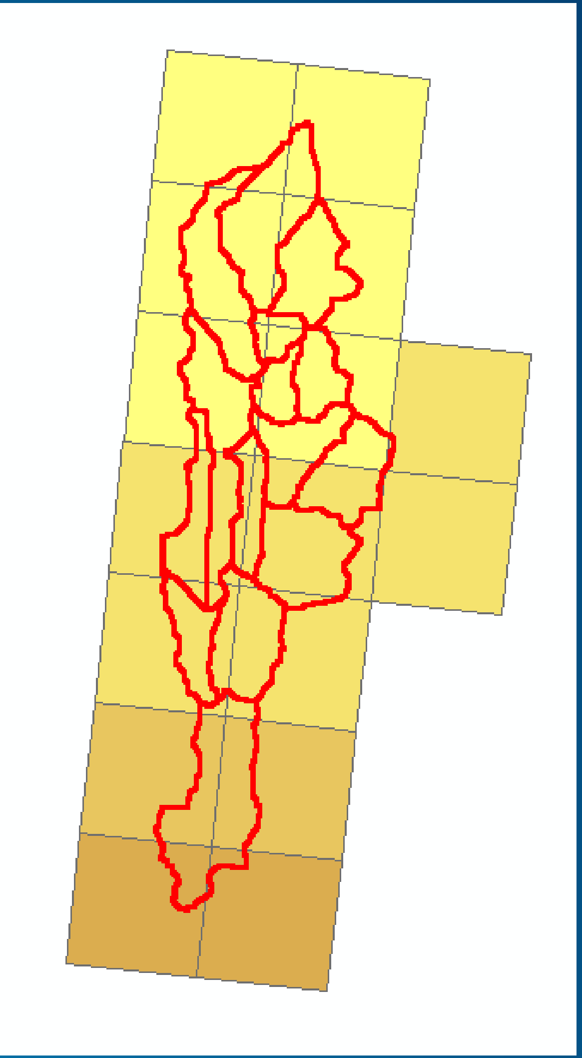
Integration Planning

- **Identify where outputs from one model (HMS) become input to the second one (RAS).**
  - **Flow exchange points**



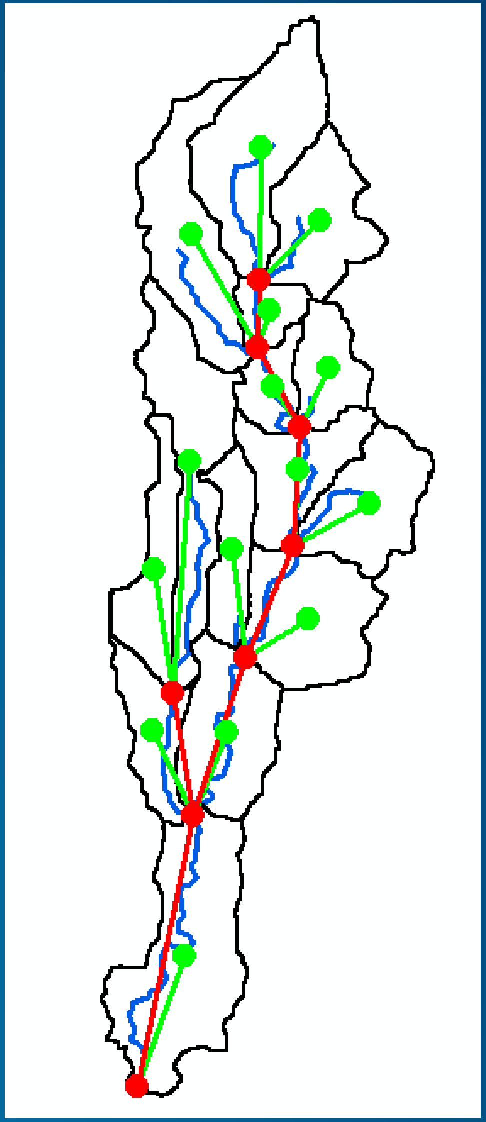
Precipitation Sources

- **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)**



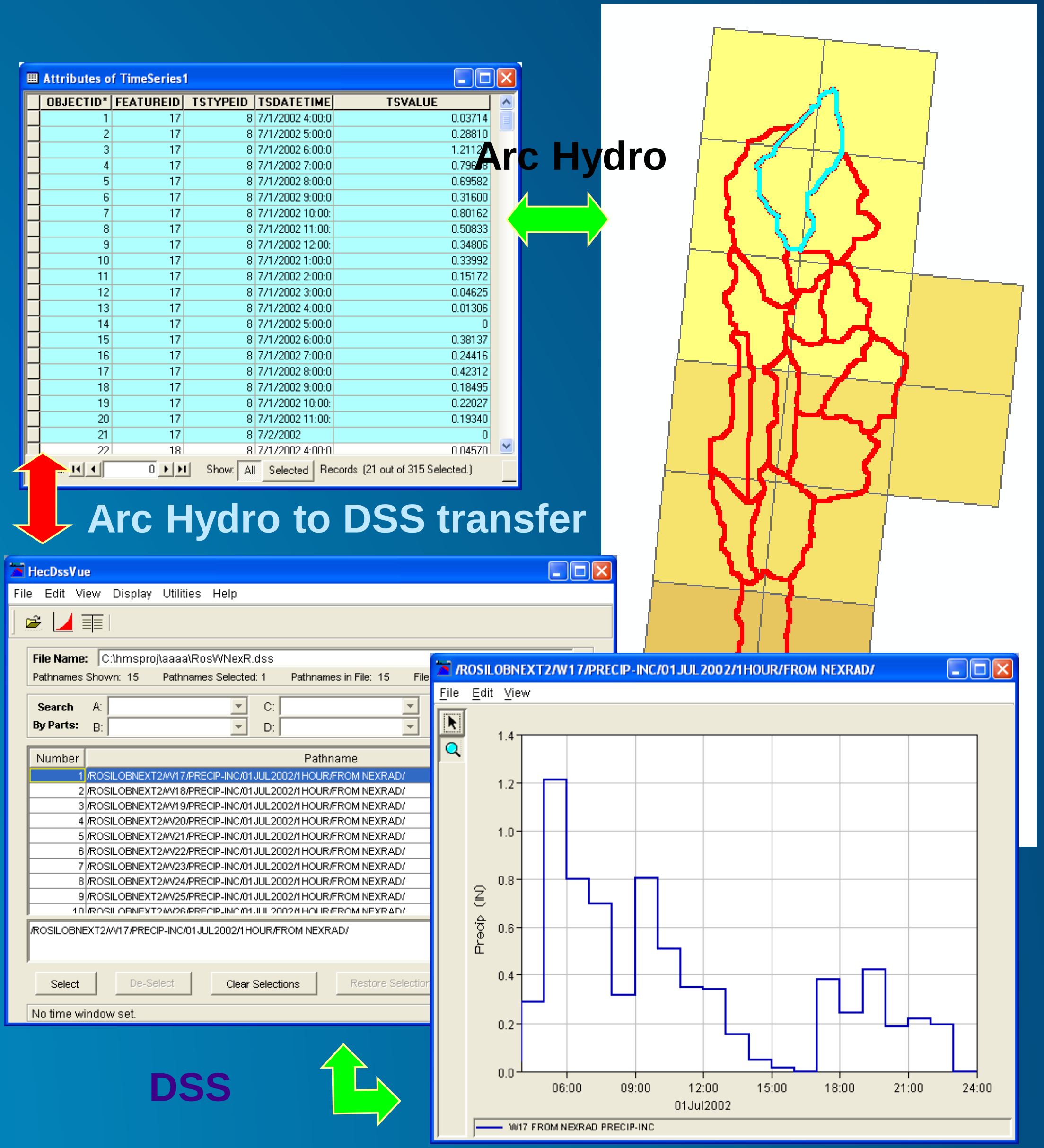
Develop GeoHMS Model

- 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



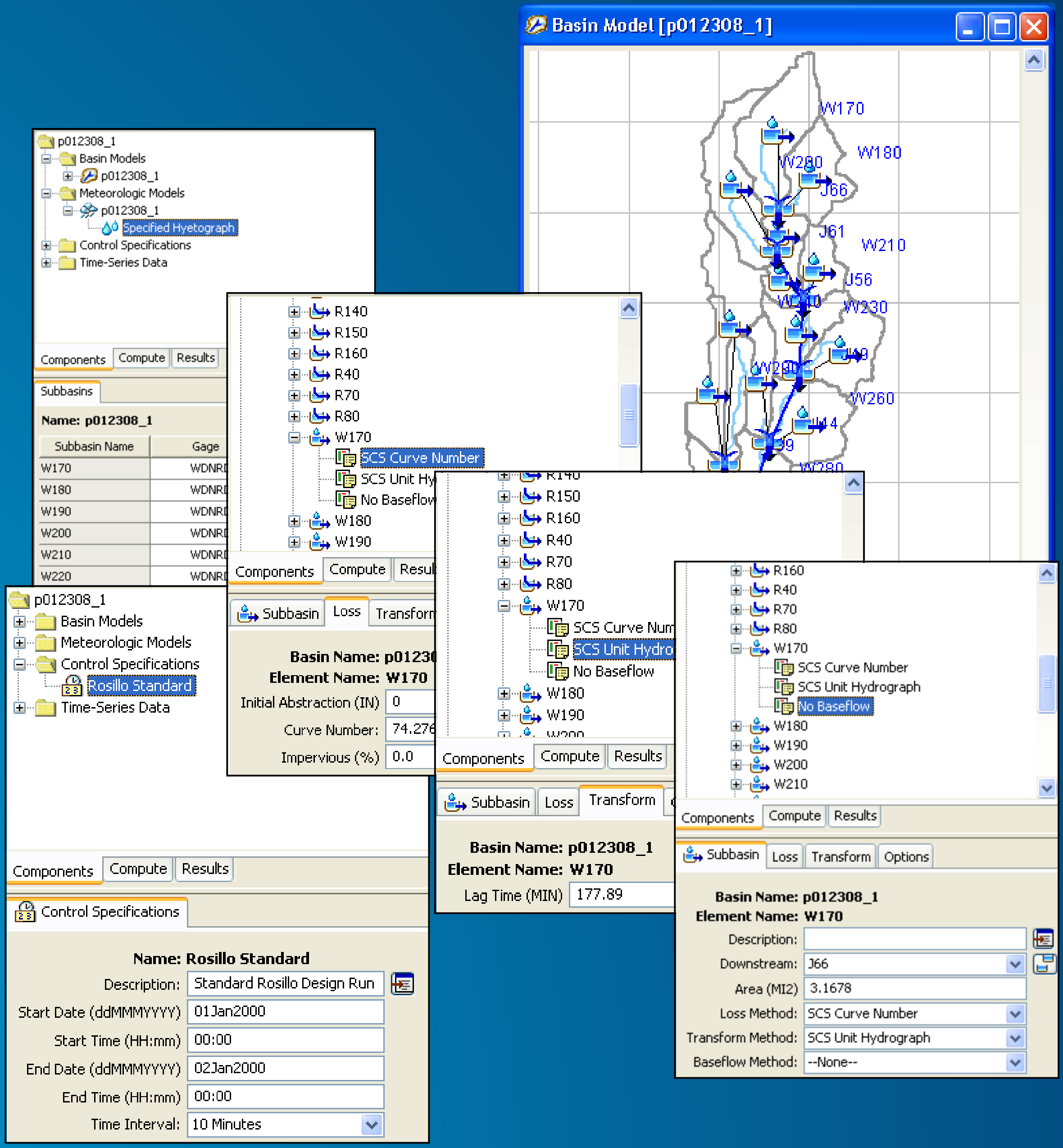
Meteorological Component

- **Develop a custom rain "gauge" for each subbasin or for each rainfall observation element with corresponding weights for subbasins.**



Finalize and Run HMS

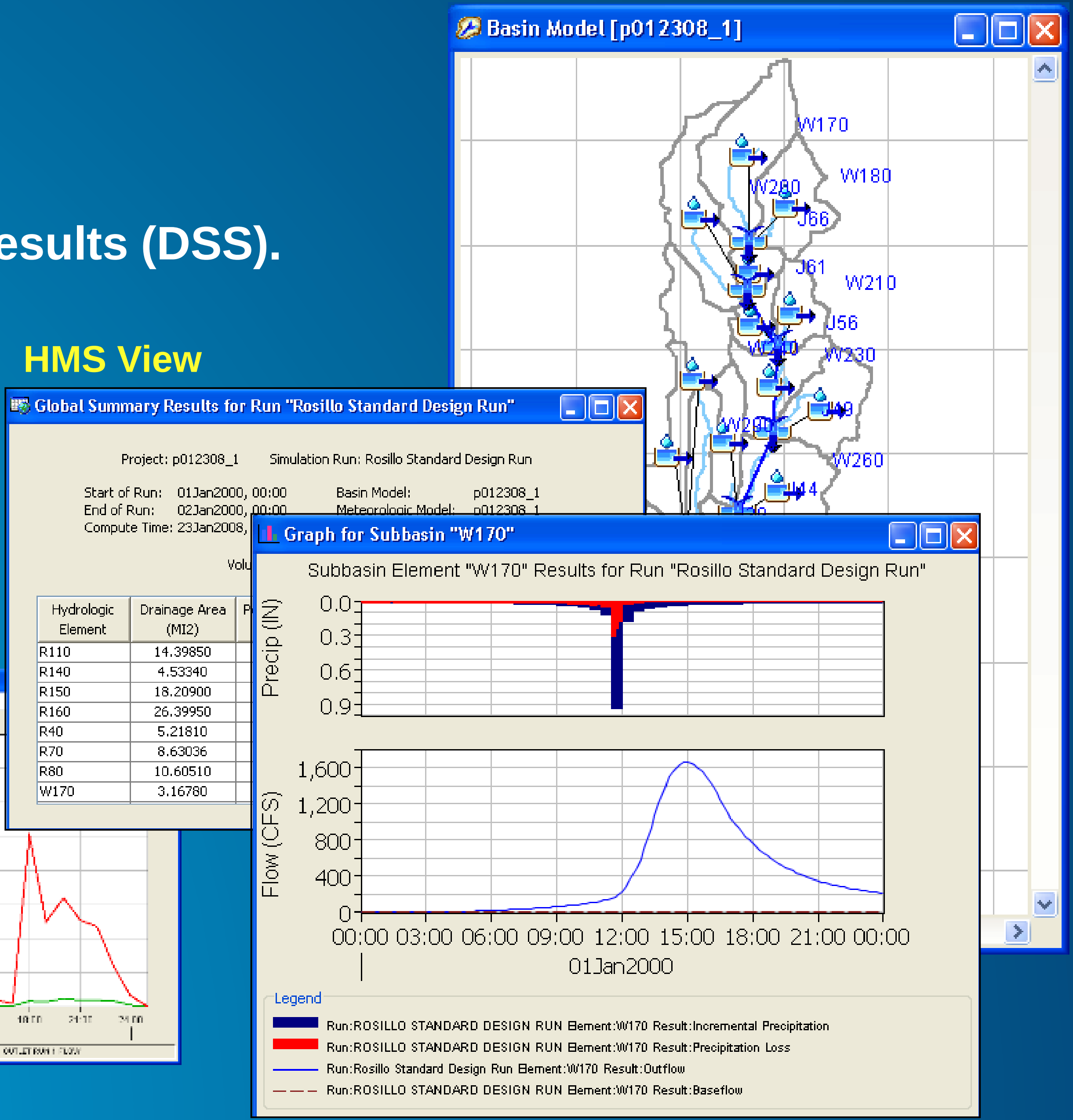
- **Complete HMS model with any additional parameters including meteorological model and control specifications.**



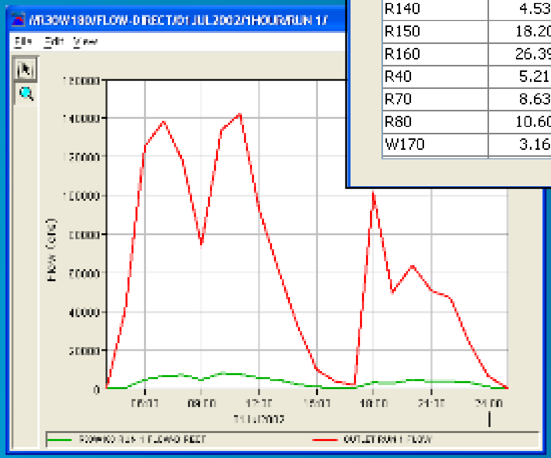
Finalize and Run HMS (2)

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

HMS View

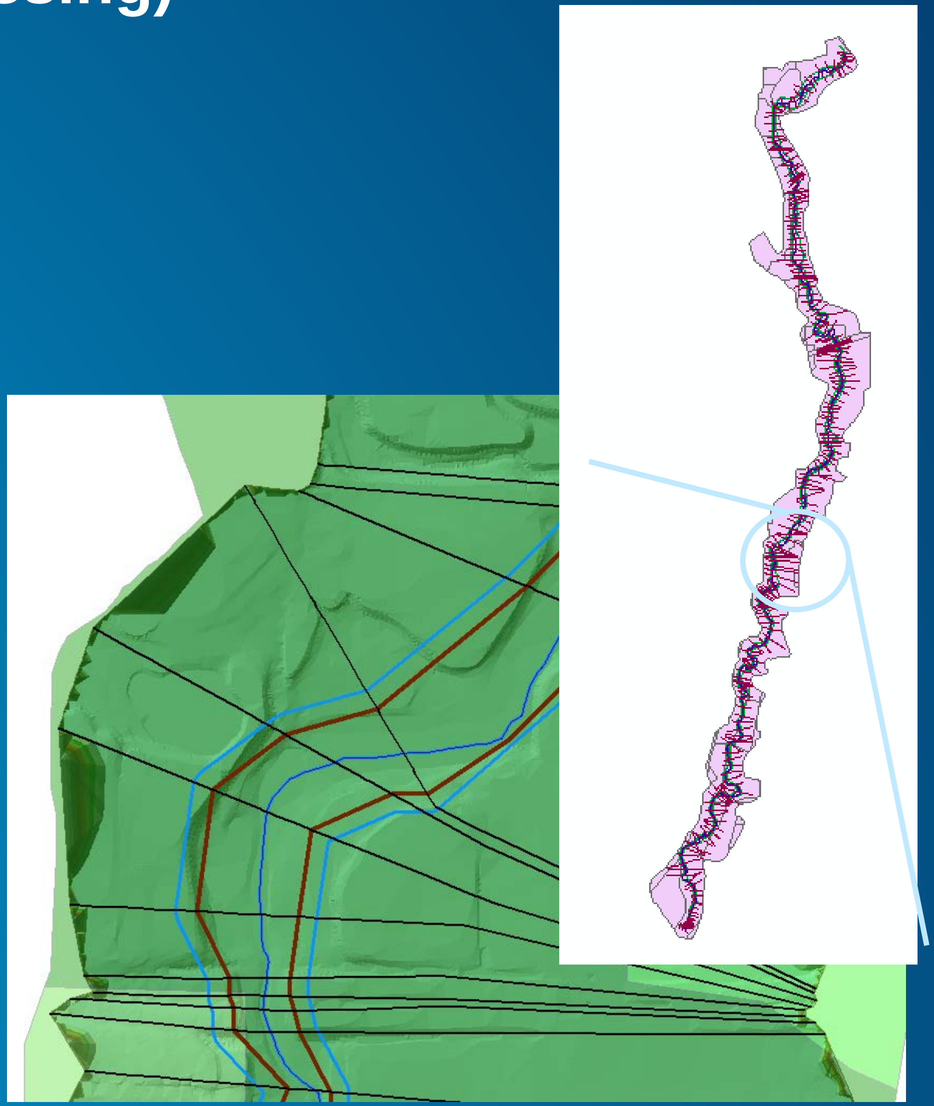


DSS View



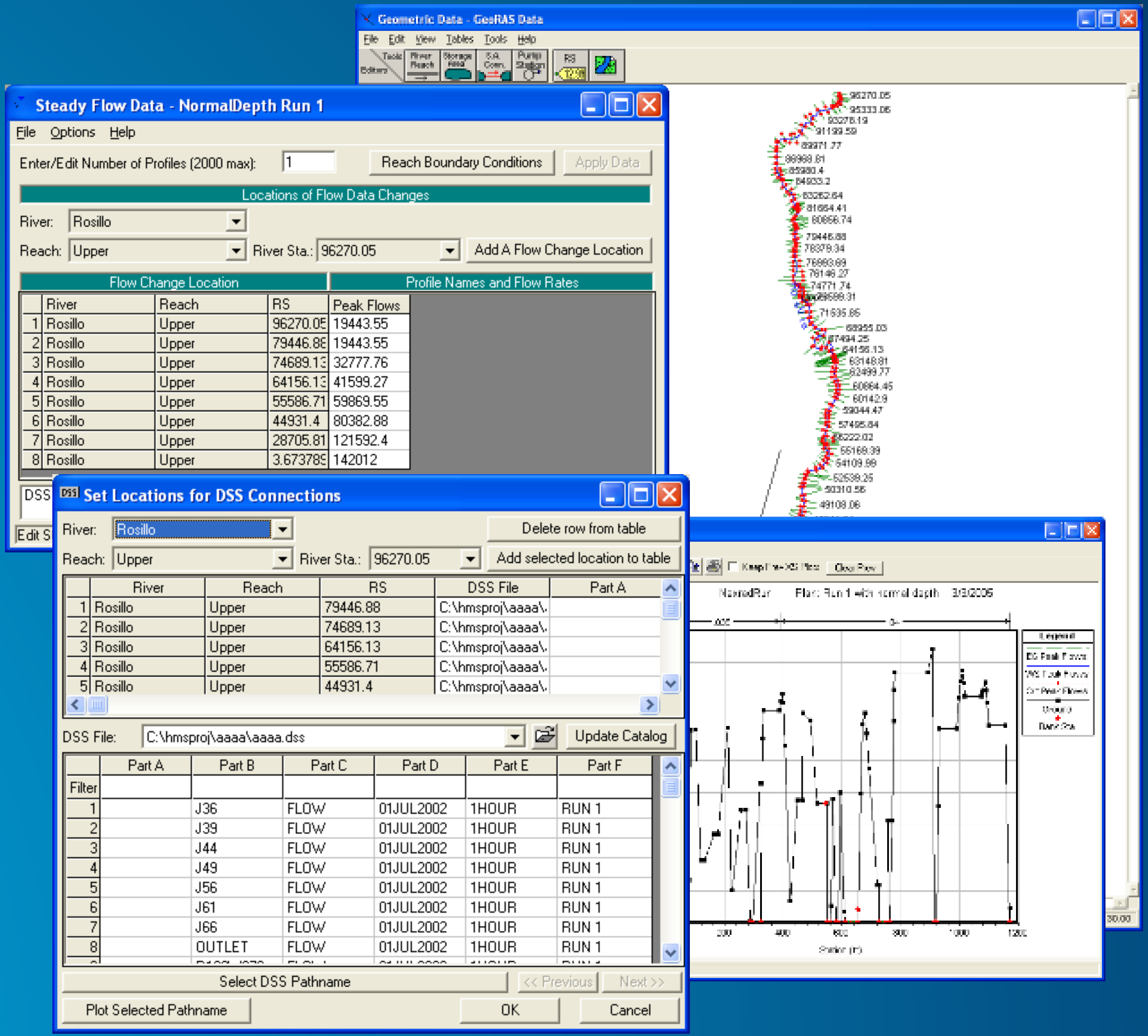
Develop GeoRAS Model (preprocessing)

- **Follow all principles in development of a hydraulic model for element placement (confluences, structures, …).**
- **In addition, take into consideration integration planning aspects developed earlier.**



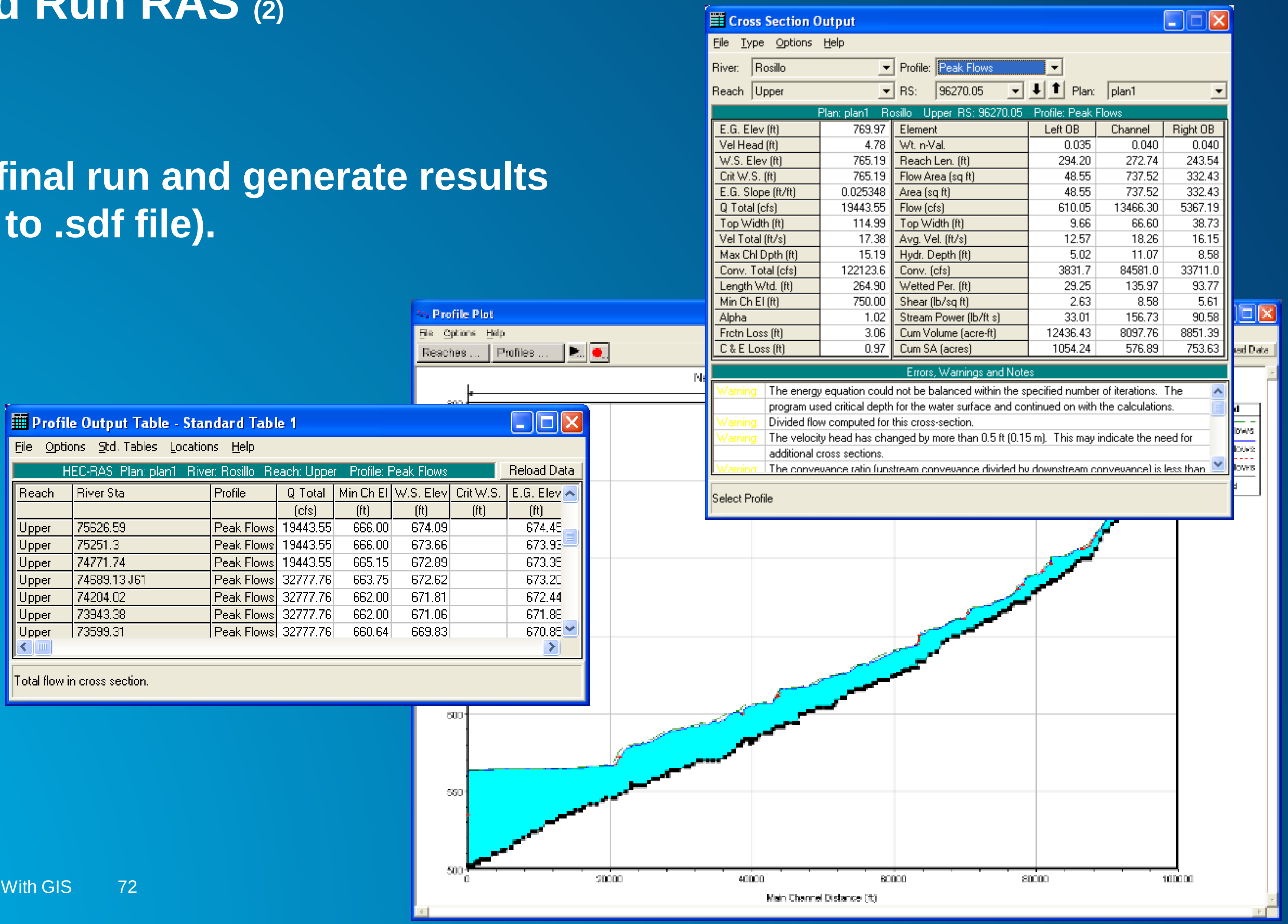
Finalize and Run RAS

- **Complete RAS model with any additional parameters including initial and boundary conditions.**



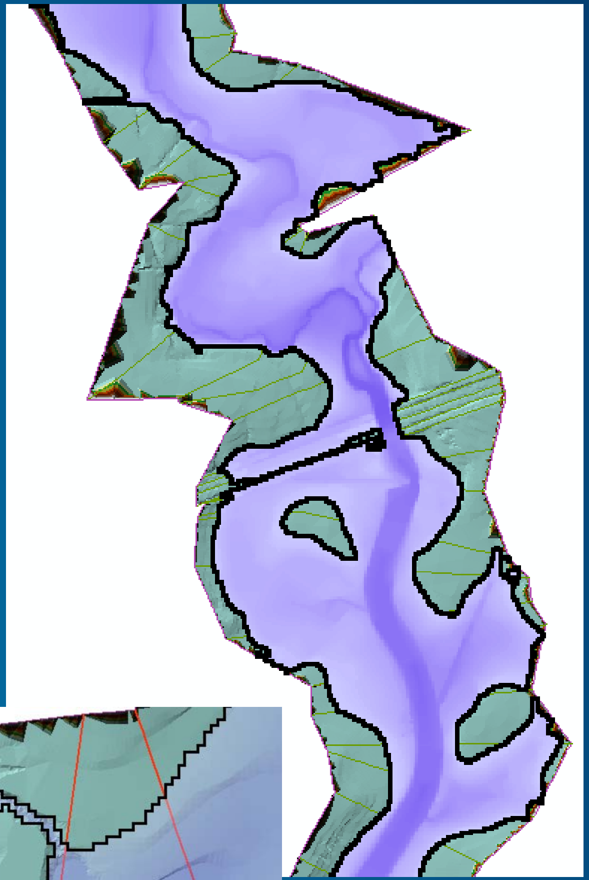
Finalize and Run RAS (2)

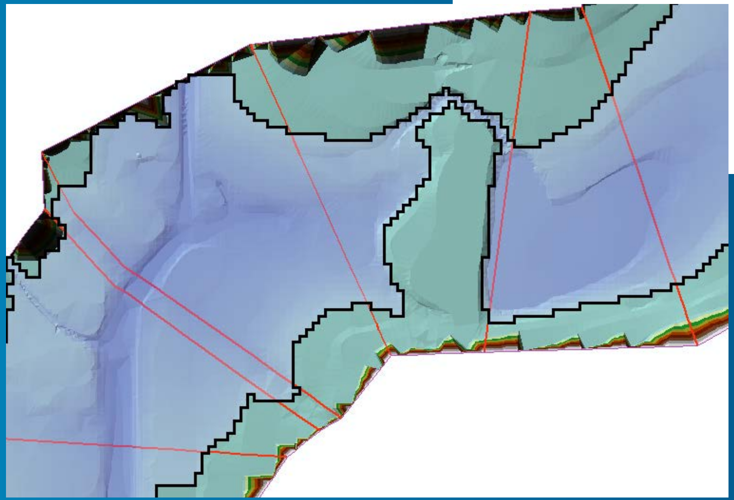
- **Do the final run and generate results (export to .sdf file).**



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.

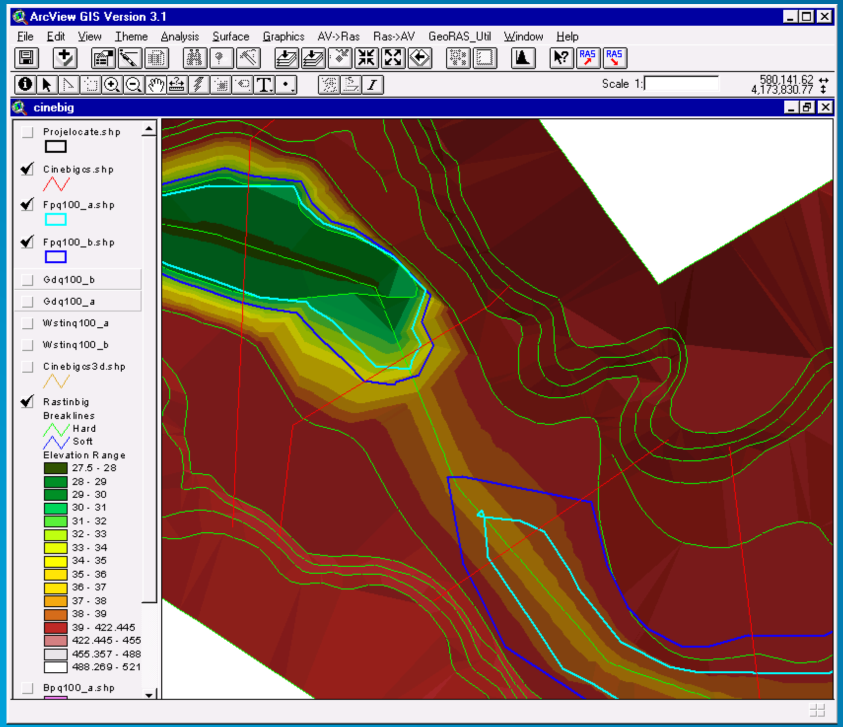


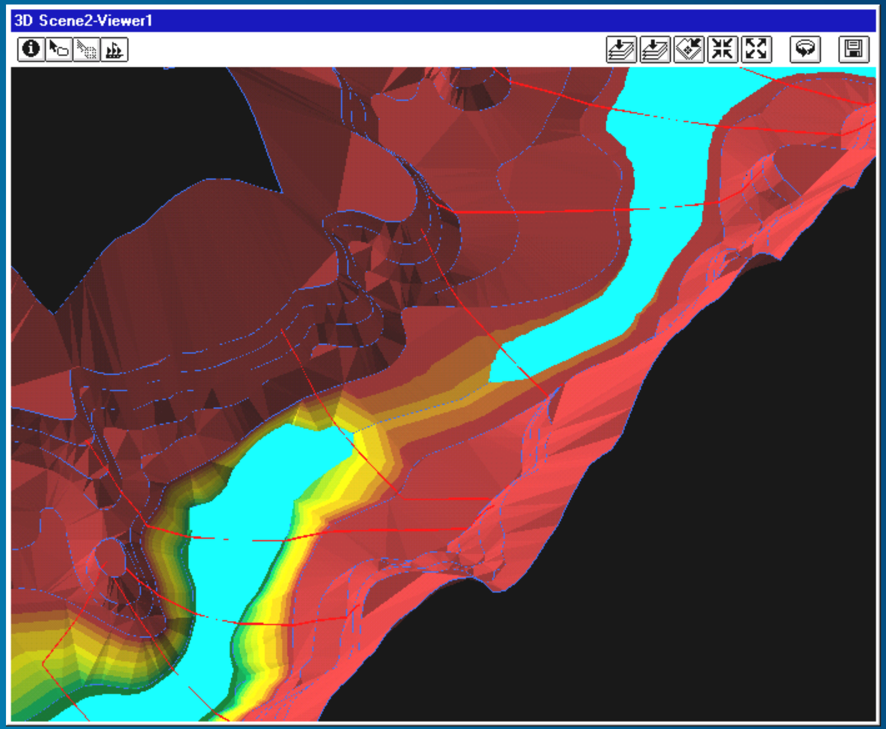


GIS–HMS–RAS Feedback

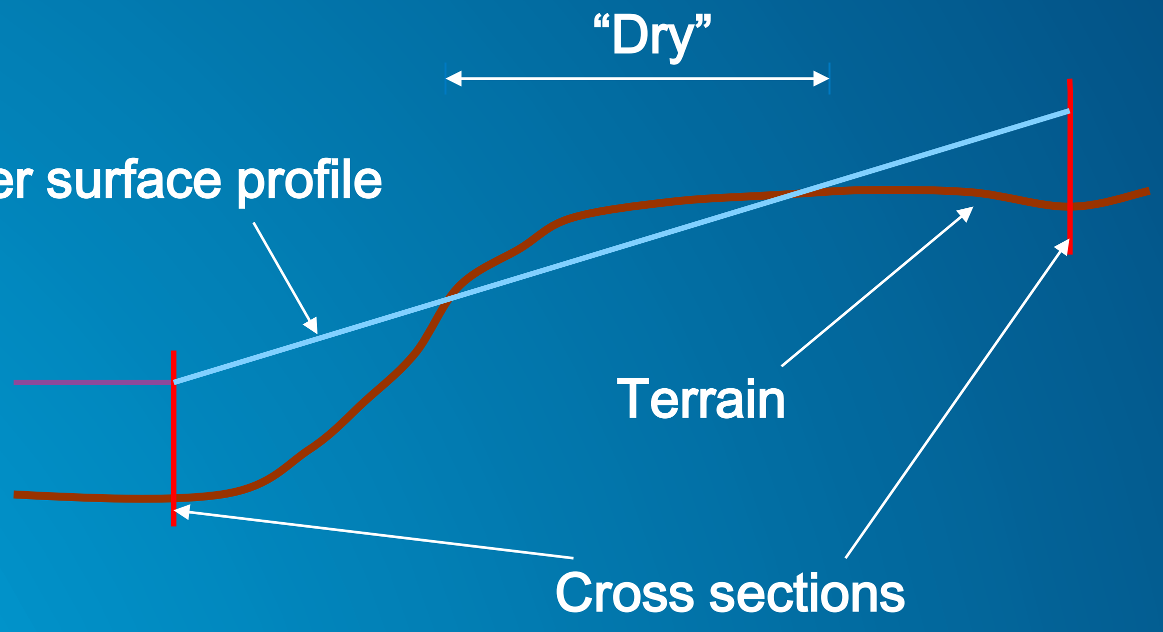
- At present, it is manual and at the discretion of the modeler.
  - GIS–H&H interaction
  - H–H interaction
- Visualization in both pre- and postprocessing is not just a “pretty picture.”
  - Flyover in preprocessing (GeoHMS and GeoRAS)
    - Identification of data problems
    - Modeling element placement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

Floodplain Discontinuity

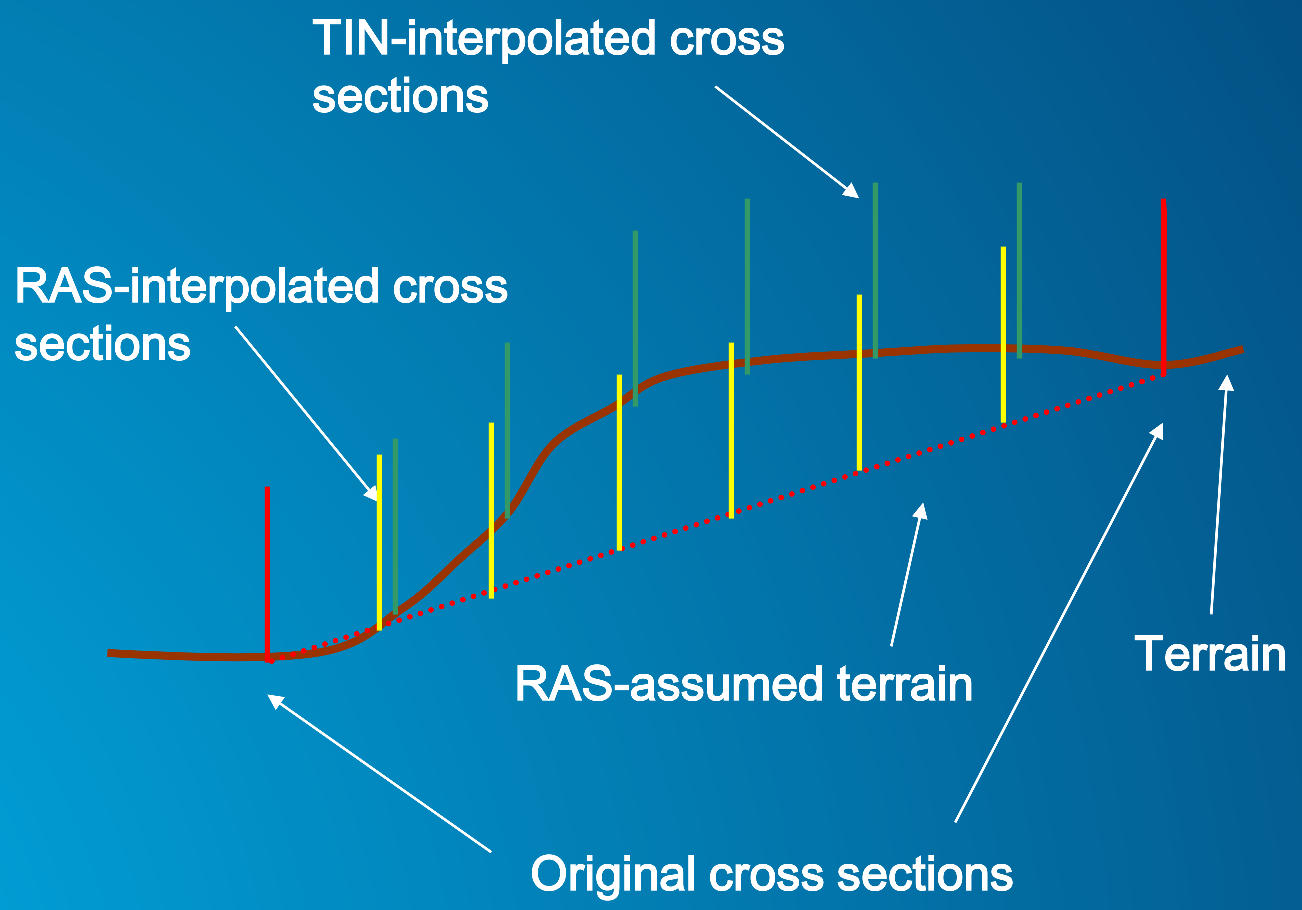




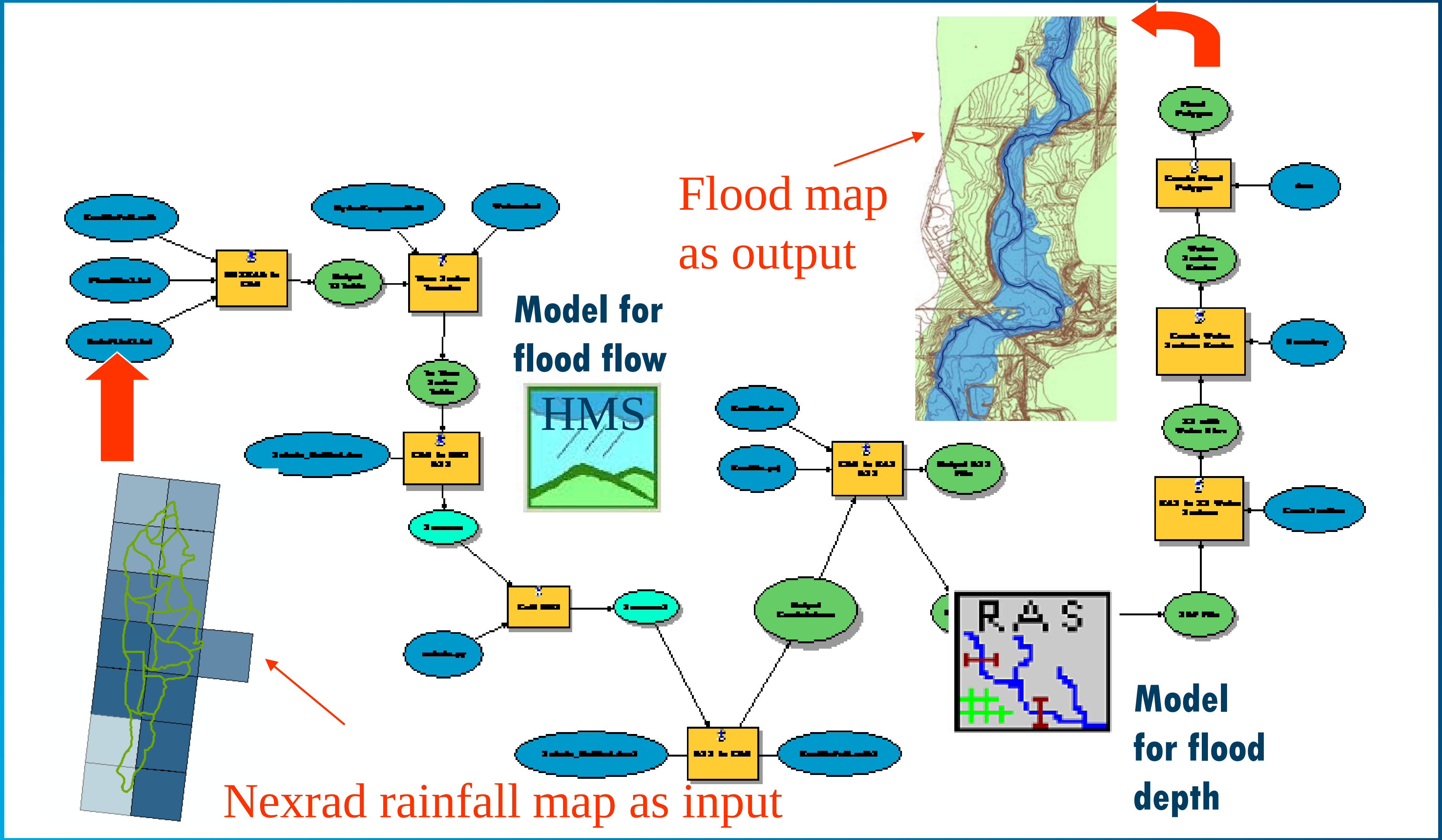
Floodplain Discontinuity (cont.)



Cross-Section Interpolation



Map2Map (rainfall to floodplain)



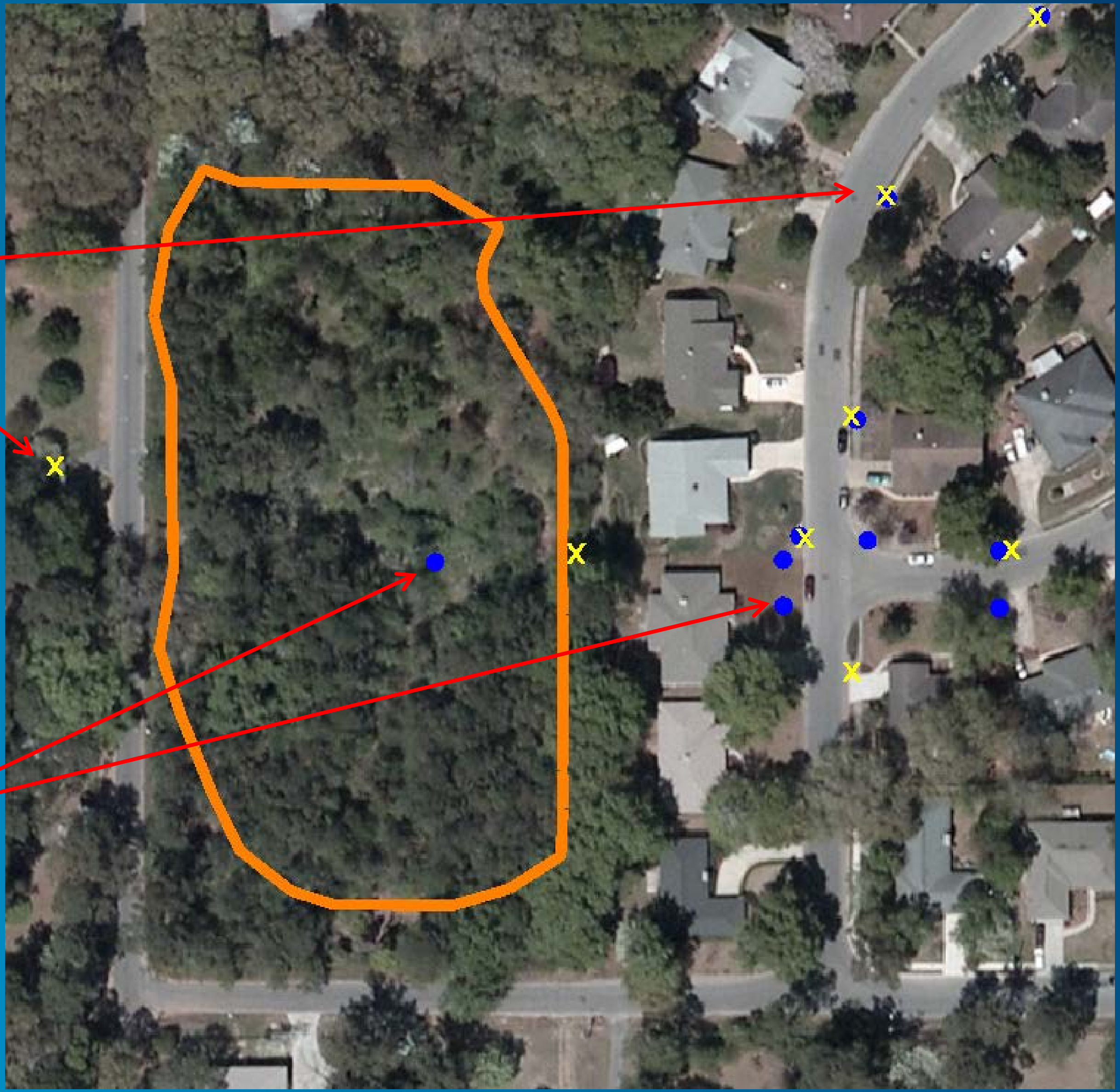
Integrated H&H

(ICPR^{4G} - shape of the things to come)

ICPR^{4G} interface

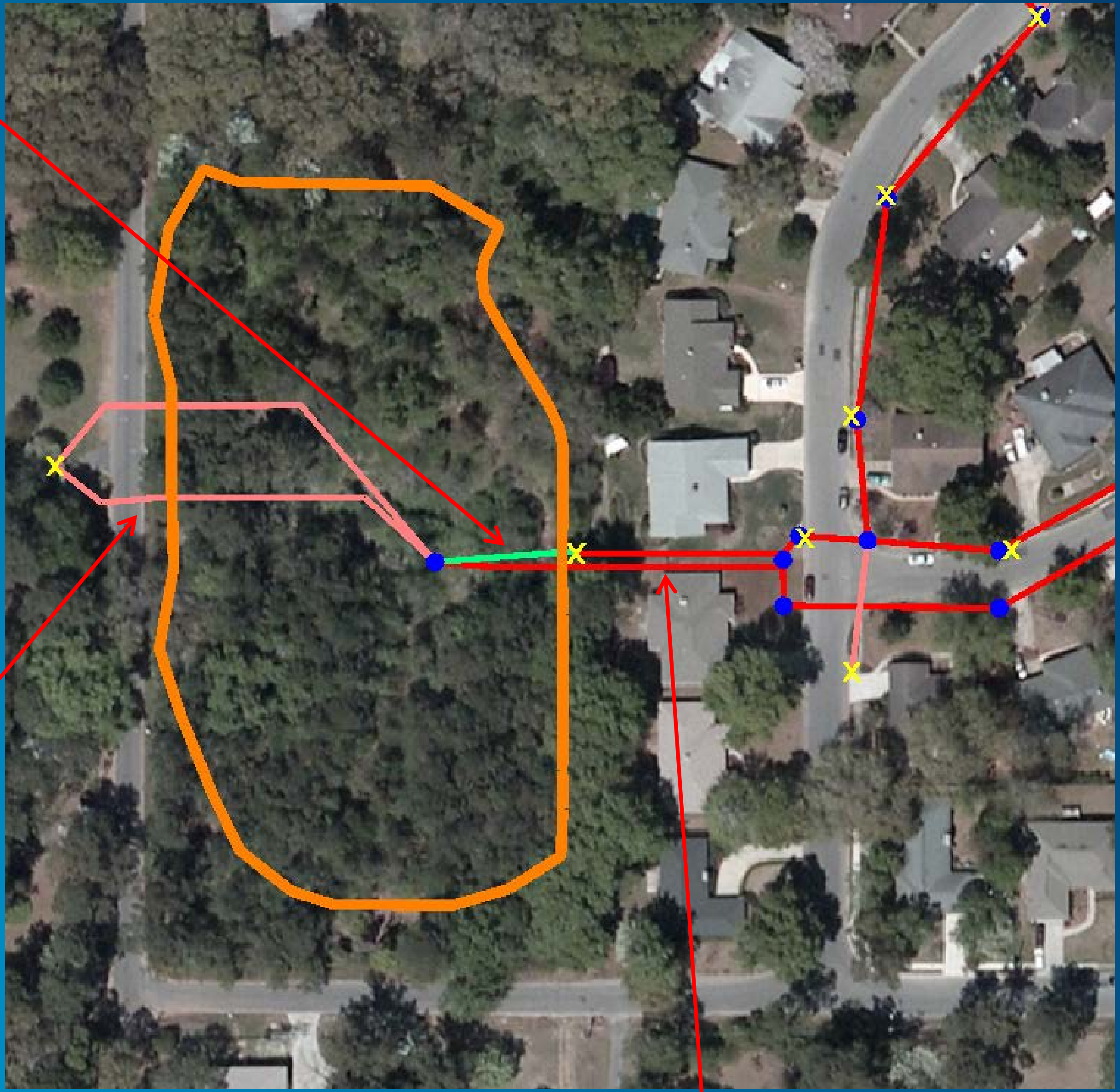
- Transition from ICPR 3 (1-D, node-link model) to full 2.5-D, spatially distributed, process integrated, H&H model.
- Interface fully integrated within AH.
- Model structure and results I/O (XML for model structure, TBD for results).

1D/2D Interface
(Storm Inlets)



1D Nodes
(Pond, Manholes)

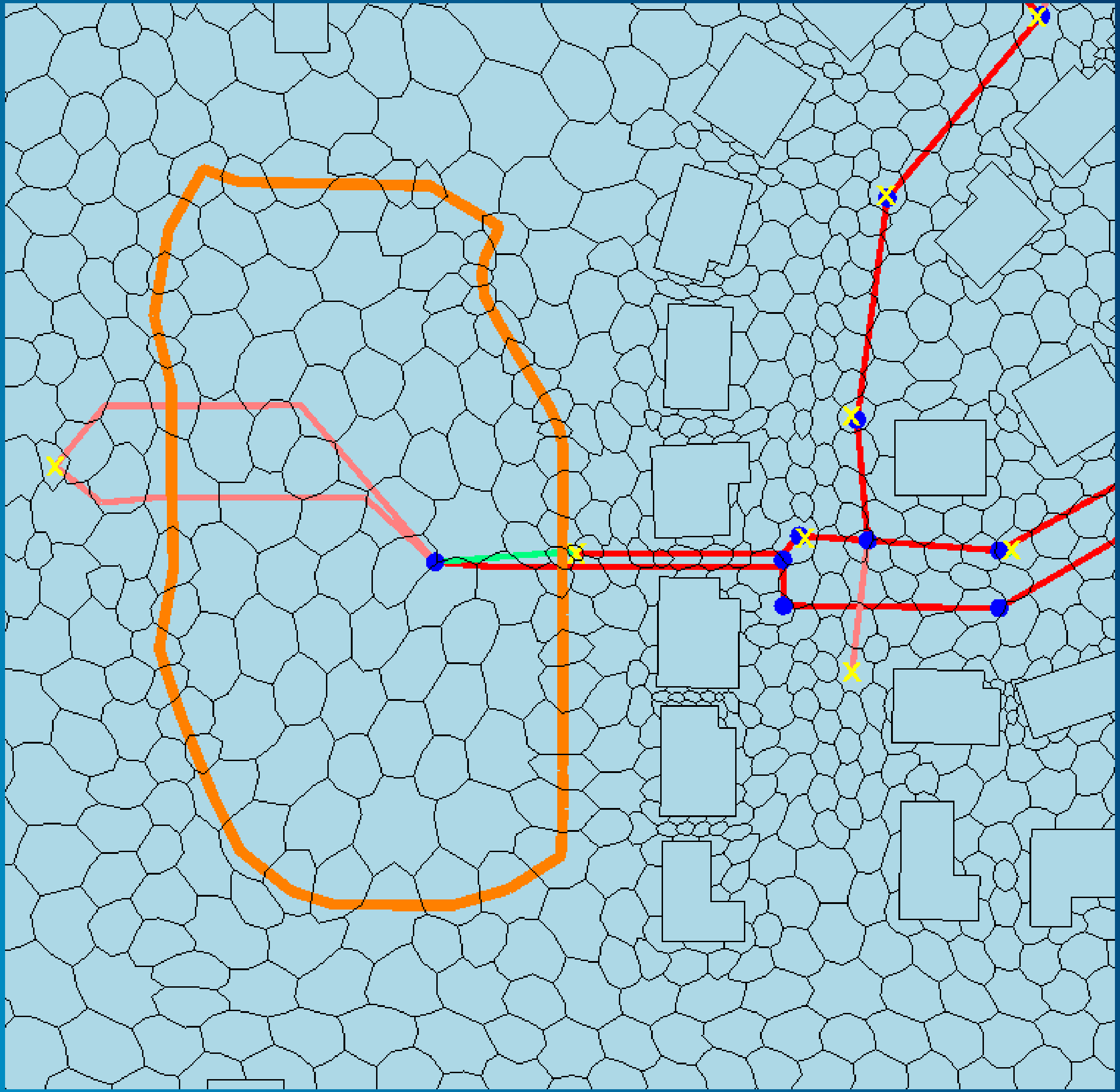
1D Weir Link



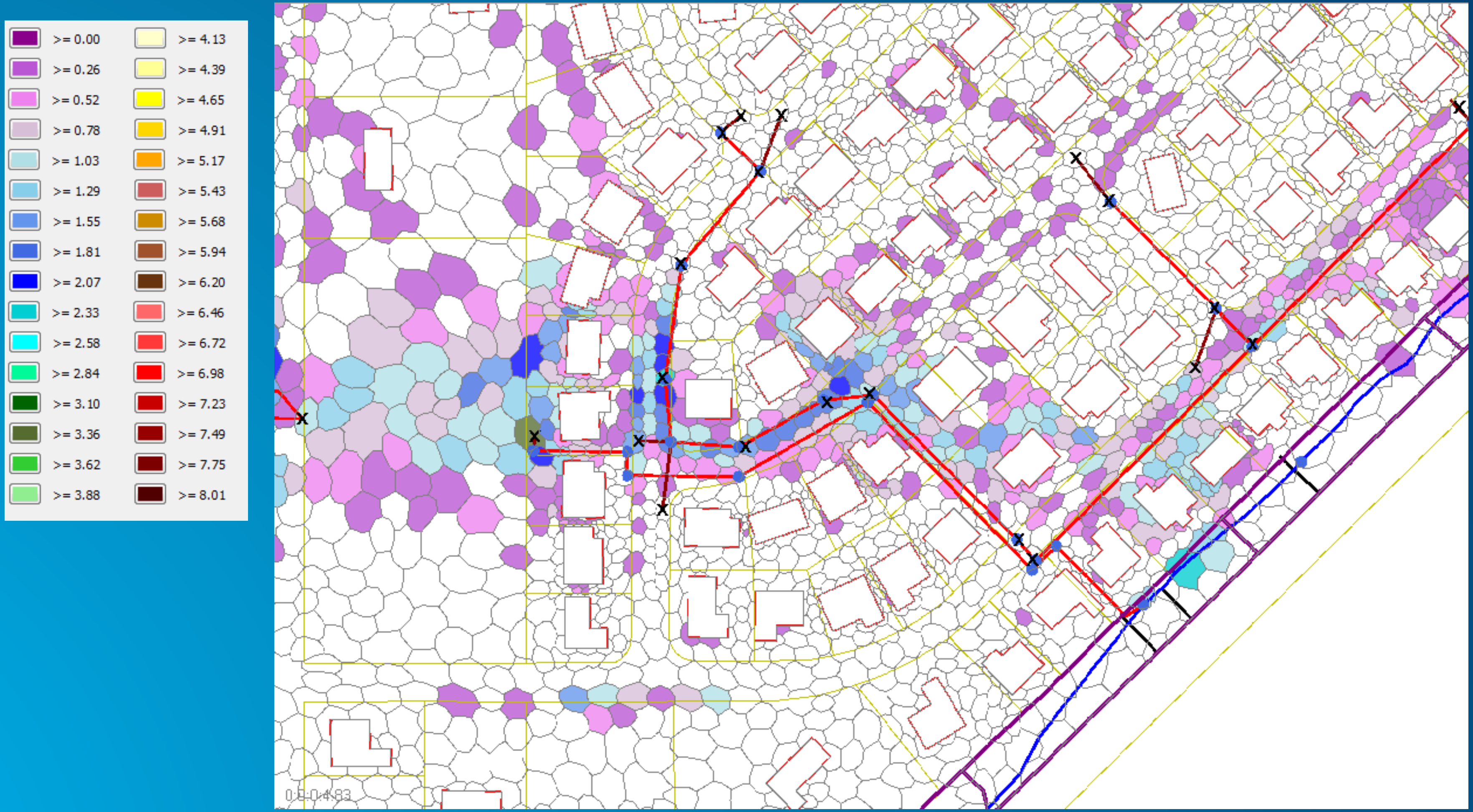
1D Drop Structure Link

1D Pipe Link

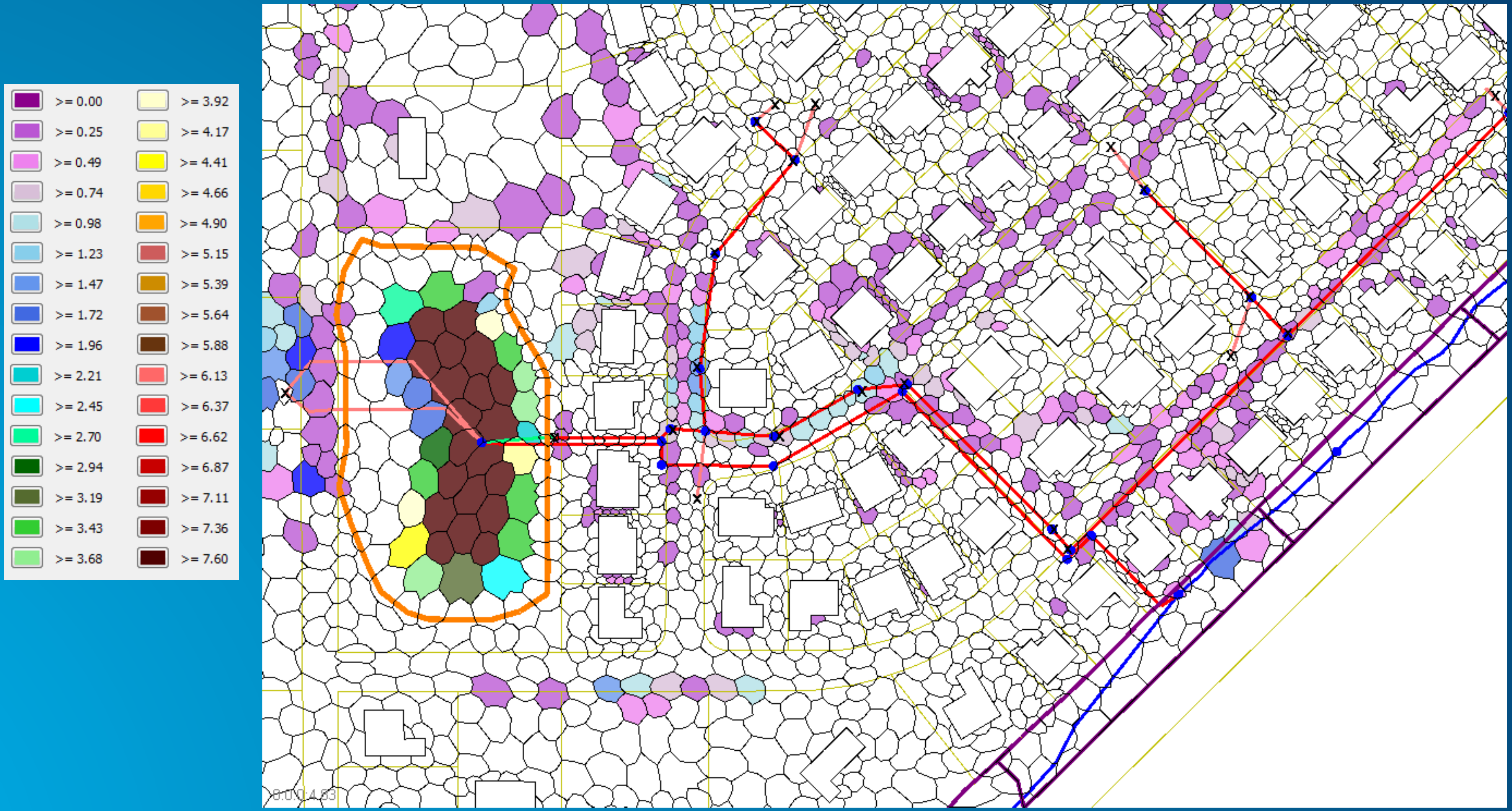
2D Honeycomb
with
1D Elements



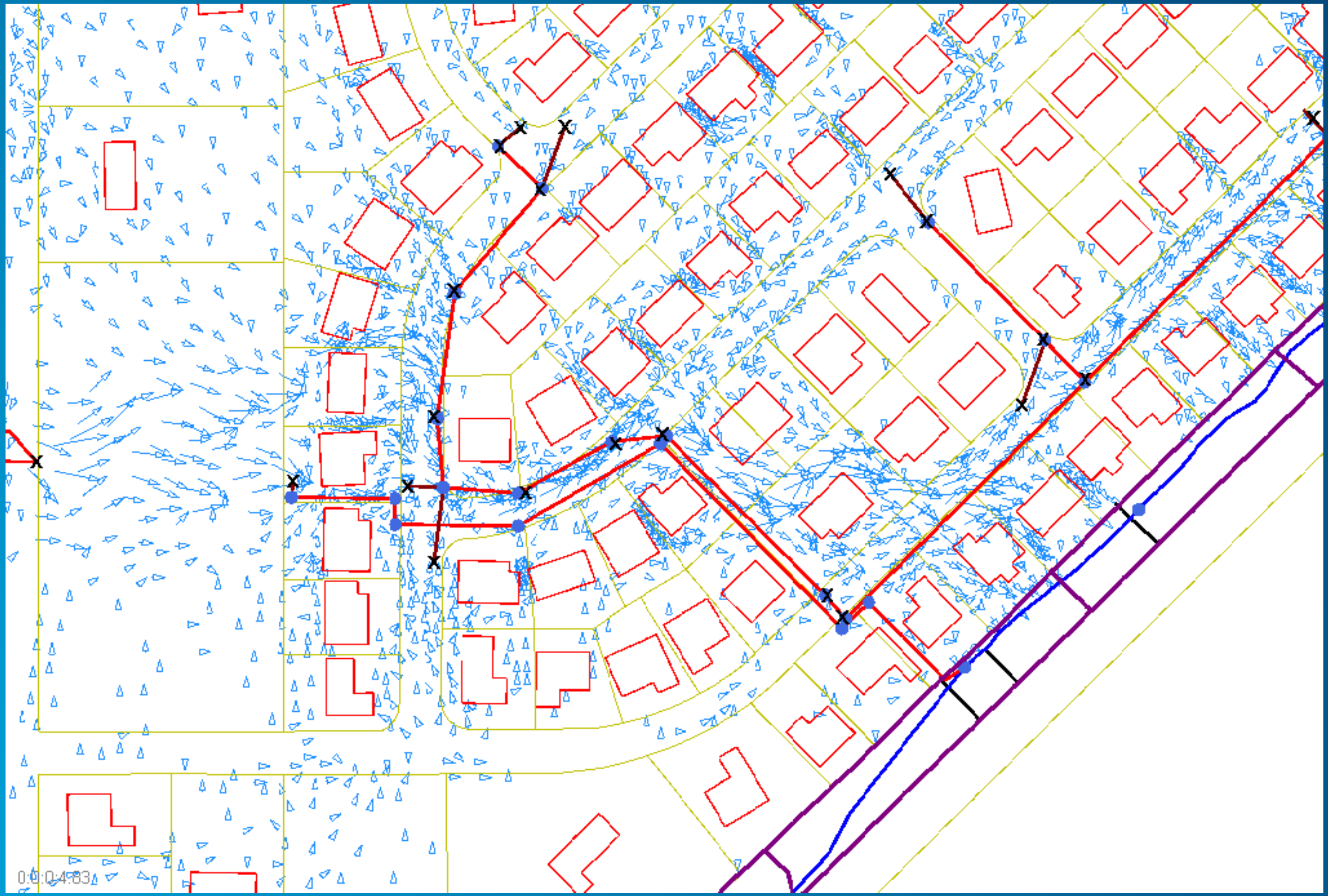
Flood Depths, Existing Condition



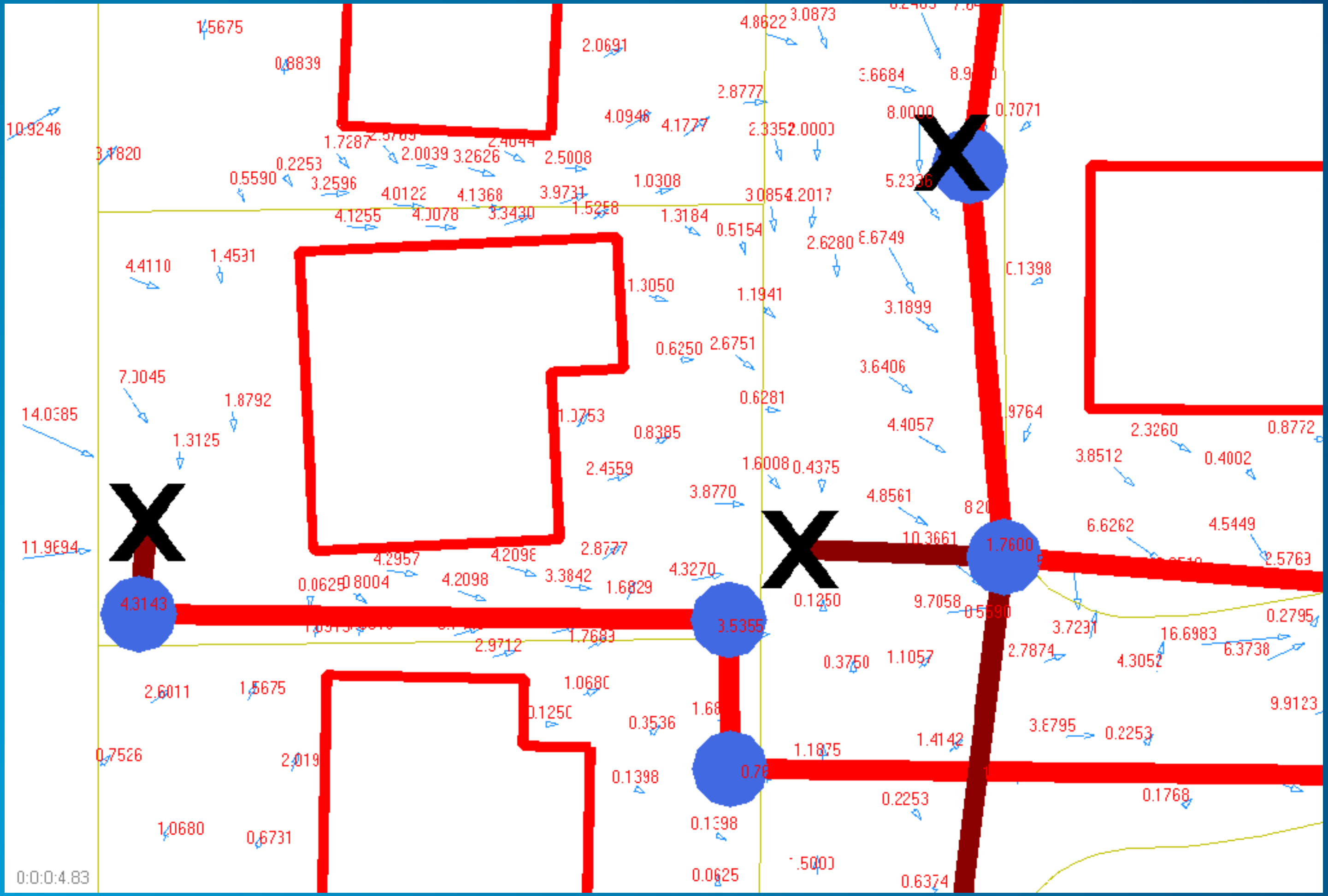
Flood Depths, Alternative 4



Flow Vectors, Existing Conditions



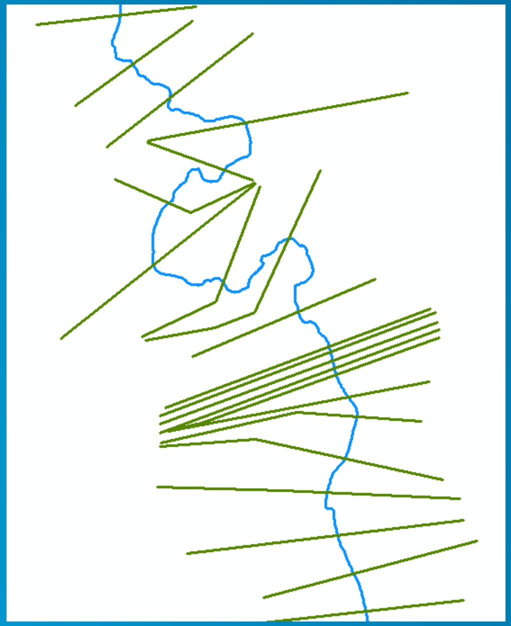
Flow Vectors with Labels, Existing Conditions

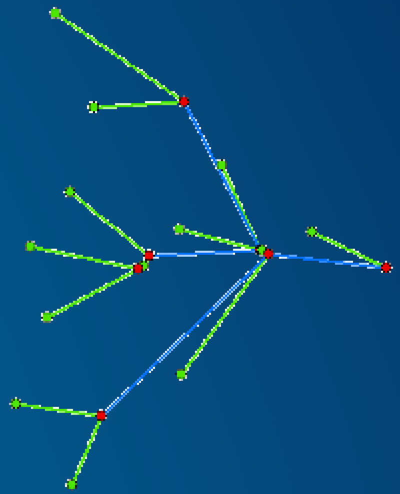


Overview of GIS techniques for H&H modeling support data simplification

Schematization – 1D

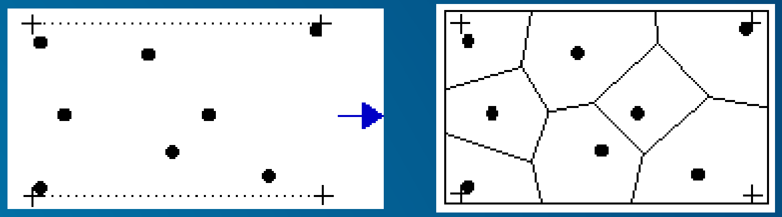
- **Node – link representation**
- **Wireframe representation**



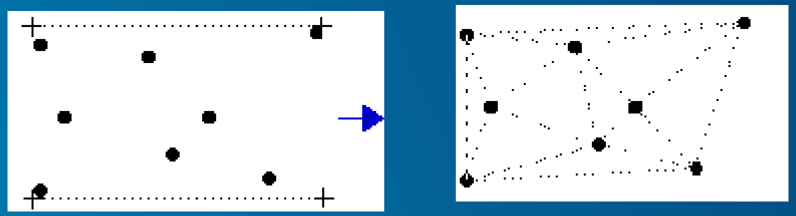


Schematization – 2D

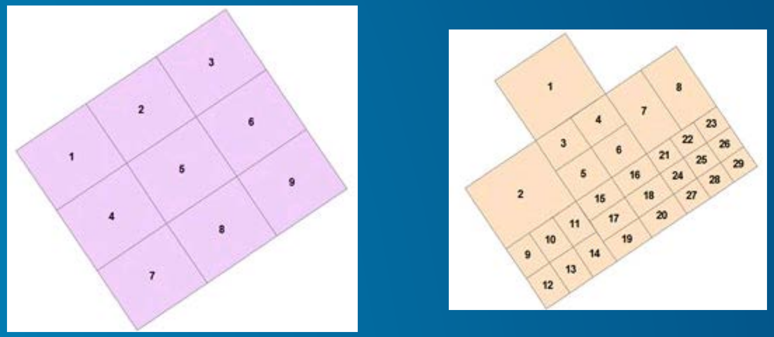
- Thiessen polygon



- TIN



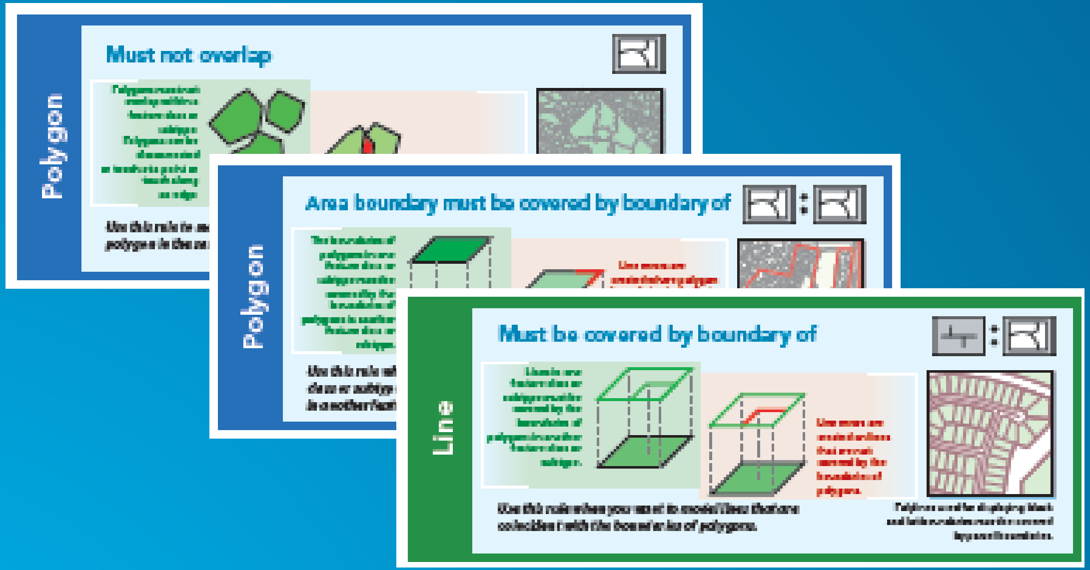
- Fish Net

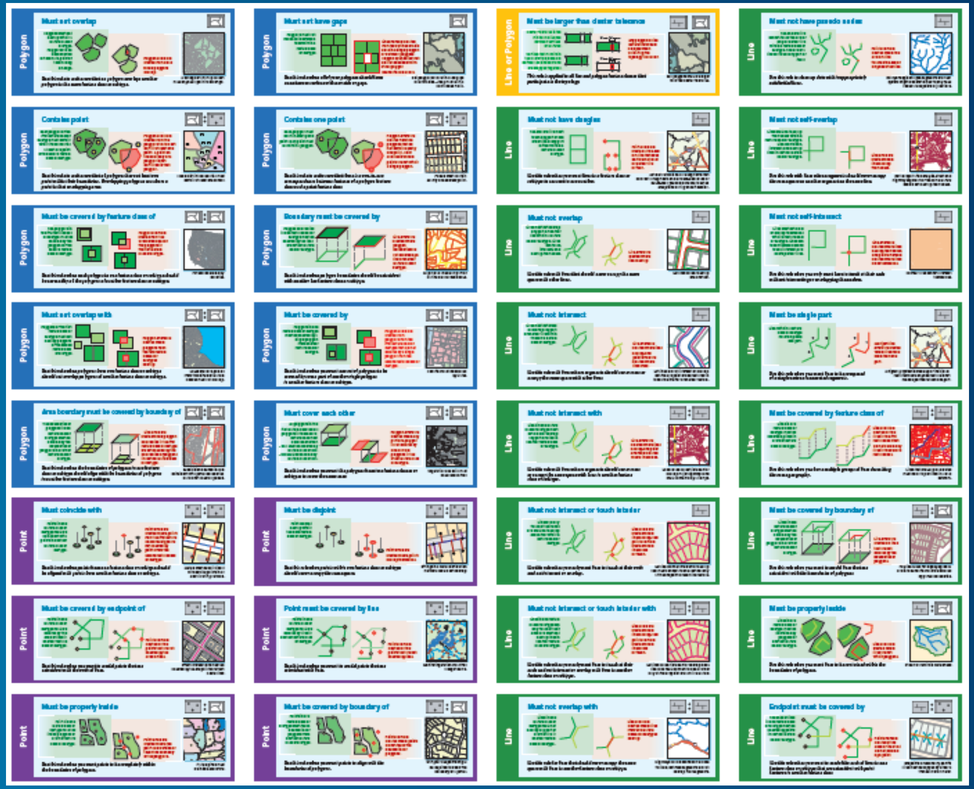


- Can get tricky – need to understand solvers for optimal tessellation!

Schematization – 2D

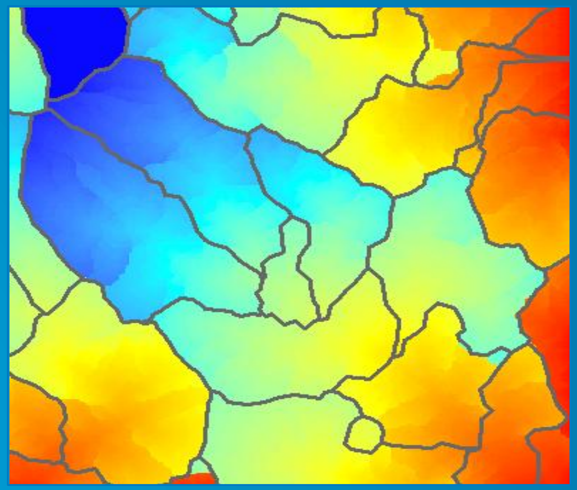
- Topology to ensure spatial consistency within and across layers

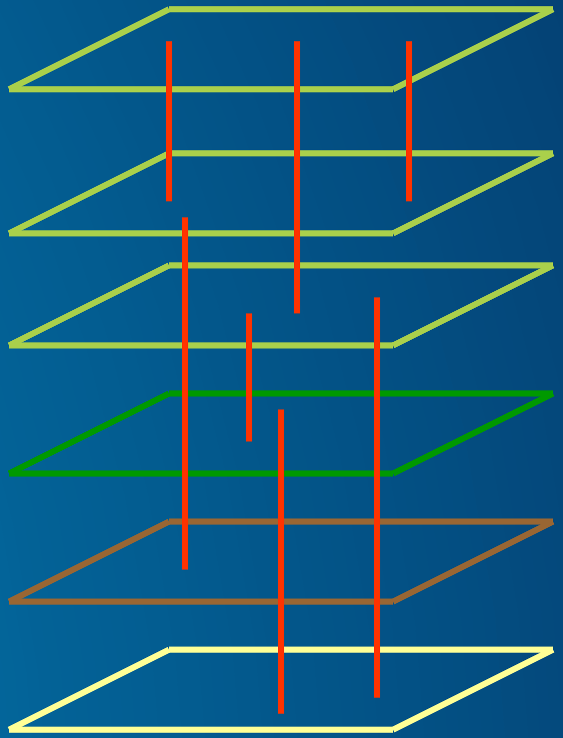




“Lumping”/characterization

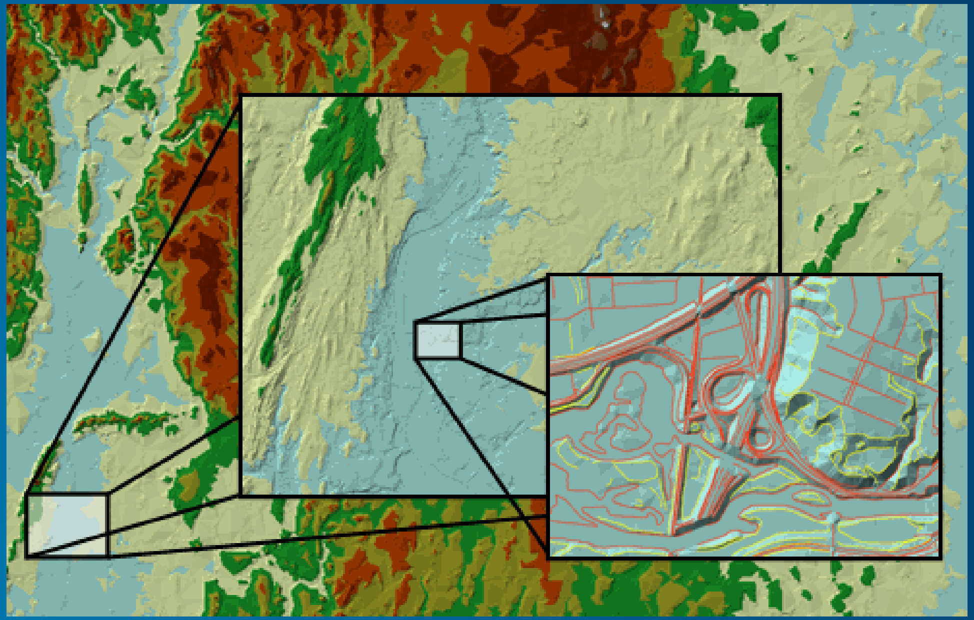
- Push-pin (not much to do unless it needs “vertical” aggregation)
- “Lumping”/characterization
  - Zonal stats operations
  - Can do interpolation first, then stats

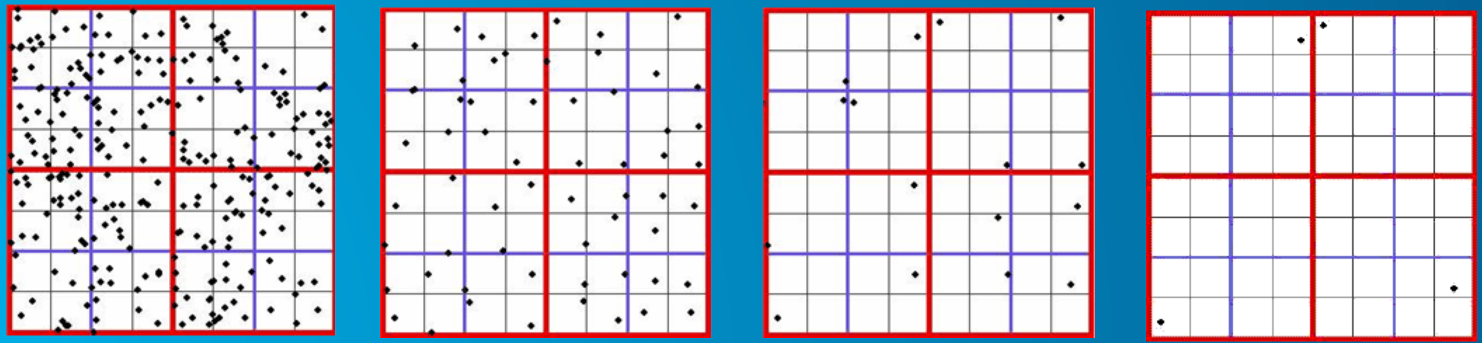




“Weeding”/VIP identification

- 2D (terrain/surface)
  - Terrain dataset (terrain pyramids)
    - Window size
    - Z-tolerance





“Weeding”/VIP identification

- “1D”

Table

XLine3DSimplified

OBJECTID *	Shape *	Shape_Length	HydroID	FEATUREID	AREAPCT	LENGTHPCT	PNTCOUNT0	PNTCOUNT1
1	Polyline Z	14507.643301	<Null>	1	100.01038	99.996045	1452	435
2	Polyline Z	19955.248114	<Null>	2	99.953482	99.988502	1998	598

0 (0 out of 2 Selected)

XLine3DSimplified

Table

XLineTBL

OBJECTID *	FEATUREID	POINTINDEX	INCLUDED	AREAIMPACT	ACCAREA0	ACCAREA1
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1407	1	1406	1	0.001729	2310991.917979	2306996.725614
1408	1	1407	1	0.001729	2311169.305129	2307174.112764
1409	1	1408	1	0.001729	2311336.235132	2307341.042767
1410	1	1409	0	1	2311520.519762	<Null>
1411	1	1410	0	1	2311683.678762	<Null>
1412	1	1411	1	0.001729	2311830.374621	2307833.249336
1413	1	1412	0	1	2311991.113774	<Null>
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1415	1	1414	0	1	2312261.224304	<Null>
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1426	1	1425	0	1	2313350.427389	<Null>
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1434	1	1433	0	1	2313685.759199	<Null>
1435	1	1434	1	0.001733	2313699.483755	2309689.781308
1436	1	1435	0	1	2313710.081905	<Null>
1437	1	1436	1	0.001733	2313717.661702	2309708.290516
1438	1	1437	0	1	2313723.184152	<Null>
1439	1	1438	0	1	2313728.163002	<Null>
1440	1	1439	0	1	2313732.558153	<Null>
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1442	1	1441	0	1	2313740.357256	<Null>
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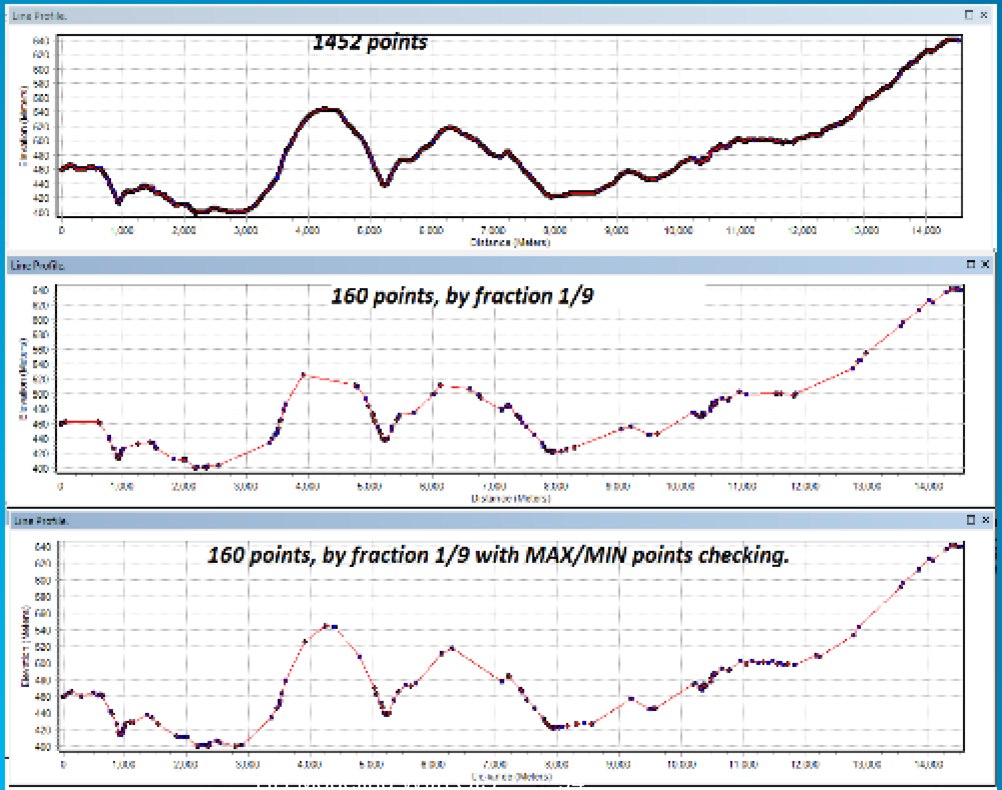
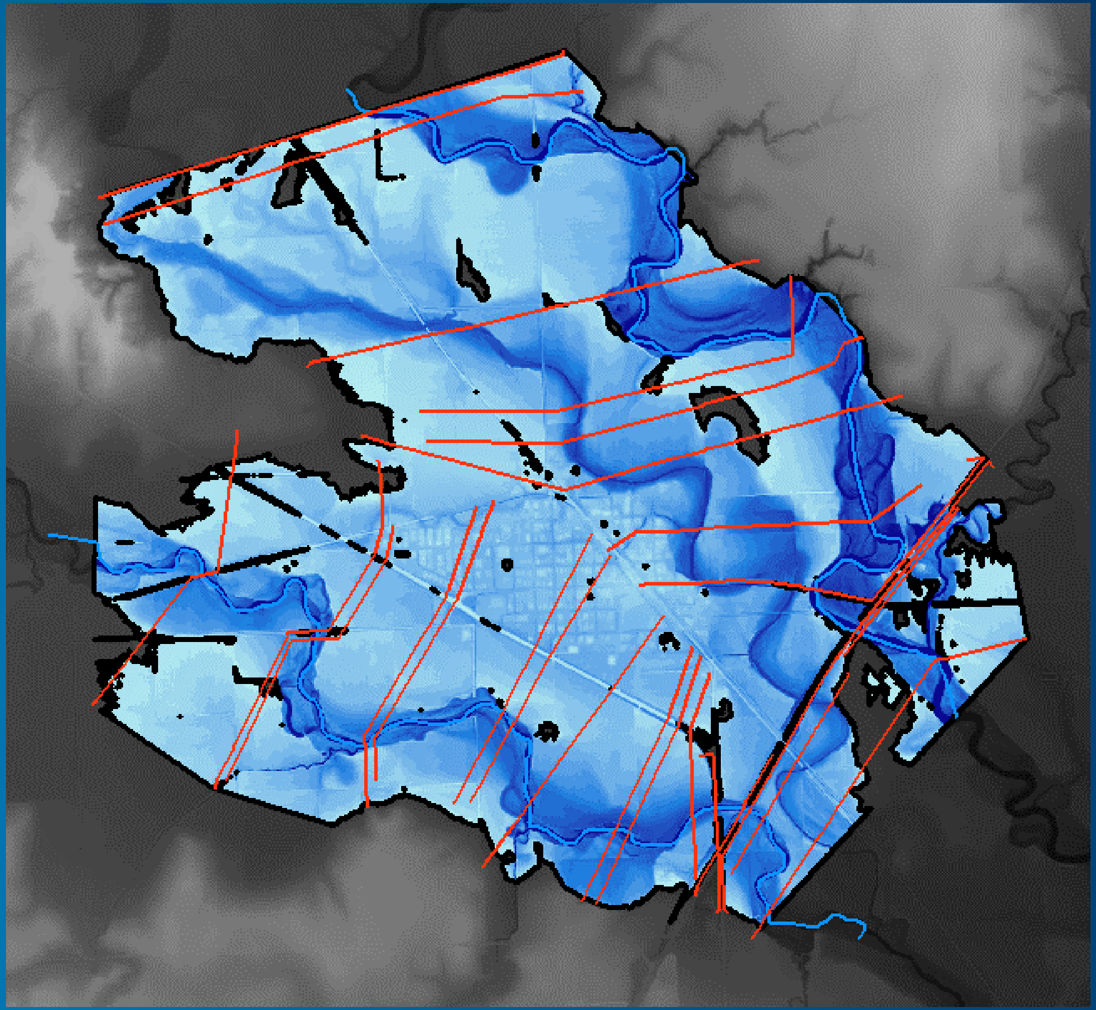


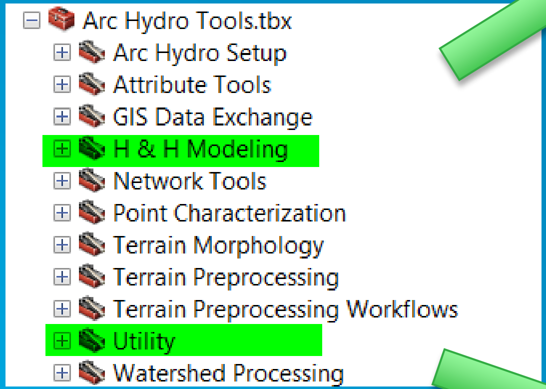
Simplified Floodplain DelineationTools

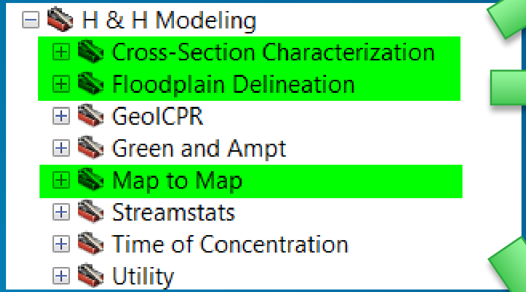
- Support for floodplain analysis
  - Real-time (observed, forecasted flows)
  - Planning (flood frequency)
- Facilitate landscape characterization for floodplain analysis
  - Streams
  - Cross-sections
  - Floodplain
- Floodplain delineation
  - Points
  - Cross-sections
  - From models

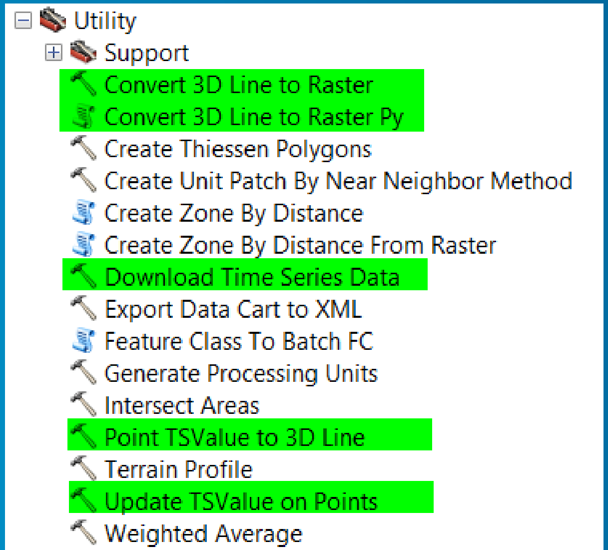


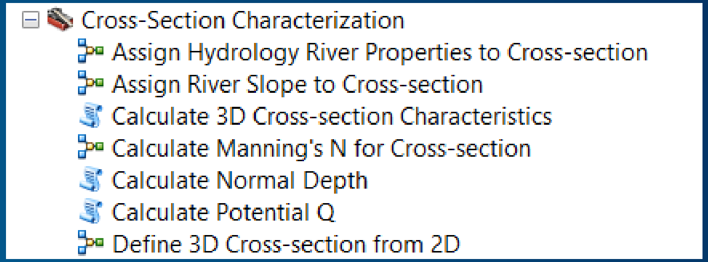
Tools

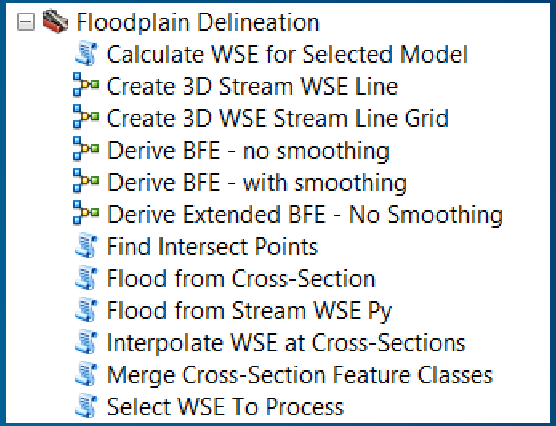
- Organized in several AH toolsets (most in “H & H Modeling” and “Utility”)
- ~ 35 tools

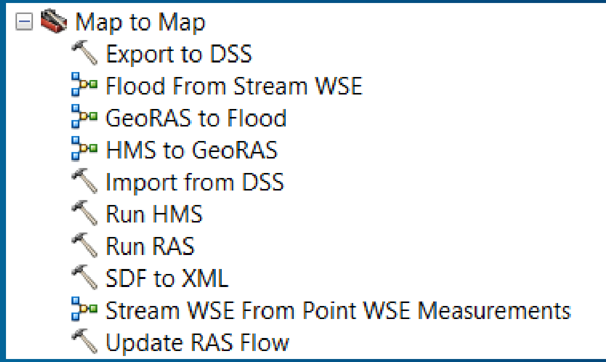












Sample Implementation Use Cases

- DEM only:
  - Create synthetic streams from DEM
  - “Flood out” WSE along streams in incremental steps
- DEM + cross-sections:
  - Use TIN technique for WSE at c-s in incremental steps
- DEM + stream + observed points:
  - “Flood out” observed WSE along streams
- DEM + stream + modeled Q at points:
  - Build c-s and develop synthetic rating curve at modeled points
  - Use synthetic rating curve to get WSE from modeled Q
  - Alt 1 – use flood out technique at points
  - Alt 2 – use TIN technique at c-s

Summary

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.**
- **Needs approach to GIS as an analytical technology**

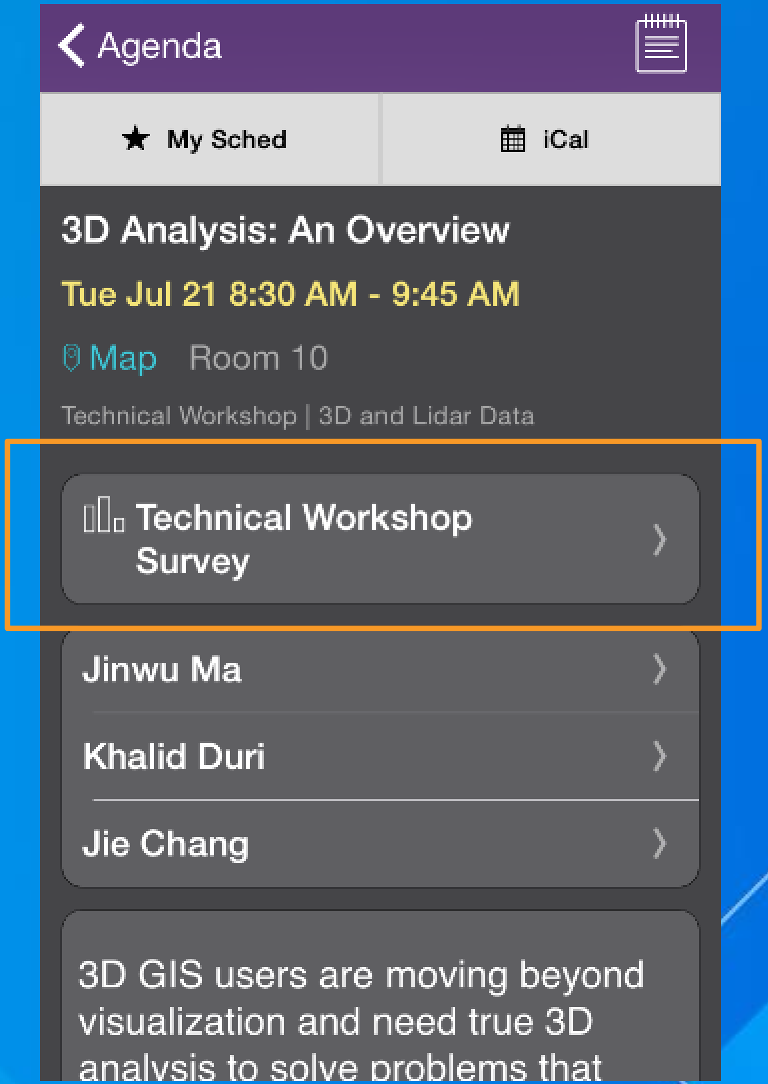
Summary

- Easy evaluation of alternatives
- H&H model integration and automation
  - Operational and change in conditions
- Environment for integrated solution management:
  - Emergency management
  - Design
  - Decision support
- Leverage existing online templates for information augmentation and result publishing
  - E.g. identify affected people in a floodplain and present the information through operations dashboard or story map

Q & A

Thank you…

- Please fill out the session survey in your mobile app
- Select “Hydrologic and Hydraulic Modeling” in the Mobile App
  - Use the Search Feature to quickly find this title
- Click “Technical Workshop Survey”
- Answer a few short questions and enter any comments



esri

Understanding our world.