Hydrologic Analyses and Applications in ArcGIS

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SEE WHAT OTHERS CAN'T

Content

- Definitions
- Core capabilities:
  - Introduction to Hydrologic Analysis in ArcGIS
  - Overview of Hydrology tools and functions
  - Hydrologic Analysis Workflows
  - Ready-to-use hydrology services on ArcGIS Online (demo)
- Advanced capabilities:
  - Data sources and analyses nuances
  - Arc Hydro
  - Hydrologic and hydraulic modeling support with GIS
- Summary

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.
- And thus we have "**H&H**"

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.

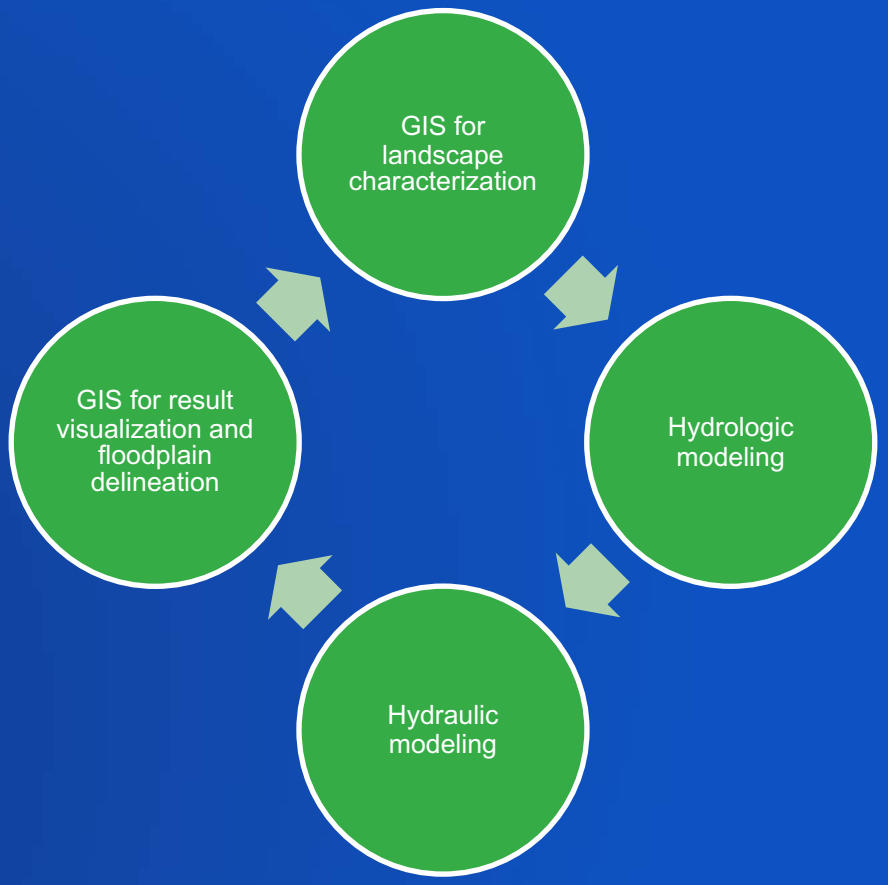
- ***GIS is used to summarize terrain and hydrologic characteristics of the watershed for input to a model*.**

Hydraulic Modeling

- **Goal: Predict water surface elevations and velocities for a given discharge.**
- **There are many ways to do hydraulics (1D, 2D, different simplifications of St. Venant equation, …).**
- ***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 for Hydro Modeling “Cycle”

- **GIS** is used for landscape characterization and model parametrization.
- **Hydrology and Hydraulics** (H&H) is used for determination of flows, depths and velocities.
- **GIS** is used for result postprocessing and visualization.
- GIS and H&H modeling are closely connected as one impacts the other



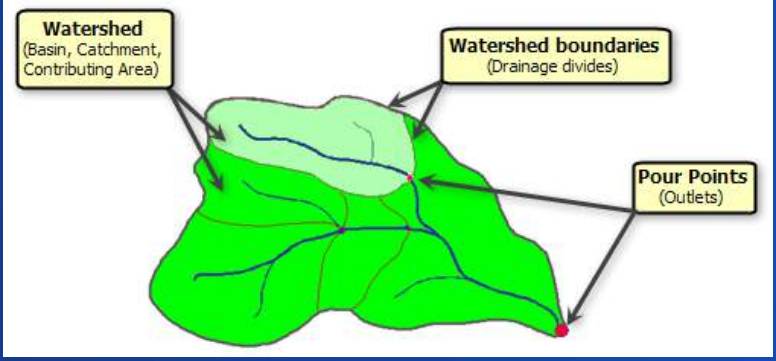
… and many arrow in between

Core Capabilities:

- Introduction to Hydrologic Analysis in ArcGIS
- Overview of Hydrology tools and functions
- Hydrologic Analysis Workflows
- Ready-to-use hydrology services on ArcGIS Online (demo)

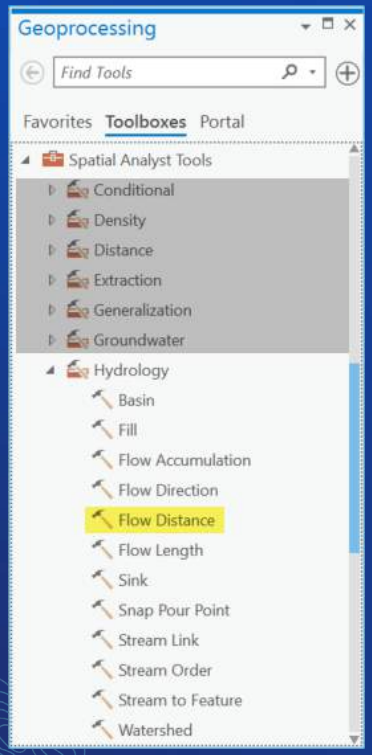
Introduction to Hydrologic Analysis in ArcGIS

- Hydrologic Analysis in ArcGIS is used to model the flow of water across a surface.
- What are the primary objectives of hydrologic analysis in a GIS?
  - Extract hydrologic information and drainage system characteristics from a digital elevation model.
  - To know where the water comes from, and where it is flowing to.

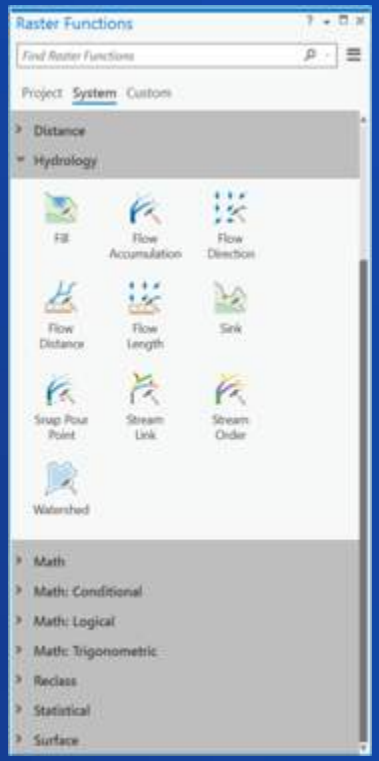


Hydrology Tools

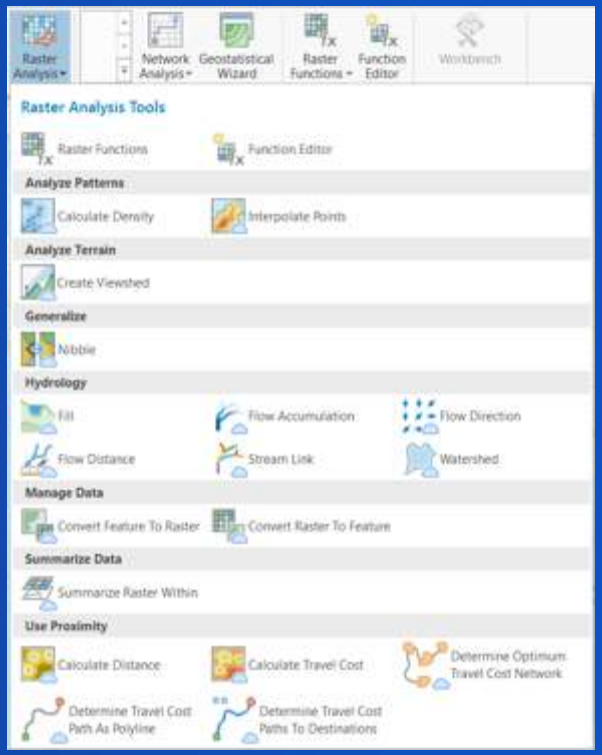
ArcMap / ArcGIS Pro



ArcGIS Pro



ArcGIS Image Server

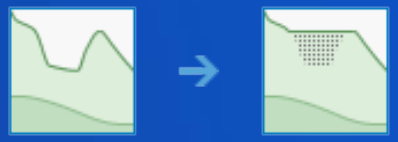


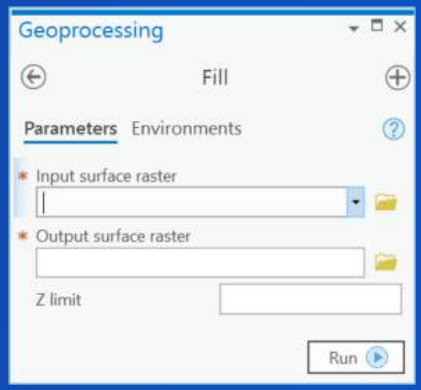
Fill

Fills sinks in a surface raster to remove small imperfections in the data.

PPF enabled

- Remove smaller imperfections and noise in surface raster.
- Remove larger sinks and pits in the terrain.
- Provide depth filter using Z-Limit.

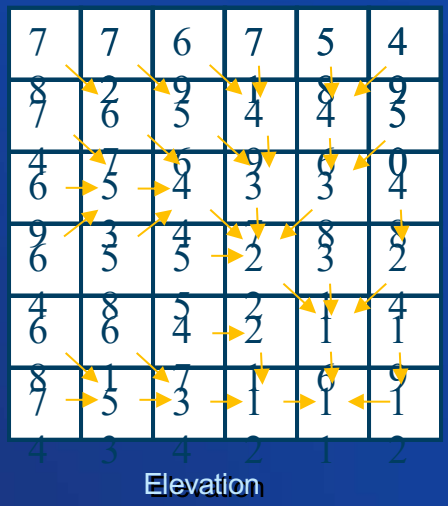




Flow Direction: D8

Create a raster of flow direction from each cell to its steepest downslope neighbor using D8 method.

PPF enabled

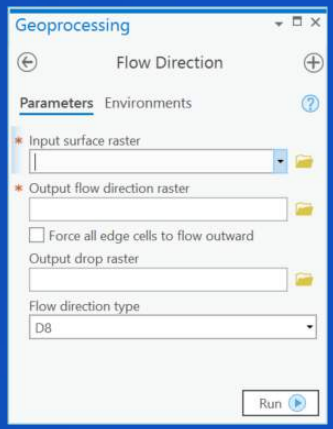


Elevation

Flow Direction

Direction Coding

D8 Method

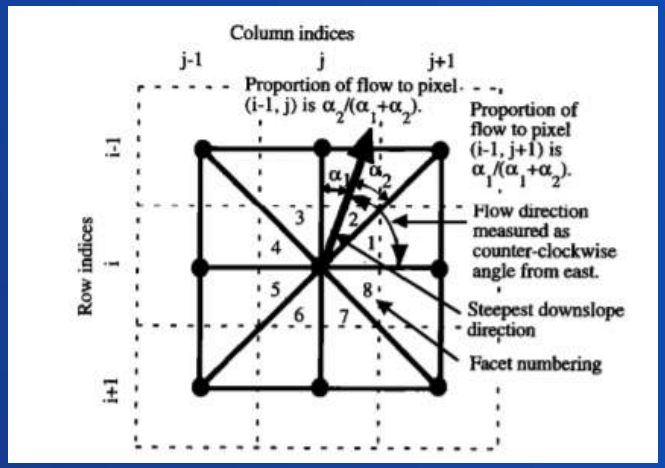


Flow Direction: D-Infinity

PPF enabled

Creates flow direction as the steepest downward slope on eight triangular facets formed in a 3X3 cell window centered on each cell

D-Infinity best for modeling distributed hydrologic processes, such as runoff generation or erosion.



D-Infinity Method

Steepest downslope direction

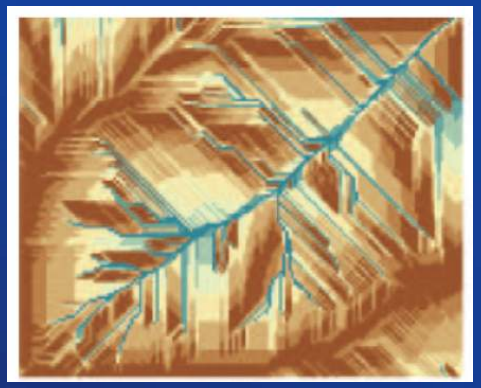
Divergent flow: flow proportioned up to two downstream neighbors

Tarboton, D. G., (1997), "A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models," Water Resources Research, 33(2): 309-319.

Flow Direction: Multiple Flow Direction (MFD)

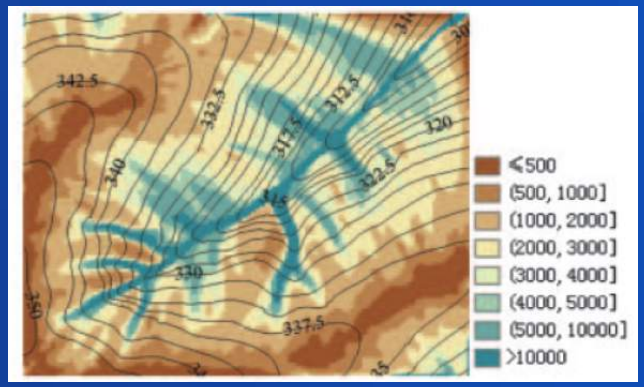
PPF enabled

- Better flow accumulation maps in low-relief areas
- Flow partitioning is adaptive to local terrain conditions.

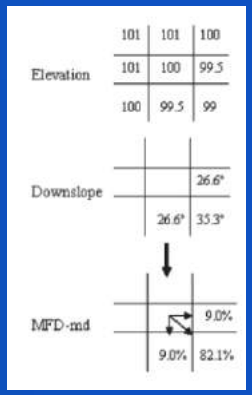


D8 Flow Accumulations

V S



MFD Flow Accumulations



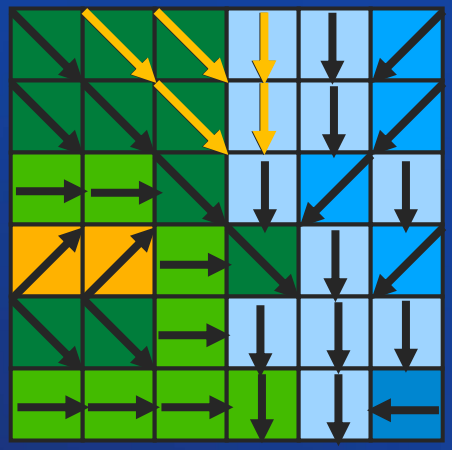
Flow proportioned to all downstream neighbor(s)

Qin, C., Zhu, A. X., Pei, T., Li, B., Zhou, C., & Yang, L. 2007. "An adaptive approach to selecting a flow partition exponent for a multiple flow direction algorithm." International Journal of Geographical Information Science 21(4): 443-458.

Flow Accumulation

Creates a raster of accumulated flow into each cell. A weight factor can optionally be applied. Select from D8, D-Infinity or MFD flow methods.

PPF enabled



Flow Direction

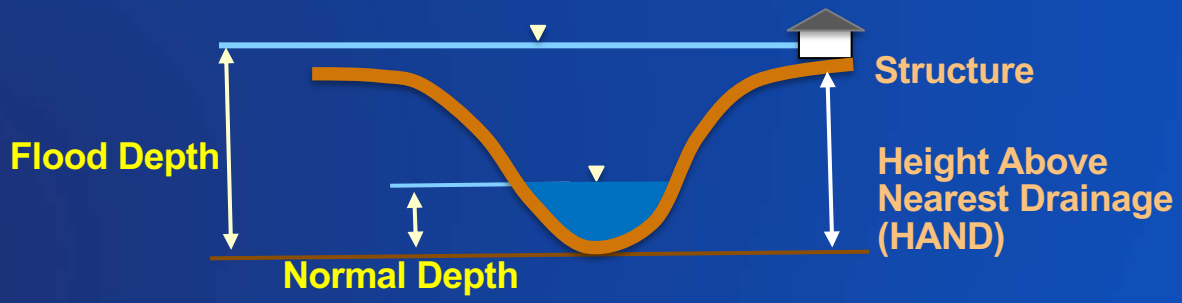
0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	2	0	1
0	0	0	1	2	0
0	2	4	7	3	2

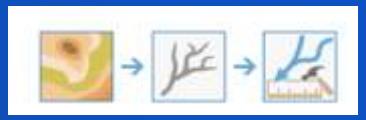
Flow Accumulation

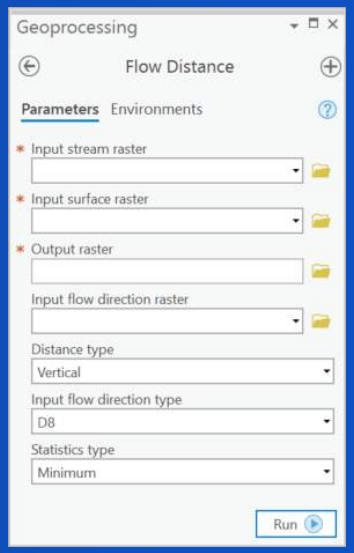
Flow Distance

PPF enabled

- Compute vertical/horizontal downslope distance to streams over single or multiple flow paths.
- Supports D8, D-Infinity and MFD algorithms for computing flow distance.
- In case of multiple flow paths, minimum, weighted mean, or maximum flow distance can be computed.
- Used in computation of Height Above Nearest Drainage (HAND). Flooding occurs when water depth is greater than HAND.



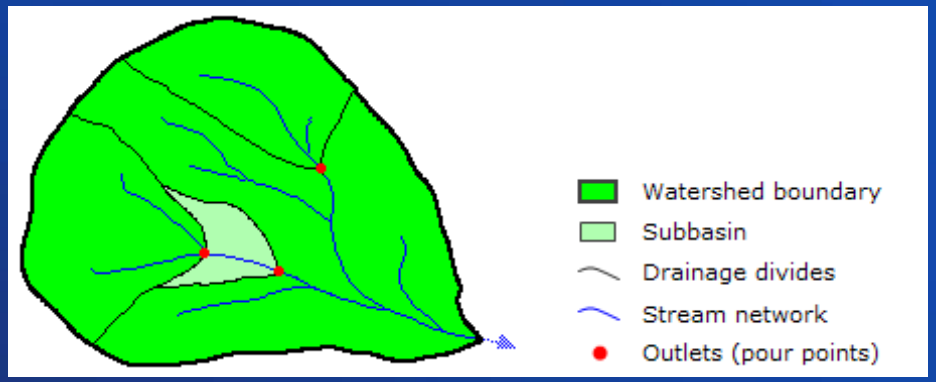


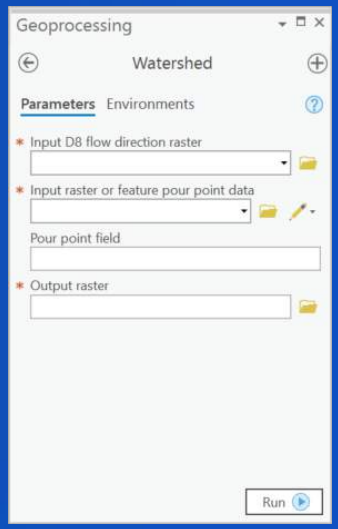


Watershed

Determines the contributing area above a set of cells in a raster.

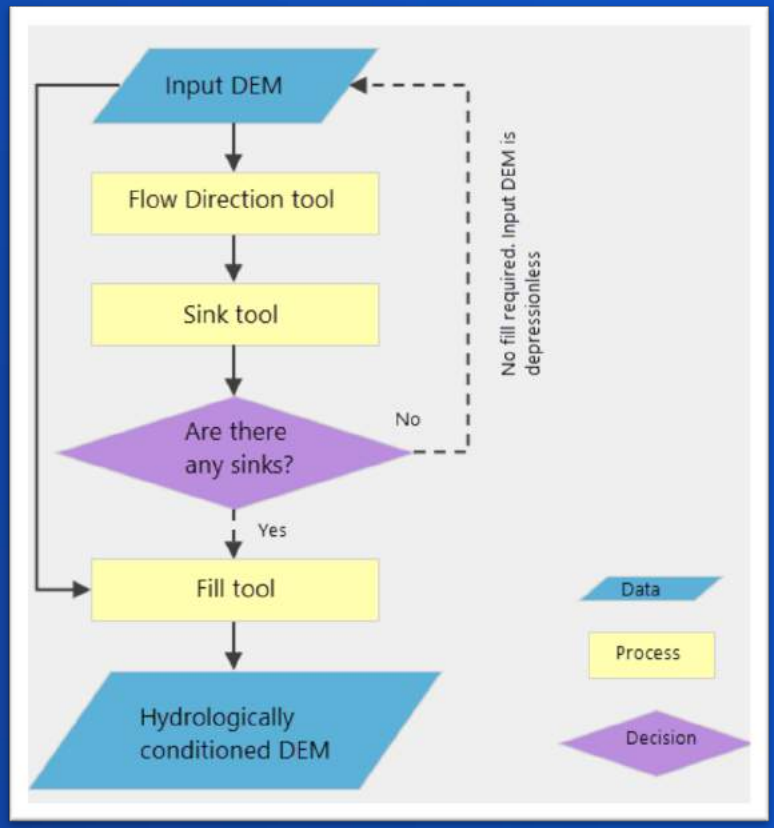
PPF enabled



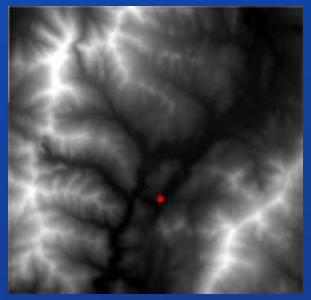


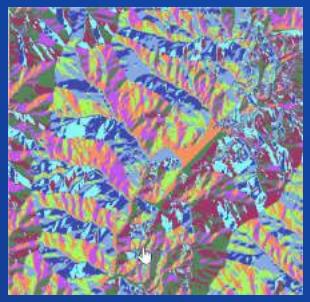
Hydrologic Conditioning Workflow

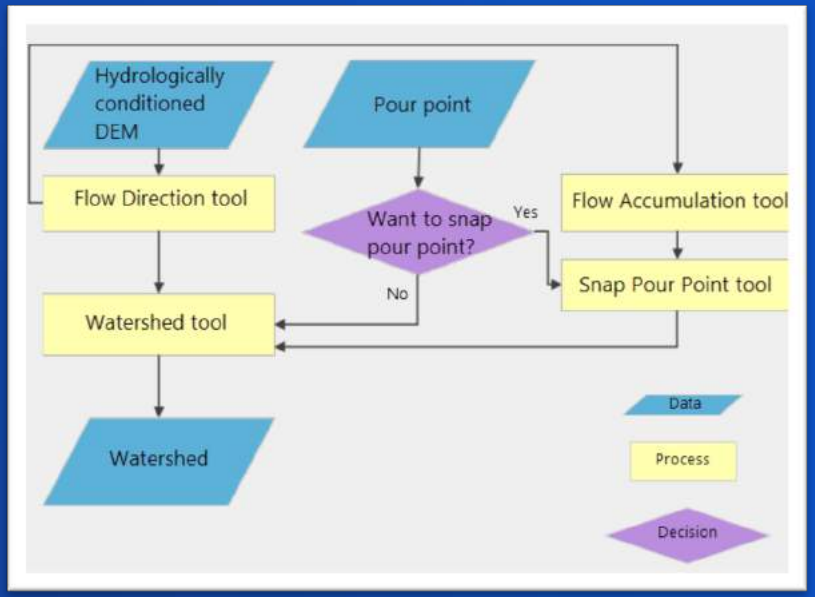
- **Hydrologically conditioned DEM is a surface raster whose flow direction defines expected flow of water over the terrain (DEM).**



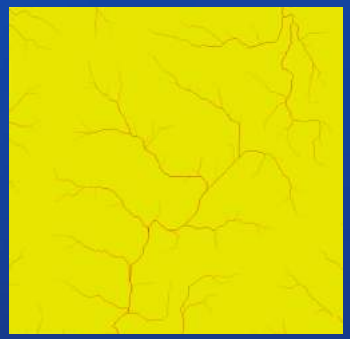
Watershed Delineation Workflow

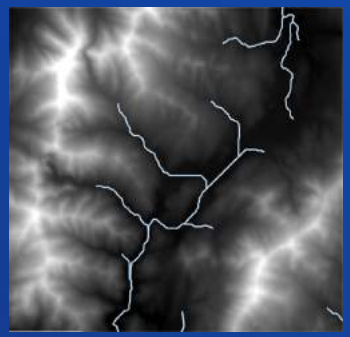


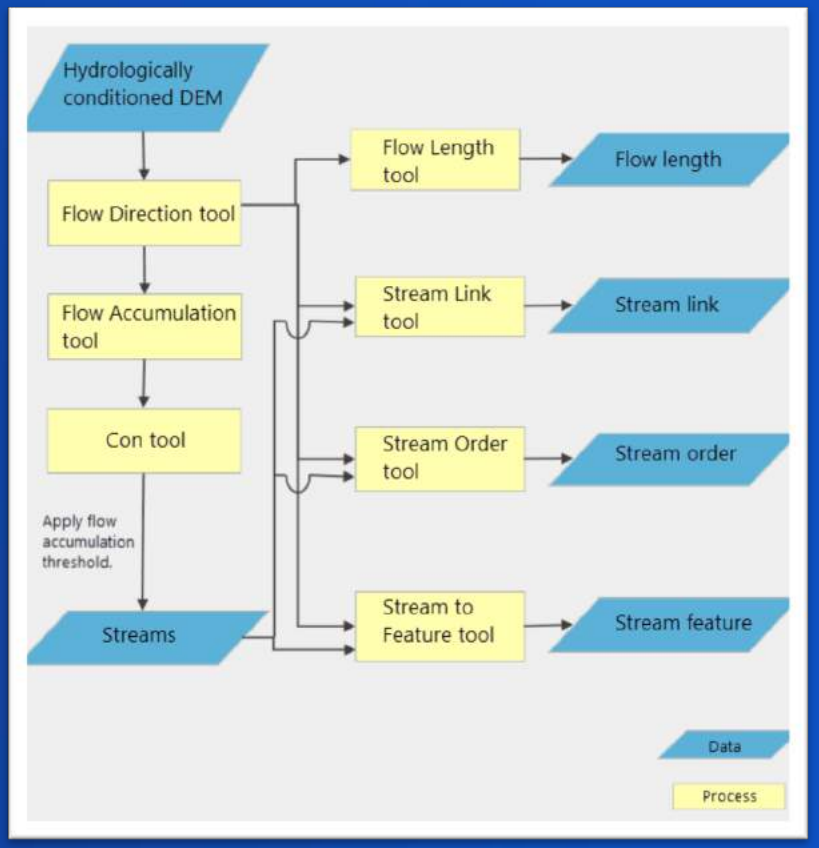




Stream Network Characteristics Workflow







Ready-to-use services on ArcGIS Online: Create Watershed & Trace Downstream

Advanced Capabilities:

- Data sources and analyses nuances
- Arc Hydro
- Hydrologic and hydraulic modeling support with GIS

GIS Data for Hydrologic and Hydraulic Modeling

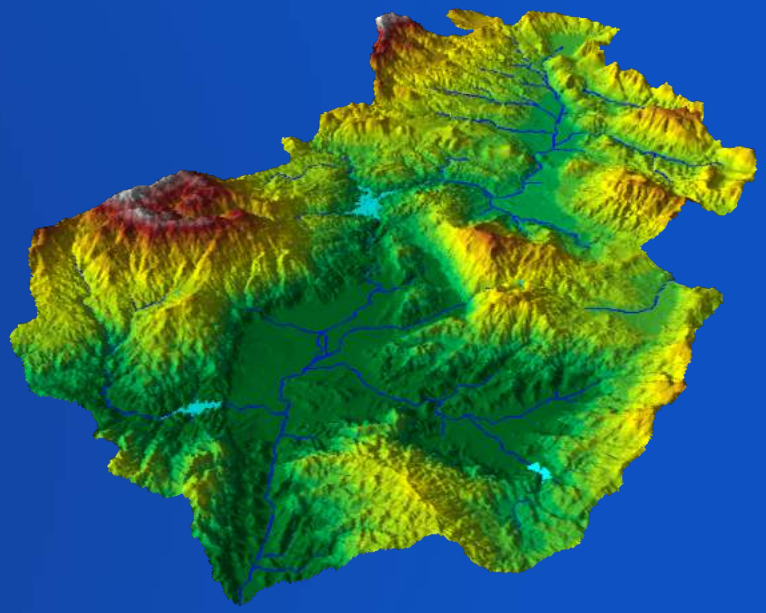
- Check out Esri's Living Atlas (AGOL)
- Digital Elevation Model and land cover
  - http://seamless.usgs.gov/
  - https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution
- Watershed boundaries
  - http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/
- Hydrography
  - 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!”

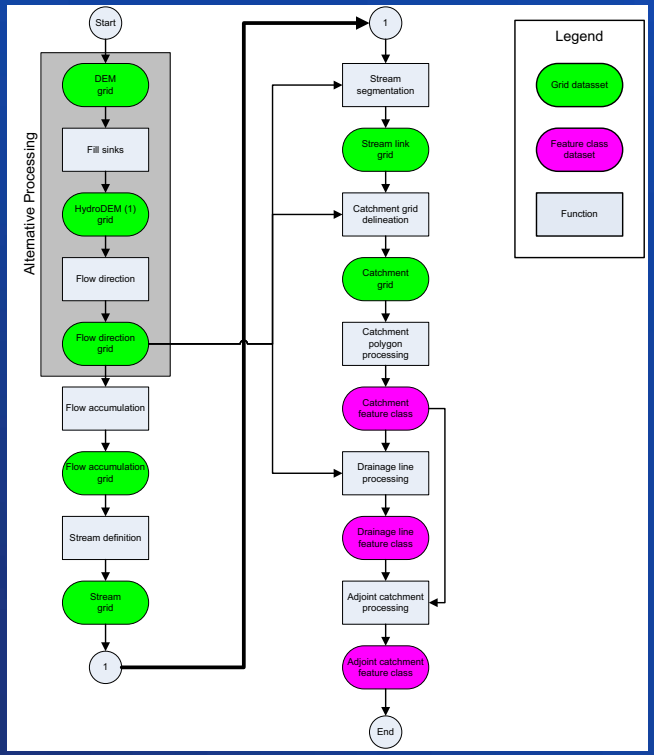
Elevation Data – Key Dataset

- Resolution and extent
- Projection (for hydrology – use equal area)
- Source of elevation data (consistency)
- Hydro conditioning of DEM
  - Varies with the analysis purpose
    - Floods
    - Droughts
  - Different morphologies
    - Dendritic, deranged, combined

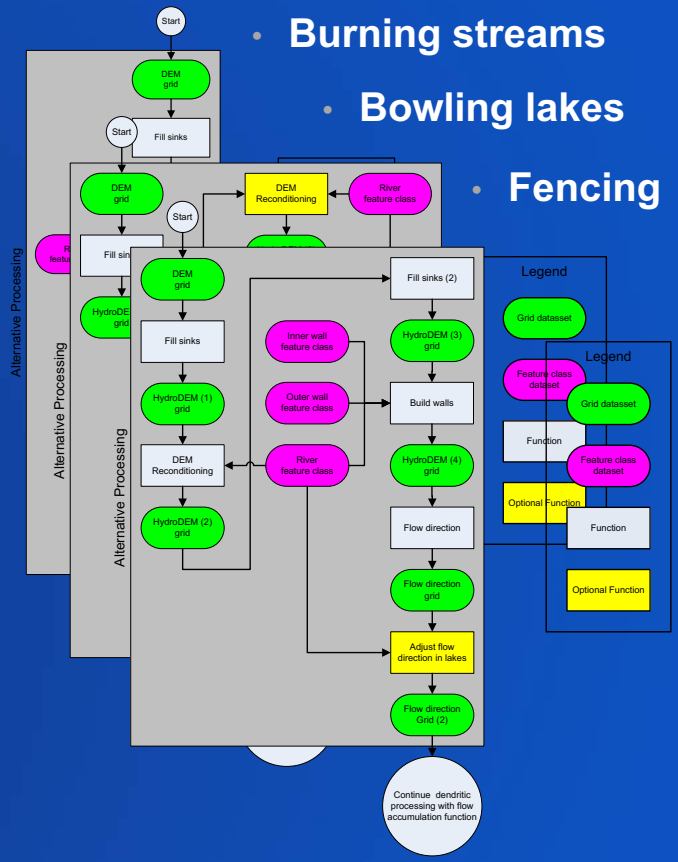


Workflows, Workflows, Workflows

- "Basic" dendritic preprocessing



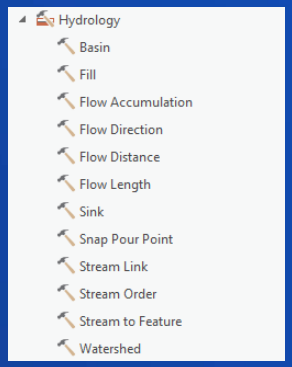
- Burning streams
- Bowling lakes
- Fencing

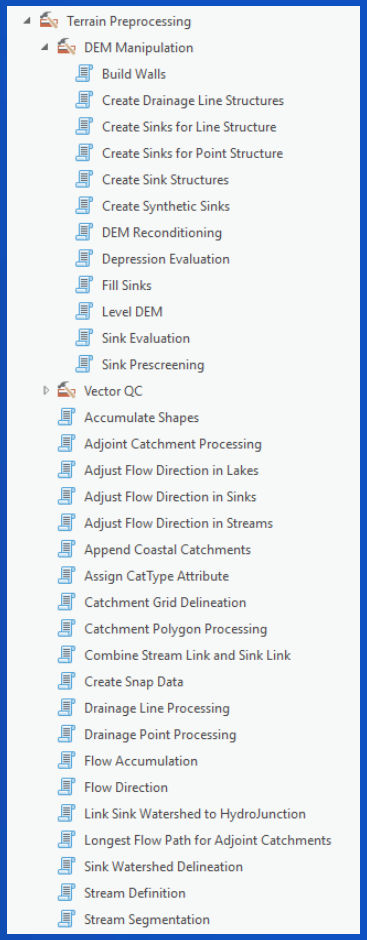


Where is this Functionality?

- Core capabilities:
  - ArcMap/Pro Spatial Analyst Toolbox
    - Tools in the Hydrology Toolset
  - ArcGIS Raster Functions
  - ArcGIS Image Server

- Extended capabilities:
  - Arc Hydro Tools
    - Arc Hydro Toolbox
    - Arc Hydro Toolbar

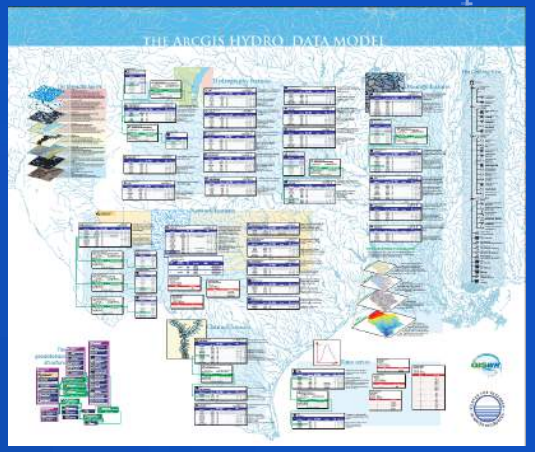


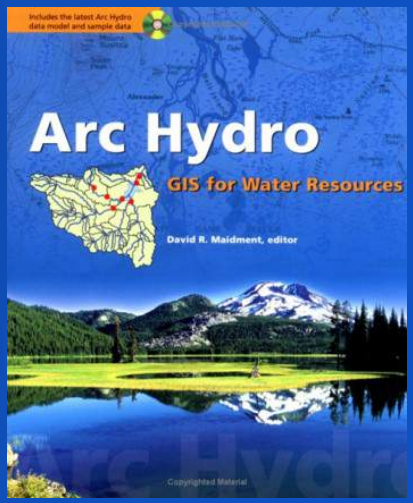


Brief History

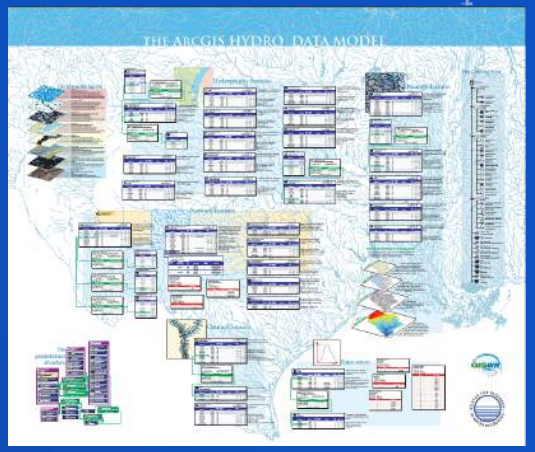
1999 – 2002

- Project to demonstrate geodatabase capabilities in water resources.
- Worked with Dr. David Maidment at the University of Texas.
- Focused on the Arc Hydro Data Model.
- Released in 2002 as a data model, a toolset, and an Esri Press book (Arc Hydro).
  - Initial set of ~ 30 tools (8.3) developed by Esri (PS) as a complement to the data model.



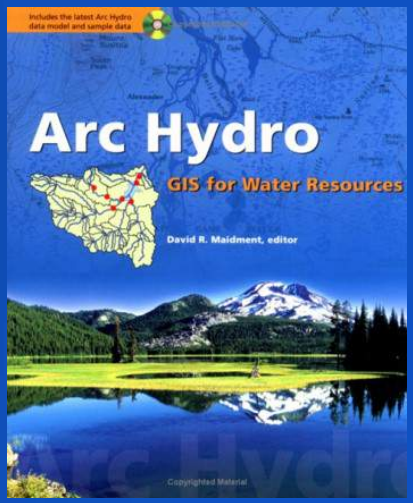


Brief History



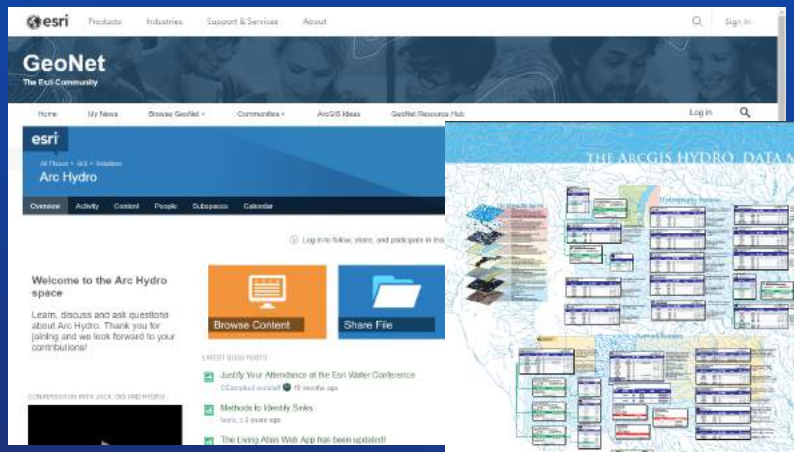
Since 2003:

- **Arc Hydro tool development through projects.**
  - This added ~300+ tools over the years.
- **Tool maintenance** (version updates, move to Pro, etc.).
- **User support** (Web pages, GeoNet, response to emails, etc.).
  - **https://community.esri.com/community/gis/solutions/arc-hydro**
- **Training classes** (managed as standard Esri training and are delivered by PS).
- **Arc Hydro Groundwater**
  - Added in 2007.
  - Collaboration with Aquaveo and published Esri Press book (Arc Hydro Groundwater, 2011).
  - Aquaveo provides extensions (fee) and support

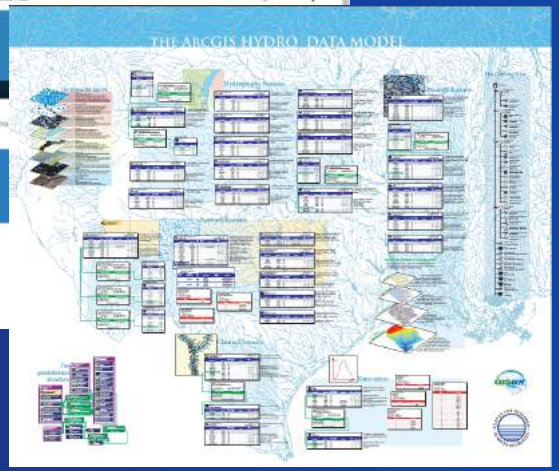


Vision

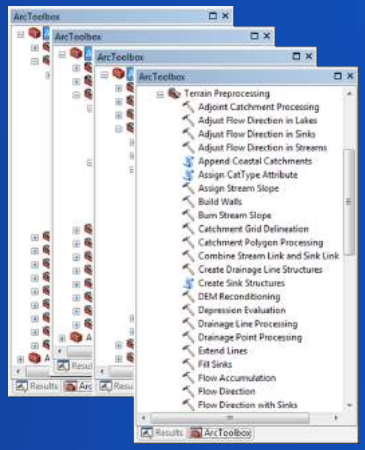
"Provide practical GIS framework for development of integrated analytical systems for water resources market."



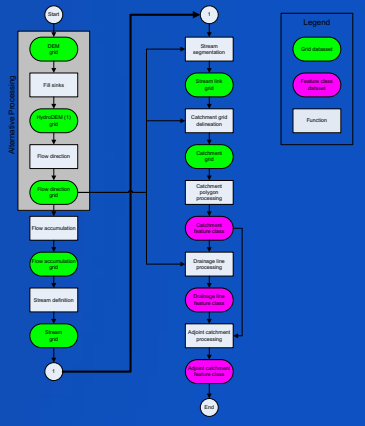
Community



Data Model



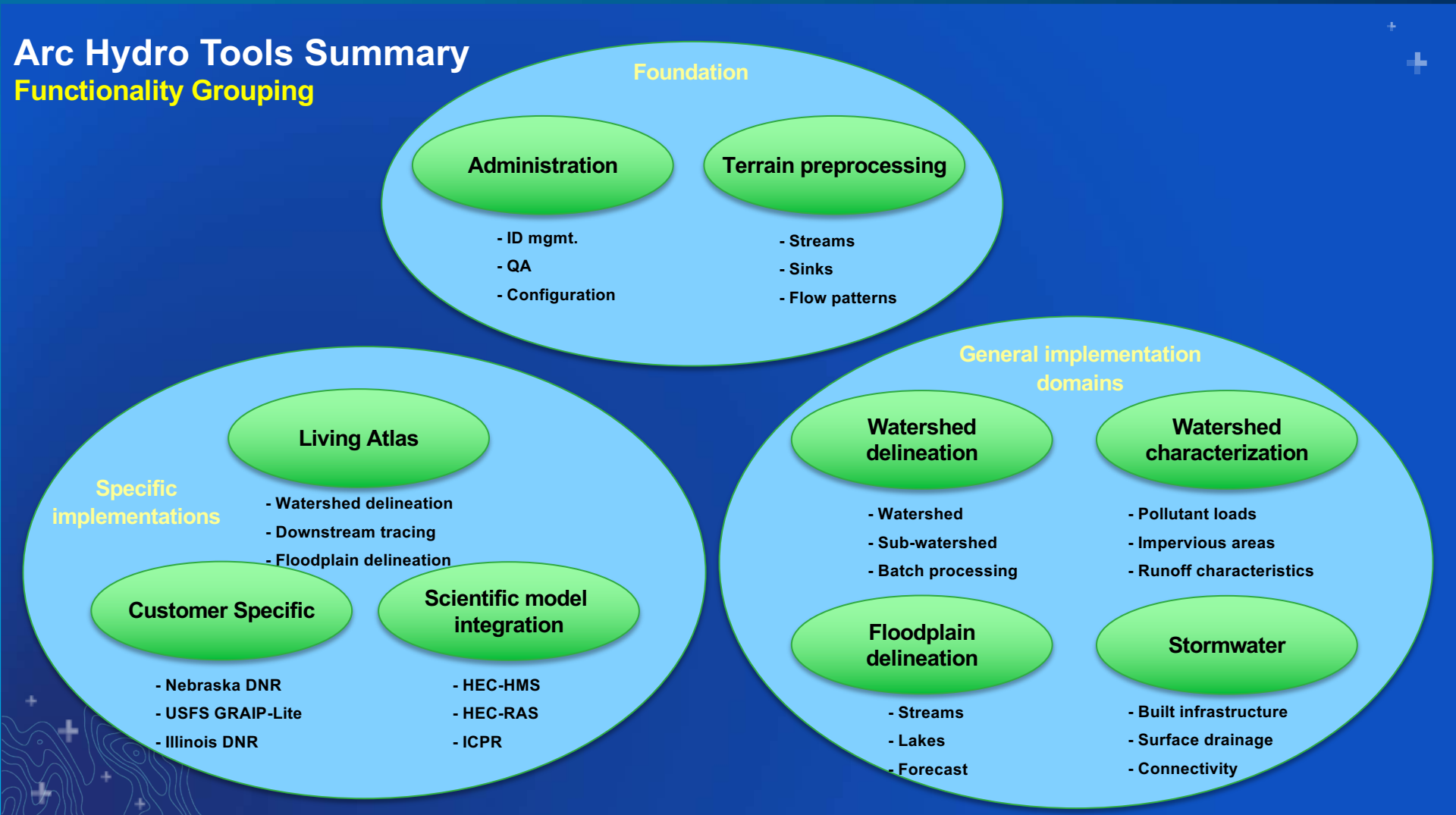
Tools



Workflows

Arc Hydro Tools Summary

Functionality Grouping



“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

Arc Hydro

Demo

Hydrologic and Hydraulic Modeling Support with GIS:

- Hydrologic modeling:
  - Statistical hydrology - StreamStats
- Hydraulic modeling:
  - Floodplain delineation

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

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:

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

- 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

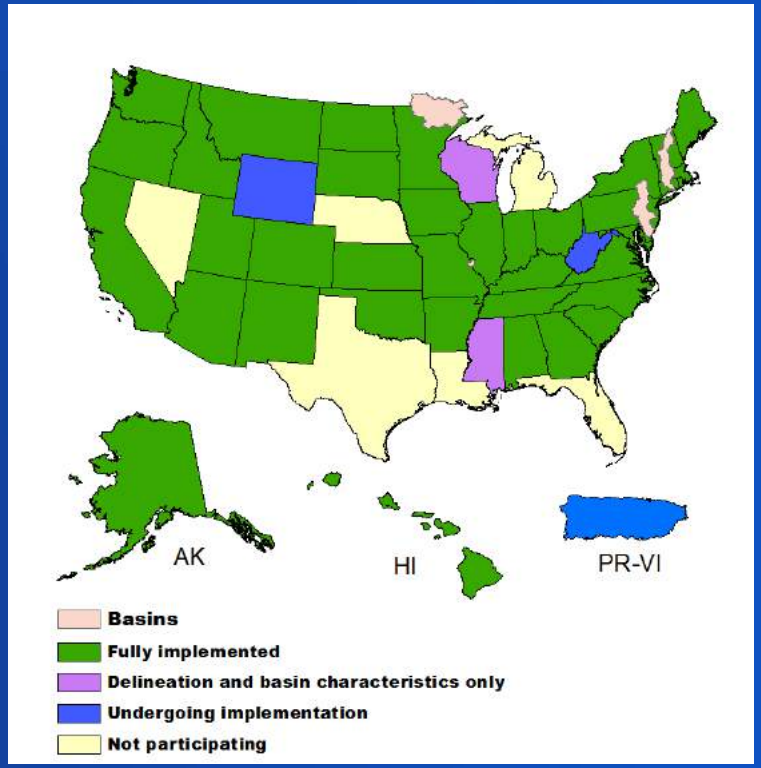
Role of GIS

- 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.

StreamStats Implementation Activities

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

Source: https://streamstats.usgs.gov/ss/



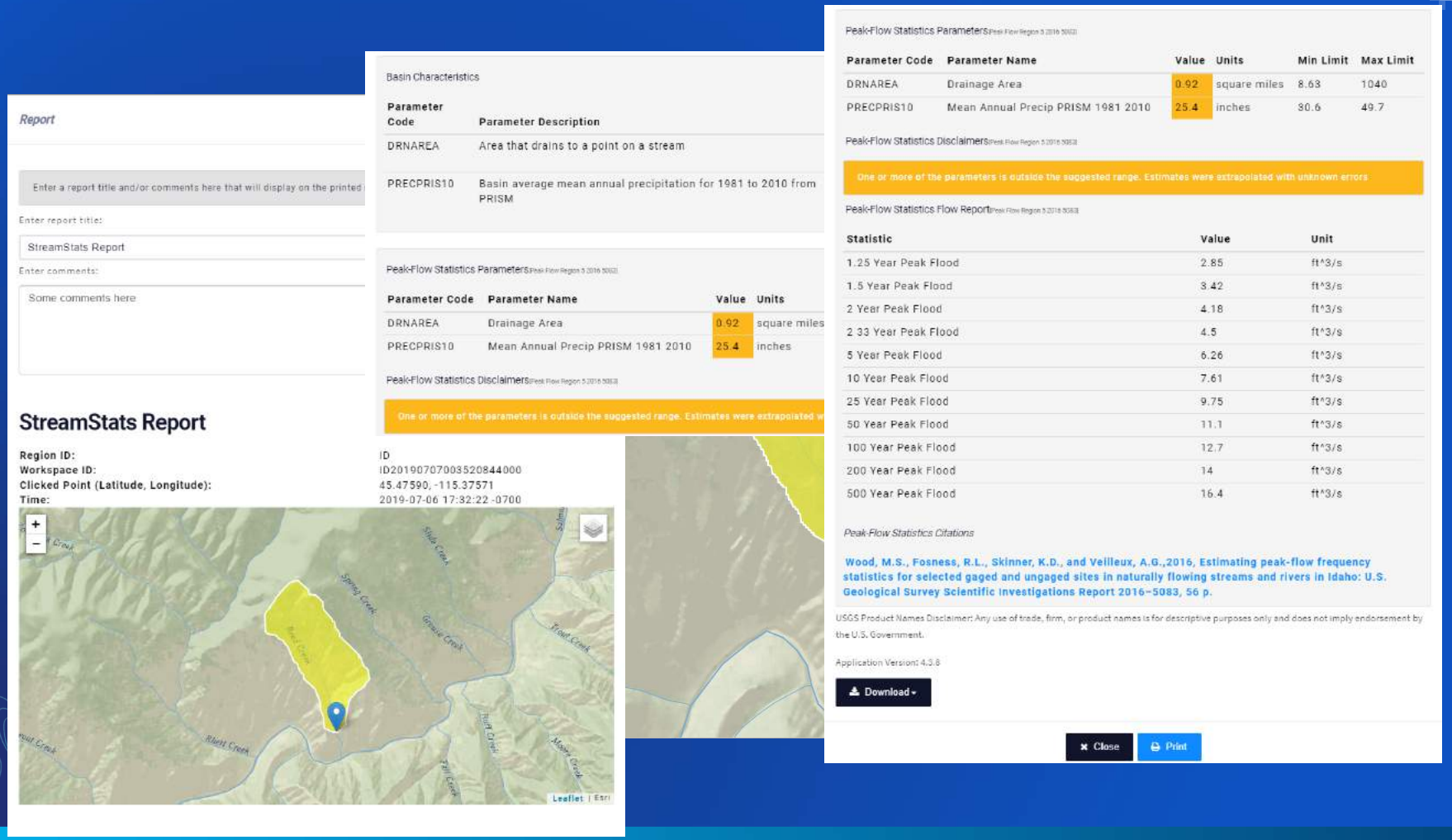
July 2018

StreamStats

Demo

https://streamstats.usgs.gov/ss/

StreamStats Demo



Report

Enter a report title and/or comments here that will display on the printed

Enter report title:

StreamStats Report

Enter comments:

Some comments here

StreamStats Report

Region ID:
Workspace ID:
Clicked Point (Latitude, Longitude):
Time:

ID
ID20190707003520844000
45.47590, -115.37571
2019-07-06 17:32:22 -0700

Basin Characteristics

Parameter Code	Parameter Description
DRNAREA	Area that drains to a point on a stream
PRECPRIS10	Basin average mean annual precipitation for 1981 to 2010 from PRISM

Peak-Flow Statistics Parameters

Parameter Code	Parameter Name	Value	Units
DRNAREA	Drainage Area	0.92	square miles
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	25.4	inches

Peak-Flow Statistics Disclaimers

One or more of the parameters is outside the suggested range. Estimates were extrapolated w

Peak-Flow Statistics Parameters

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.92	square miles	8.63	1040
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	25.4	inches	30.6	49.7

Peak-Flow Statistics Disclaimers

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors

Peak-Flow Statistics Flow Report

Statistic	Value	Unit
1.25 Year Peak Flood	2.85	ft^3/s
1.5 Year Peak Flood	3.42	ft^3/s
2 Year Peak Flood	4.18	ft^3/s
2.33 Year Peak Flood	4.5	ft^3/s
5 Year Peak Flood	6.26	ft^3/s
10 Year Peak Flood	7.61	ft^3/s
25 Year Peak Flood	9.75	ft^3/s
50 Year Peak Flood	11.1	ft^3/s
100 Year Peak Flood	12.7	ft^3/s
200 Year Peak Flood	14	ft^3/s
500 Year Peak Flood	16.4	ft^3/s

Peak-Flow Statistics Citations

Wood, M.S., Fosness, R.L., Skinner, K.D., and Veilleux, A.G.,2016, Estimating peak-flow frequency statistics for selected gaged and ungaged sites in naturally flowing streams and rivers in Idaho: U.S. Geological Survey Scientific Investigations Report 2016–5083, 56 p.

USGS Product Names Disclaimer: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Application Version: 4.3.8

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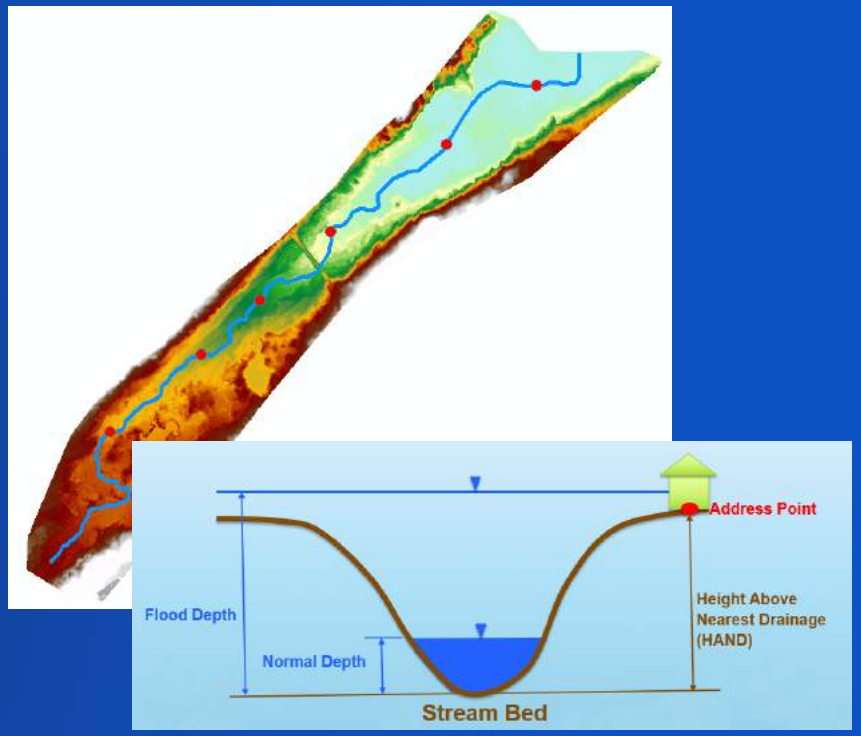
Hydraulics:
Floodplain Delineation

Pin2Flood

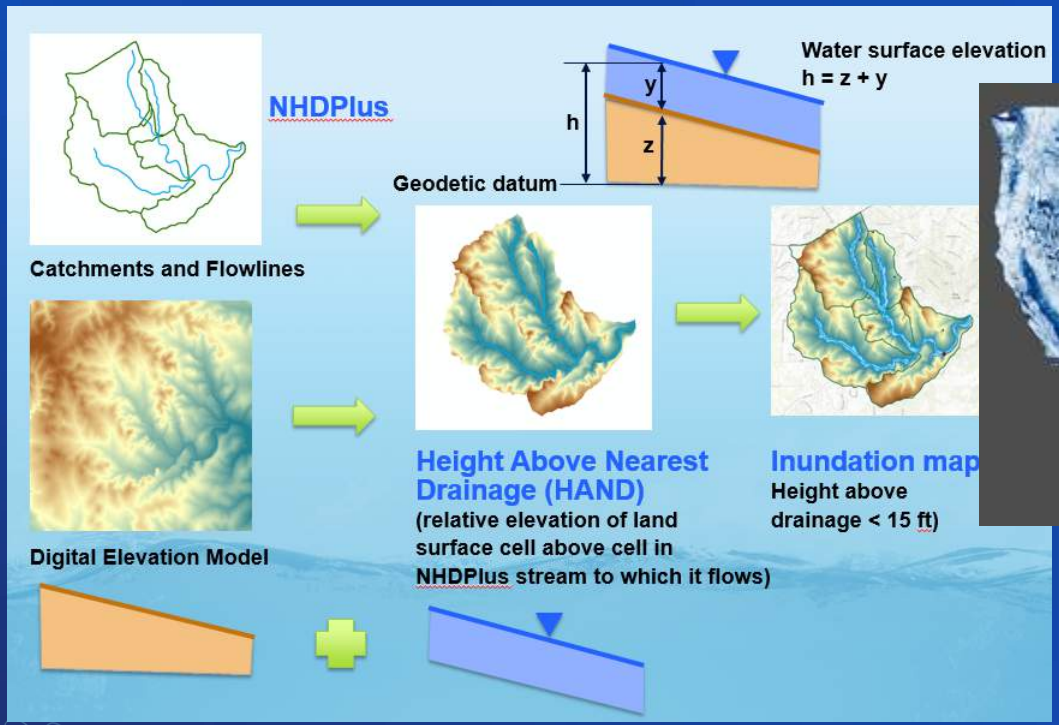
Demo

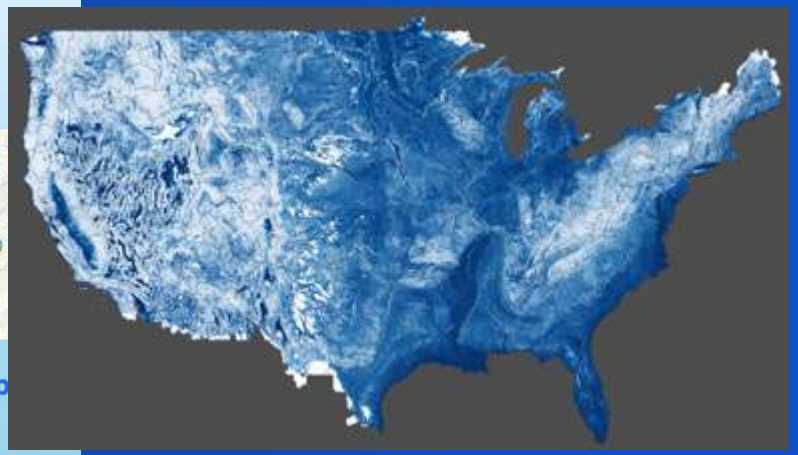
Floodplain Delineation Solutions Matrix

- Different levels of complexity are possible/needed to determine flood extents
- Simple:
  - "Flooding out" based on DEM, stream centerline, and point data (fixed depth, incremental depth, observed measurements, modeled flows at points and conversion to WSE)
  - HAND approach (constant depth of flooding per reach)



Flood Inundation Mapping – NHDPlus-HAND Method

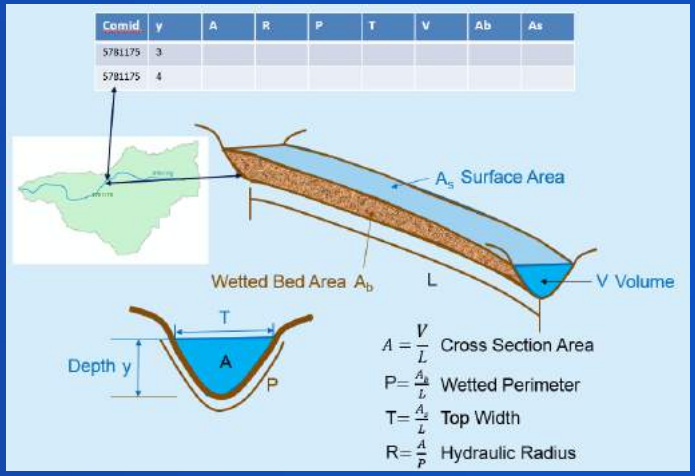




Source: Yan Liu, University of Illinois at Urbana-Champaign

Landscape characterization

- Streams
  - DEM alignment and thalweg adjustment
  - Longitudinal WSE interpolation based on point values
- Cross-sections/reach
  - Characterization: h, A, B, P, R curve
  - Synthetic rating curve (based on normal depth with n and S_0 assumption)
  - WSE Interpolation
- Floodplain (for incremental or specific stages)
  - Depth of flooding
  - Water surface elevations
  - Flood extent

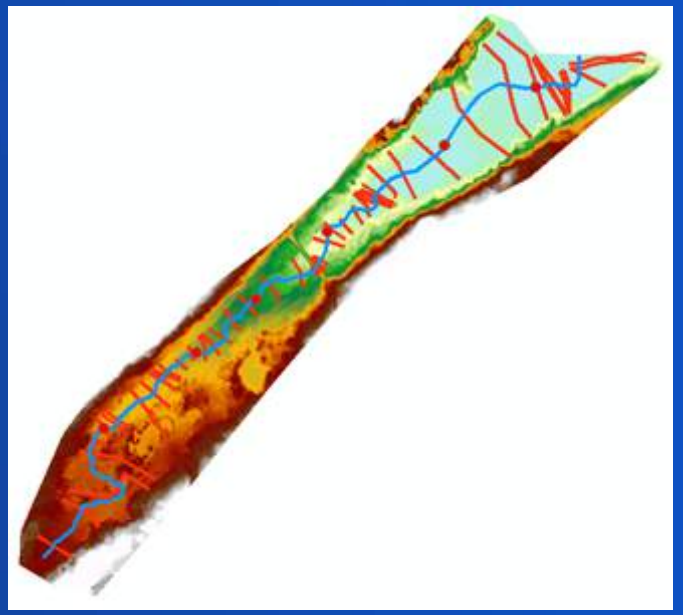


Source: David R. Maidment, UT Austin

XID	Z	H	A	P	R	B	Q
1451	1676.99	28.99	38655.6	1955.3	19.8	1932.3	55214.7
1451	1671.19	23.19	27689.7	1867	14.8	1850	39551.4
1451	1665.4	17.4	17209	1759	9.8	1746.6	24581
1451	1659.6	11.6	9212.7	1967.1	4.7	1957.4	13159.2
1451	1653.8	5.8	855.2	1075.3	0.8	996.4	1221.5
1452	1688.18	35.9	64511.6	2733.8	23.6	2710.2	85305.9
1452	1681	28.72	45492	2563.3	17.7	2542.4	60155.6
1452	1673.82	21.54	28000	2335.9	12	2315.7	37025.4
1452	1666.64	14.36	19863	2893.6	6.9	2873.7	26265.5
1452	1659.46	7.18	2891.5	2040.4	1.4	1877	3823.5

Floodplain Delineation Solutions Matrix

- **Less simple:**
  - **Same as above, but using cross-sections to control lateral distribution of water surface elevations along the stream centerline**

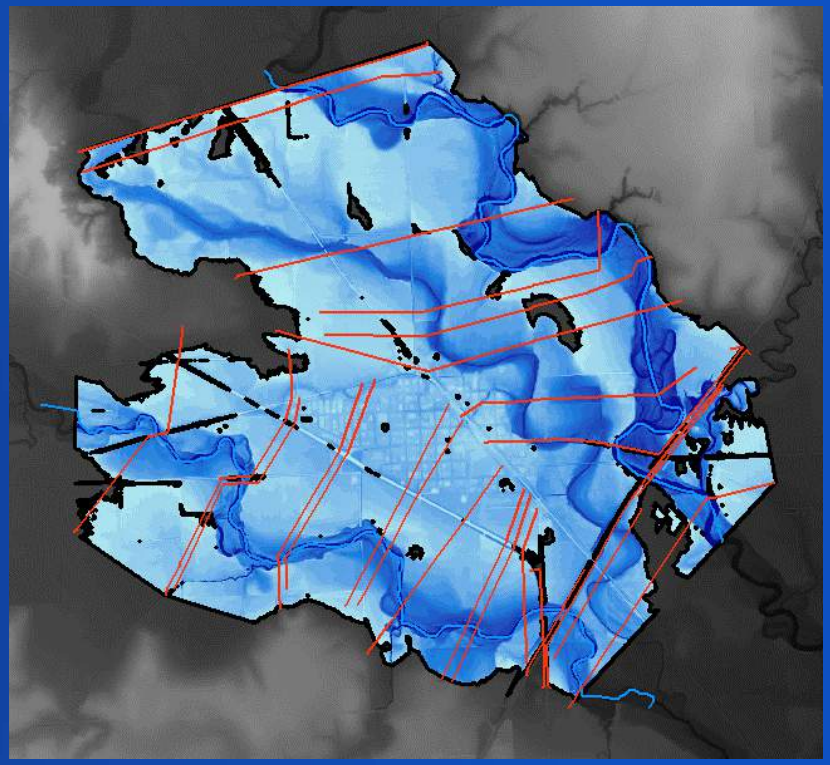


Floodplain Delineation Solutions Matrix

- More complex:
  - 1-D hydraulic modeling in operational mode (complexity in data collection)
  - 1-D hydraulic modeling in design mode (for fixed flood frequency – design discharges derived using statistical methods)
  - 1-D hydraulic modeling in design mode (for fixed flood frequency – design discharges derived using deterministic methods)
- Most complex:
  - Fully integrated 2-D hydrologic and hydraulic modeling

Simplified Floodplain Delineation Tools

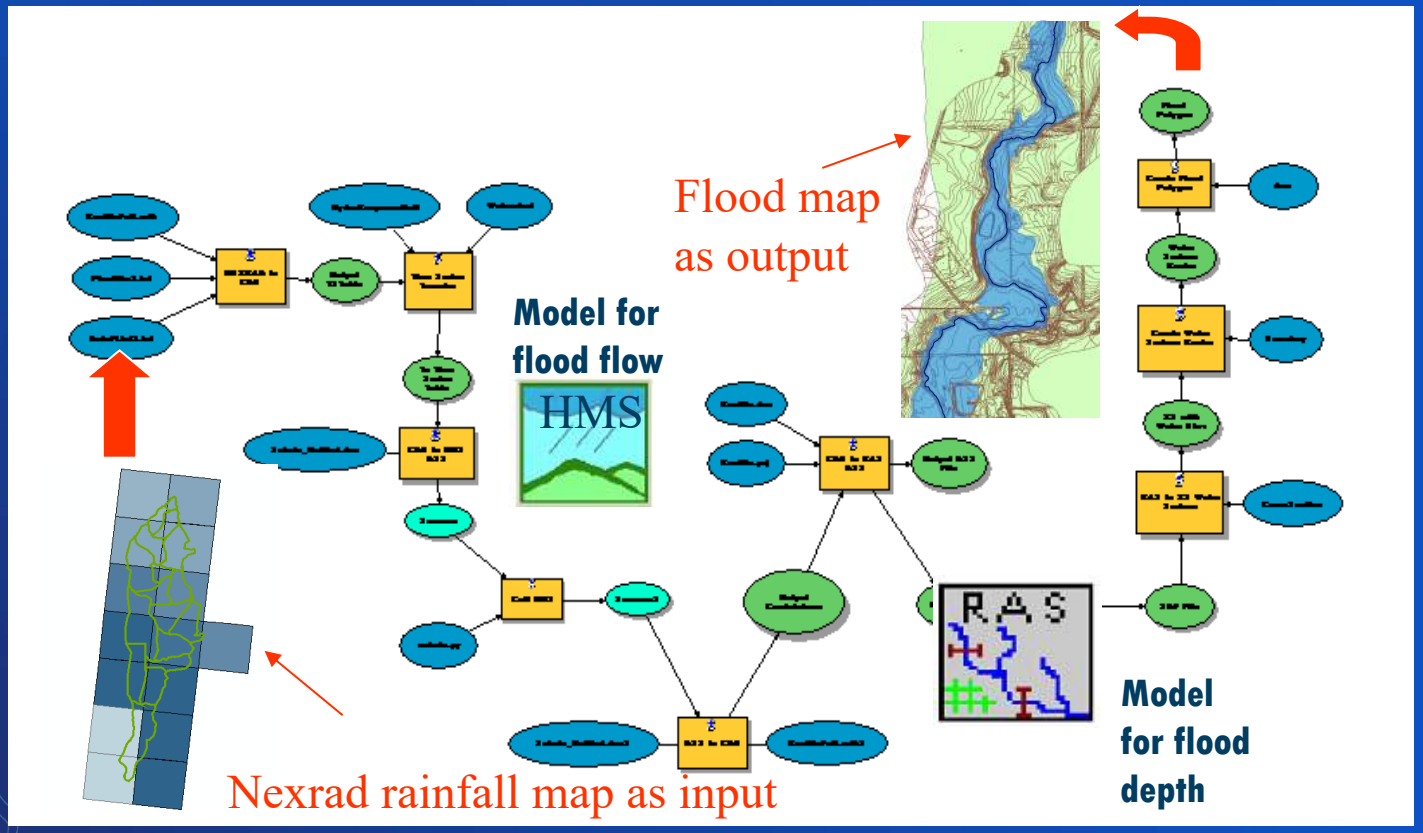
- Support for floodplain analysis
  - Real-time (observed, forecasted flows)
  - Planning (flood frequency)
- Facilitate landscape characterization for floodplain analysis
  - Streams
  - Cross-sections
  - Floodplain
- Floodplain delineation
  - Points
  - Cross-sections
  - From models



Tools

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

Map2Map (rainfall to floodplain)



Complex H&H Conditions

ICPR4 Model: Cross Bayou - Mariners Cove Area
Flood Depth Animation: T.S. Hermine (Aug 31 – Sept 1, 2016)

Summary

- GIS provides many capabilities for support of hydro analyses
- 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

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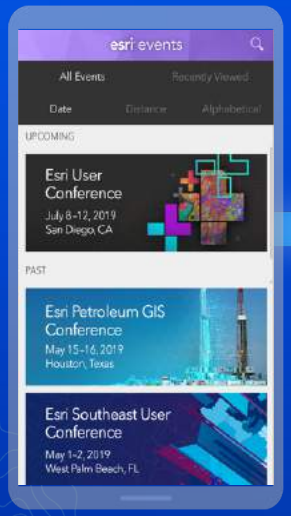
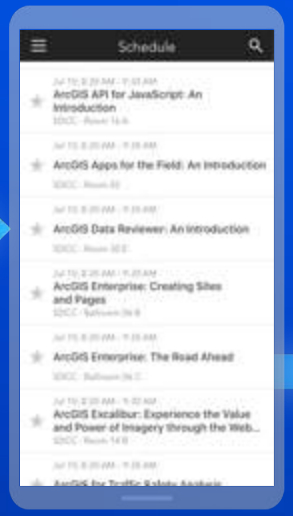
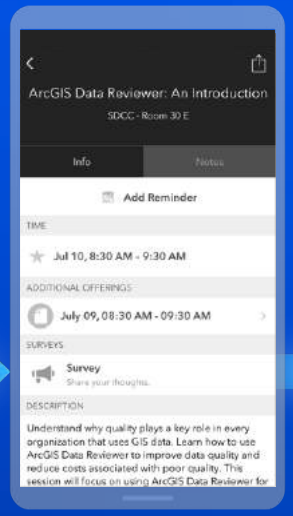


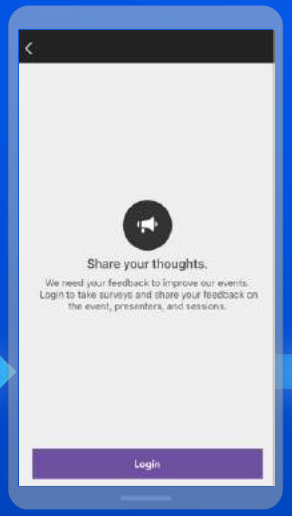
Select the session you attended



Scroll down to "Survey"



Log in to access the survey



Complete the survey and select "Submit"