# Creating a Hydrologically Conditioned DEM

Dean Djokic (ddjokic@esri.com)

# Content

- What is a “hydrologically conditioned DEM”
- How to develop hydro DEM
- Tools for hydro DEM conditioning
- Using hydro DEM/flow direction

# What is a “hydrologically conditioned DEM”

# What is a “hydrologically conditioned DEM”

- **Hydrologically conditioned DEM (Hydro DEM) is a DEM whose flow direction defines expected flow of water over the terrain (DEM).**
- **What is important is the resulting flow pattern, not the actual elevation in the DEM.**

# What is a “hydrologically conditioned DEM”

- **Elevation in the DEM is secondary to the flow direction it generates.  You are NOT “fixing” elevations in the DEM – just making changes to get the flow direction correctly.  Take advantage of that (don’t sweat the small things)!**
- **Do NOT use hydro DEM for surface characterization, just for flow direction determination.**

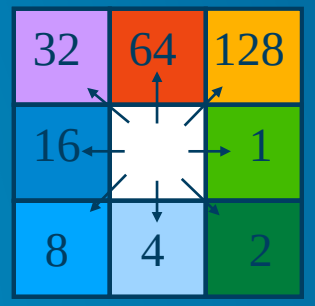
# Flow Direction

| | | | | | |
|---|---|---|---|---|---|
| 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 |

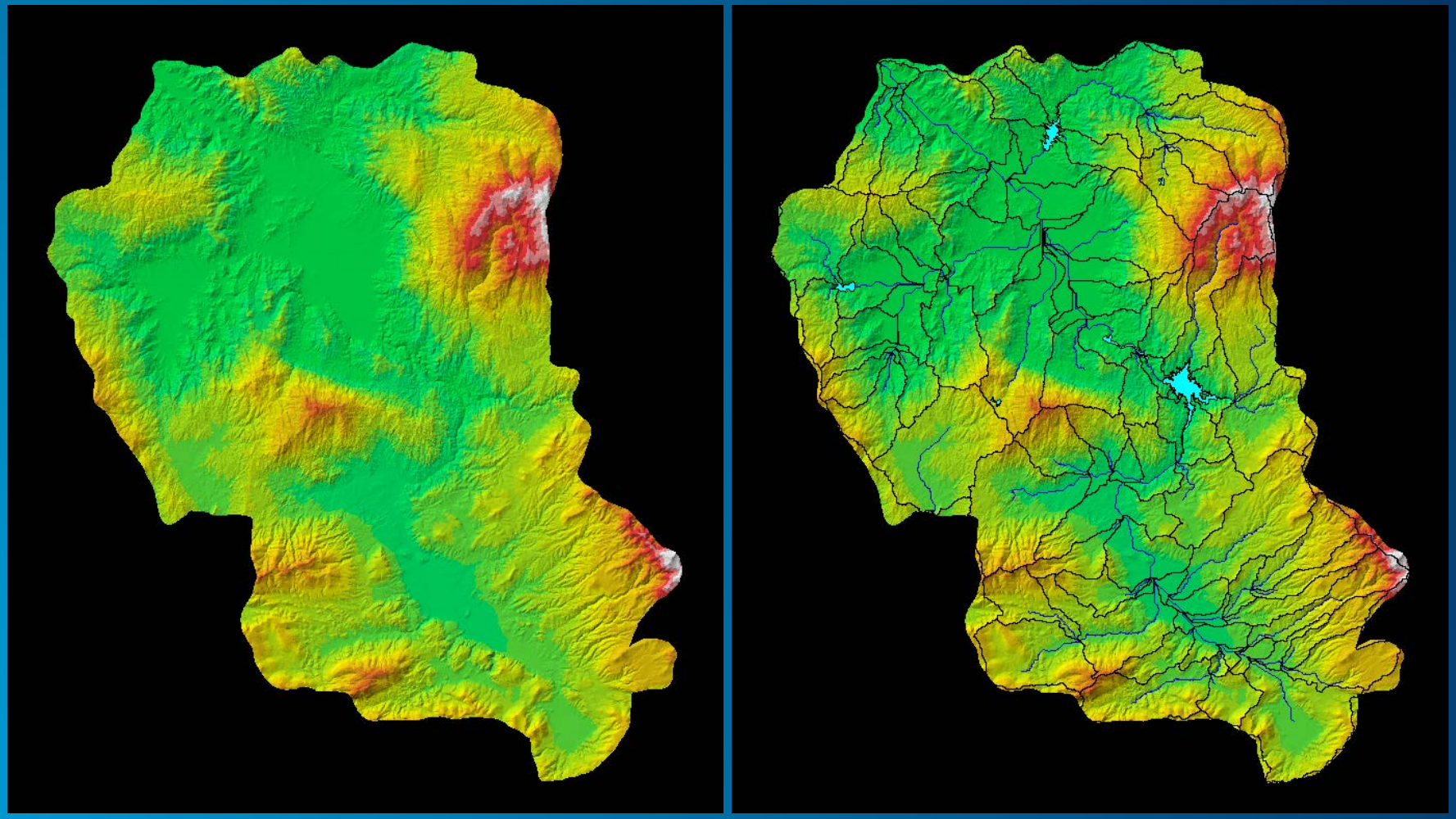
Flow Direction




Direction Coding

# Hydro DEM

- **What matters is the drainage pattern!**



# One size does not necessarily fit all

- **Hydro DEM is a function of analysis being performed. Different analyses will require different hydro DEM for the same area. Some examples:**
  - **Environmental (low) flows – small depressions in the terrain are important and should be explicitly modeled. They will catch and retain water.**
  - **High flows (floods) – smaller depressions (and some larger ones) will fill and contribute to the downstream areas. They can be "ignored".**

# One size does not necessarily fit all

- **Examples continued:**
  - **Design conditions (e.g. structure design). Most depressions can be "ignored" as it is expected that under design conditions they will be filled due to the size of the event and will eventually contribute to the flow downstream.**
  - **Real-time management (e.g. emergency management). While depressions will eventually fill and "spill", the storage they provide might be critical for timing of the runoff and timely management of the resources (e.g. evacuation).**

# One size does not necessarily fit all

- **Examples continued:**
  - **Hydrology.  Focus on getting the contributing area.  DEM can be coarser and generalized, but has to extend to larger area – whole watershed.  Have to deal with depressions but coarser DEM will "smooth" out details, so there will be less issues to deal with.**

# One size does not necessarily fit all

- **Examples continued:**
  - **Hydraulics.  Focus on channel flow conveyance.  Has to be detailed, but has more limited spatial extent – just floodplain.  Does not have to be as concerned with smaller imperfections.**
  - **Explicit models and modeling techniques.**
    - **1-D or 2-D overland models.**
    - **Are depressions modeled as storage areas or not.**
    - **DEM too detailed/large.**
    - **…**

# How to develop hydro DEM

# How to develop hydro DEM

## … carefully

- You have to know your terrain!
  - Do field work.  Talk to the locals.  Know the history.
  - Get wet - be there when it rains ☺.
- You have to know what it will be used for.
- Have supplemental topographic/hydrographic data:
  - Known drainage lines (streams).
  - Known ridges.
  - Known depressions.

# How to develop hydro DEM

## … carefully

- **Have “other” supplemental data sources such as land use, soils, vegetation, that can all help in identifying geomorphologic elements (e.g. certain soils indicate standing water that in turn indicates depressions).**

# How to develop hydro DEM

- **Process can be iterative if you do not know the existing drainage pattern or/and do not have supplemental data.**
  - **Make assumptions on the flow pattern**
  - **Apply them (burn streams, wall ridges)**
  - **Get the flow direction based on those assumptions**
  - **Evaluate the flow pattern and modify the assumptions if necessary**

# How to develop hydro DEM

- **More difficult in flat areas!**
  - **If you do not know where the critical morphological structures are (ridges in particular), it might be impossible to determine them from the DEM alone.**

# Key techniques for hydro DEM development

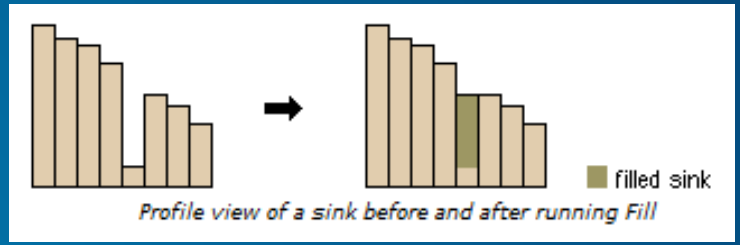
… not that many

- **“Fill” sinks.**
- **“Burn” streams.**
- **“Wall” ridges (also called “fencing”).**
- **Manage flow within lakes.**
- **When all fails – change flow direction directly instead of modifying DEM to get the right flow direction.**

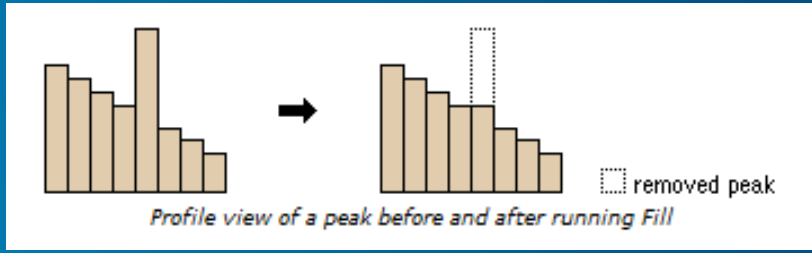
# Fill sinks

… to fill or not to fill …

- **Sinks**
  - **Global fill**
  - **Dealing with internal basins**
  - **Selective fill**
    - **Depth**
    - **Area**




*Profile view of a sink before and after running Fill*

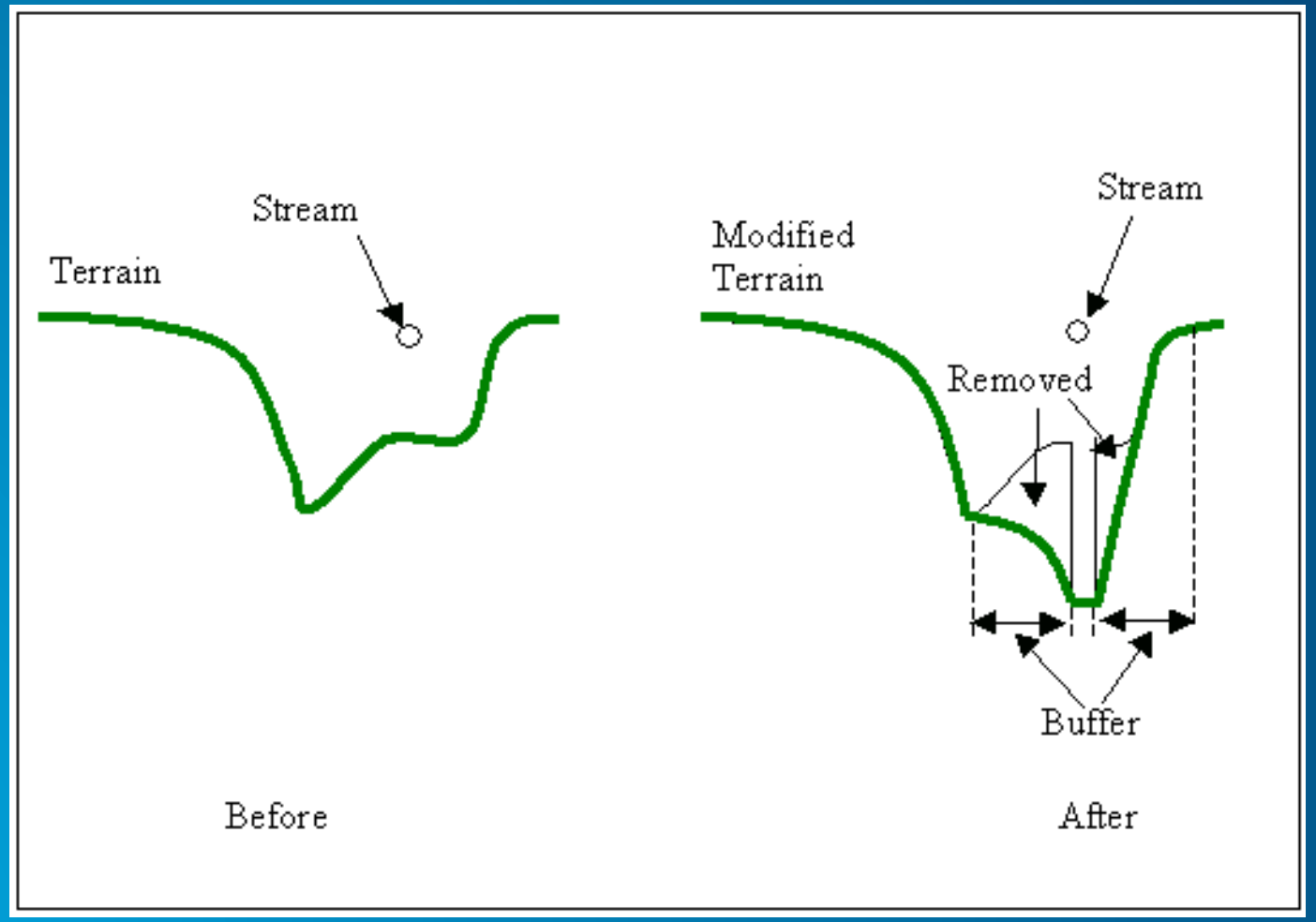



*Profile view of a peak before and after running Fill*

*… or you can shave off peaks …*

# “Burn” streams or “fence” ridges

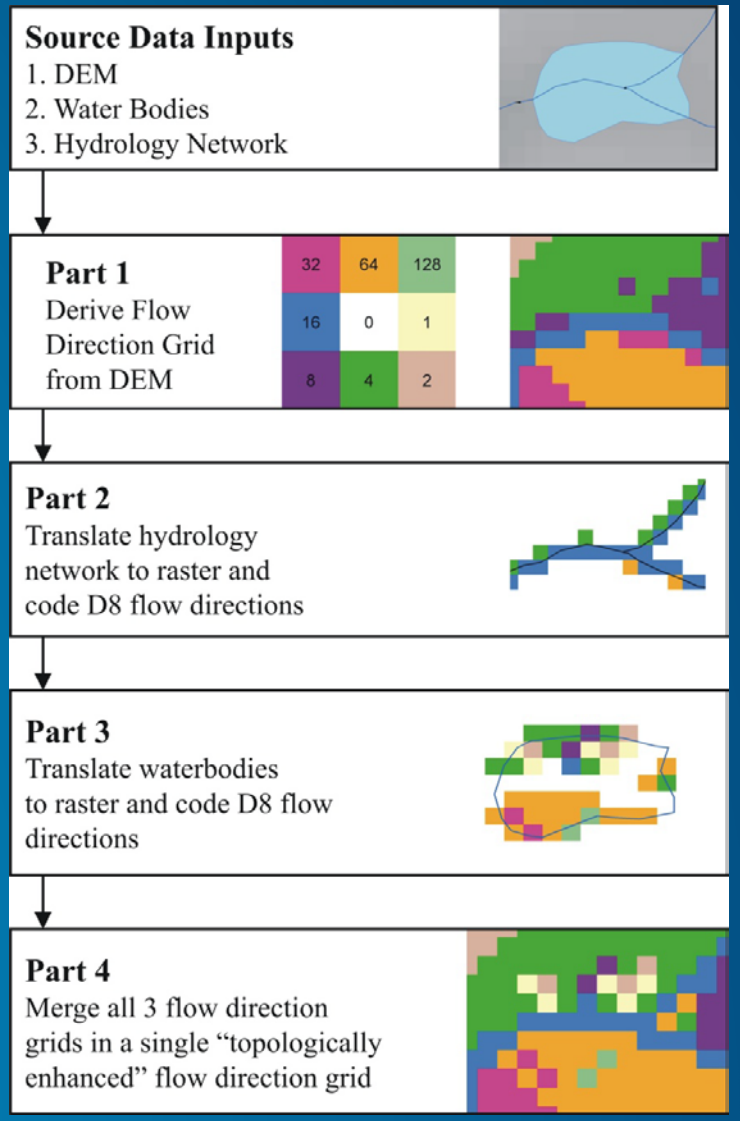
## … aka AGREE (UT – Hellweger)



# Modify flow direction directly

## … but be careful

- **Sometimes easier (for few well defined cells)**
- **Sometimes the only way (e.g. flow splits)**
- **Early work at OMNR – Kenny & Matthews**



# Automating hydro DEM development

## … does it make sense?

- **Although hydro DEM development might be iterative process and a function of the predominant terrain morphology (dendritic/deranged), the workflow can be captured and automated.**
- **Automation ensures implementation of best practices and consistency of the approach through the iterations and datasets.**

# Automating hydro DEM development

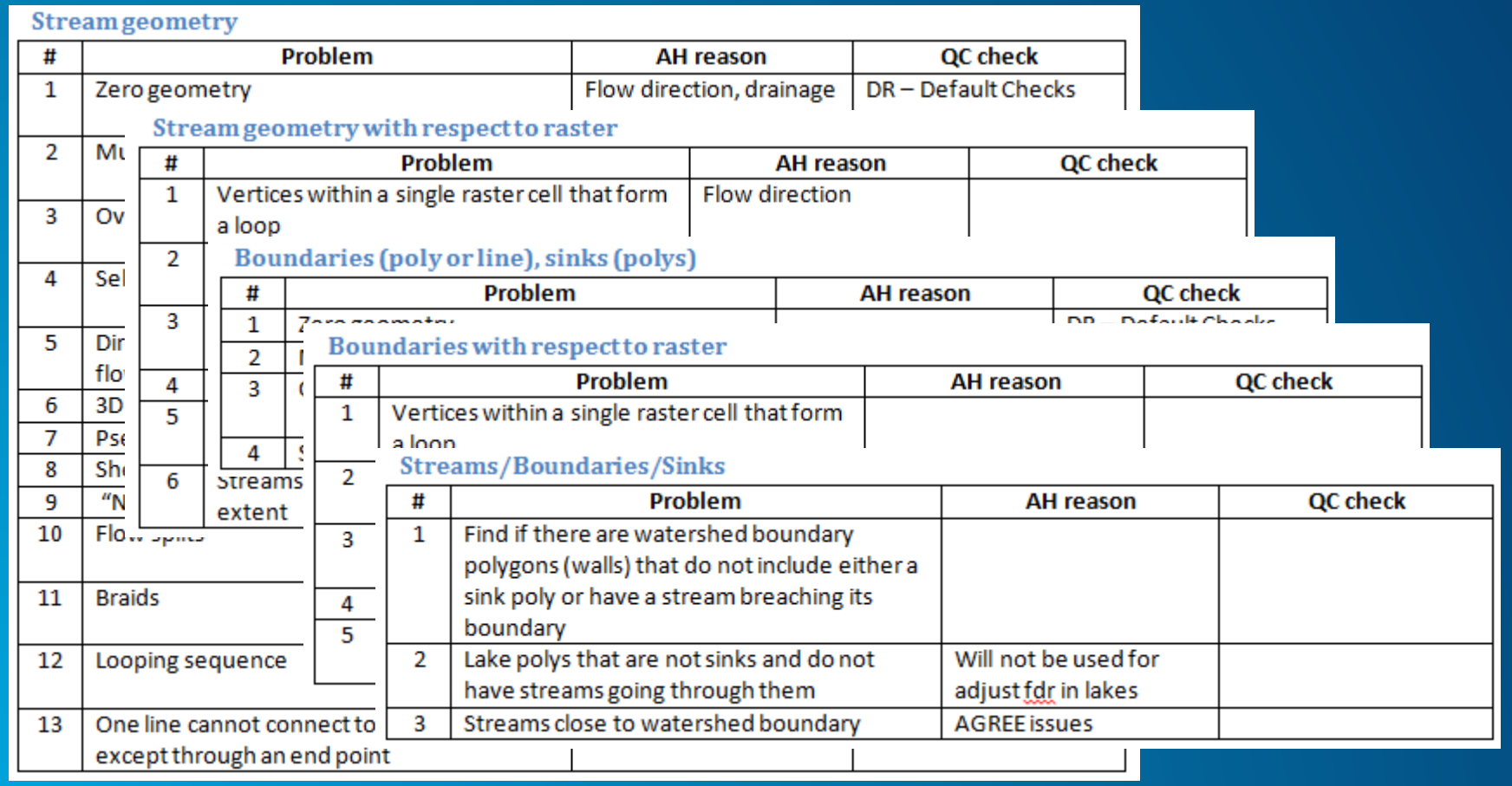
## … does it make sense?

- **Usefulness of the results of the automated process will depend on the quality of the input data and knowledge of the terrain being modeled.**
- **How much QC is needed?**
  - **QC on the DEM itself**
  - **QC on vector data as input into the processing workflow**

# AH Data Health Check (1)

- Data input checks (work in progress)
  - Vectors
    - Streams
    - Sinks, lakes
    - Boundaries
  - Mix of Data Reviewer and geoprocessing

# AH Data Health Check (2)



### Stream geometry

| # | Problem | AH reason | QC check |
|---|---|---|---|
| 1 | Zero geometry | Flow direction, drainage | DR – Default Checks |
| 2 | Mu | | |
| 3 | Ov | | |
| 4 | Sel | | |
| 5 | Dir flo | | |
| 6 | 3D | | |
| 7 | Pse | | |
| 8 | Sh | | |
| 9 | "N | | |
| 10 | Flo | | |
| 11 | Braids | | |
| 12 | Looping sequence | | |
| 13 | One line cannot connect to except through an end point | | |

### Stream geometry with respect to raster

| # | Problem | AH reason | QC check |
|---|---|---|---|
| 1 | Vertices within a single raster cell that form a loop | Flow direction | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | Streams extent | | |

### Boundaries (poly or line), sinks (polys)

| # | Problem | AH reason | QC check |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |

### Boundaries with respect to raster

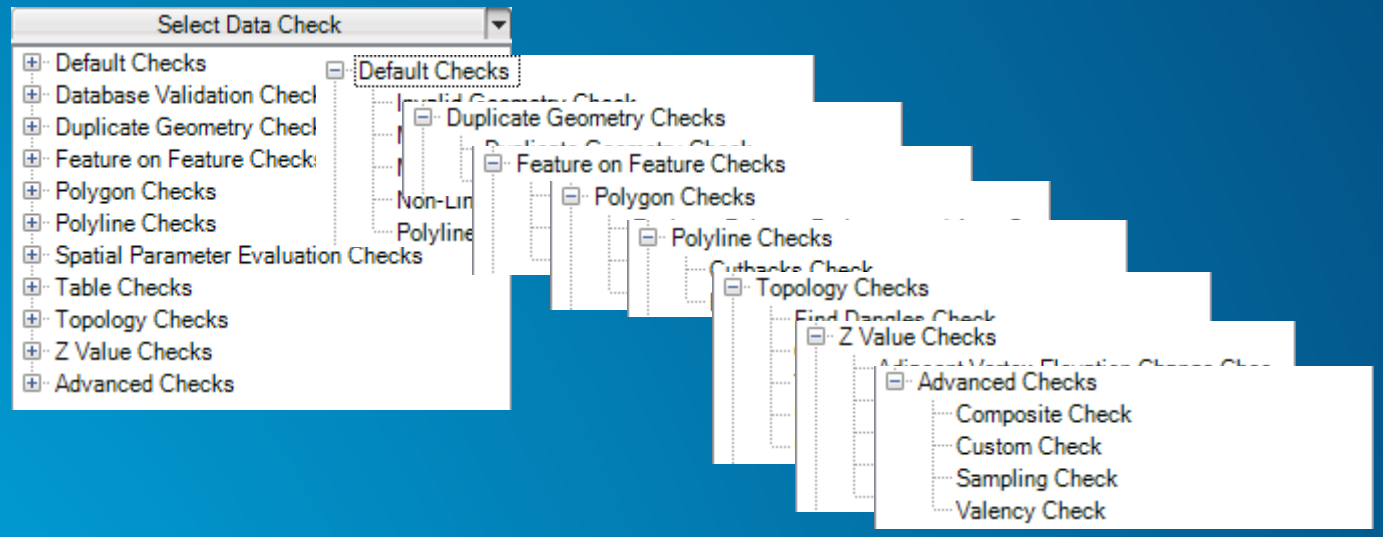
| # | Problem | AH reason | QC check |
|---|---|---|---|
| 1 | Vertices within a single raster cell that form a loop | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

### Streams/Boundaries/Sinks

| # | Problem | AH reason | QC check |
|---|---|---|---|
| 1 | Find if there are watershed boundary polygons (walls) that do not include either a sink poly or have a stream breaching its boundary | | |
| 2 | Lake polys that are not sinks and do not have streams going through them | Will not be used for adjust fdr in lakes | |
| 3 | Streams close to watershed boundary | AGREE issues | |

# AH Data Health Check (3)

- **Use Data Reviewer capabilities**




- **Custom GP QC checks when needed**

# AH Data Health Check (4)

- **Configuration on NHD / NHDPlus V2 data**
- **Check as a service**

- **Does NOT fix data – just identifies issues!**

# Tools for hydro DEM conditioning

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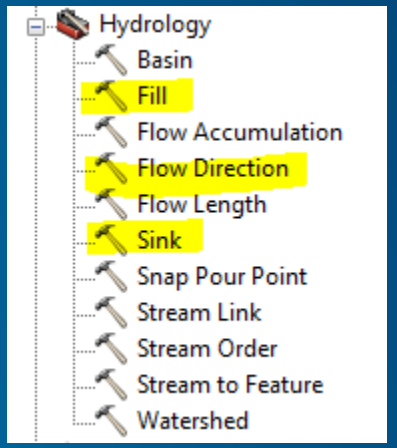
- **Specialized software (ANUDEM, TAUDEM, TOPAZ, …) that can generate raster datasets.**
- **ArcGIS**
  - **Spatial Analyst (basic functionality)**
    - **TopoToRaster**
  - **Arc Hydro (advanced functionality, automation)**

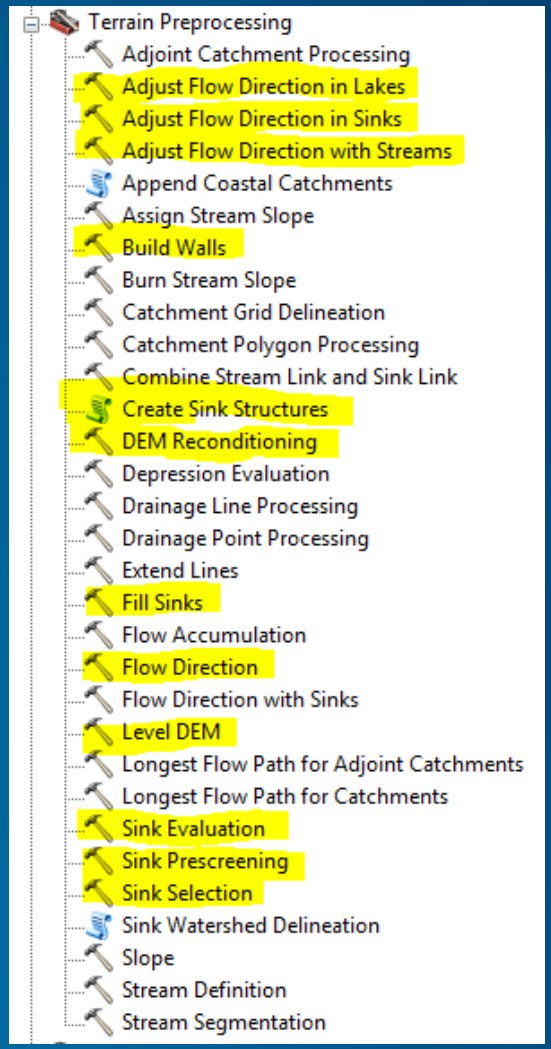
# Tools for hydro DEM conditioning

- **Spatial Analyst (Hydrology toolset)**
  - **Sink (for identification)**
  - **Fill**
  - **Flow Direction**



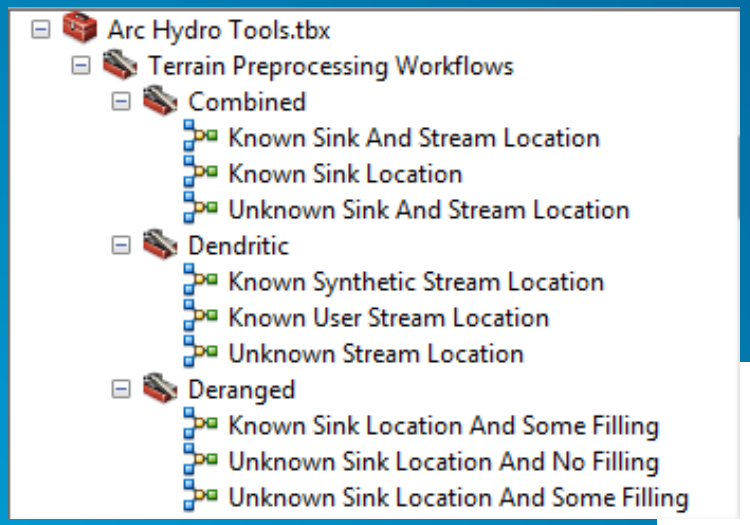
# Tools for hydro DEM conditioning

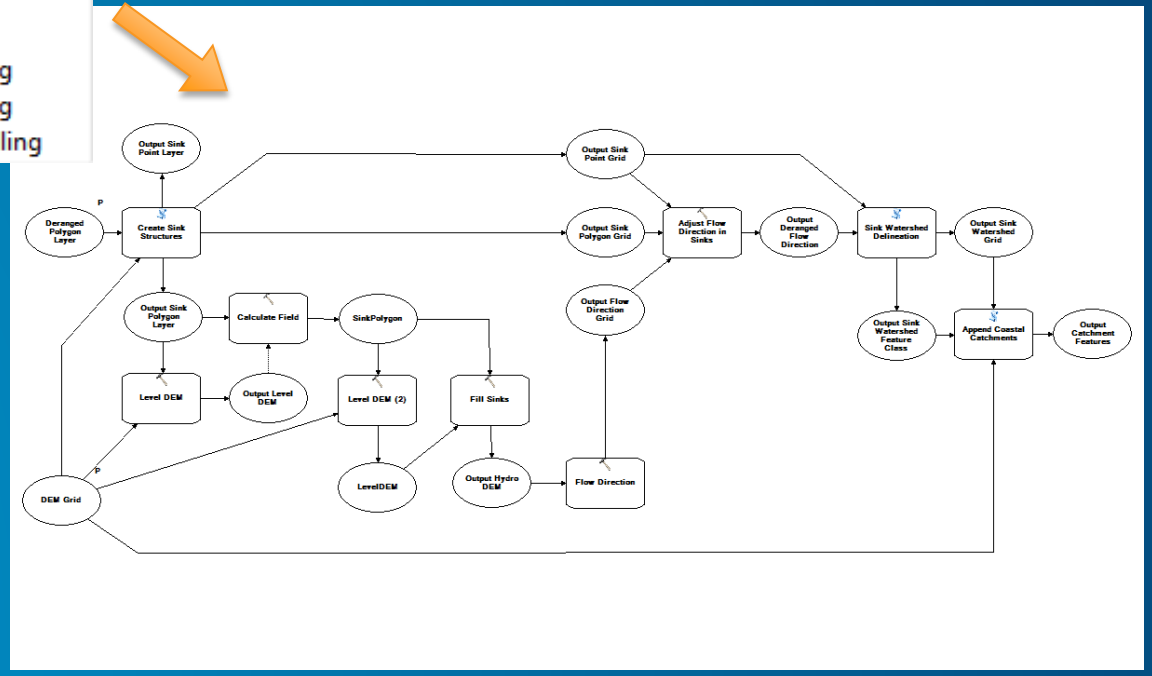
- **Arc Hydro (Terrain Preprocessing toolset)**
  - Adjust Flow Direction in Lakes
  - Adjust Flow Direction in Sinks
  - Adjust Flow Direction with Streams
  - Build Walls (*)
  - Create Sink Structures (for identification)
  - DEM Reconditioning
  - Fill Sinks
  - Flow Direction
  - Level DEM
  - Sink Evaluation (for identification)
  - Sink Prescreening
  - Sink Selection (for identification)



# Automating hydro DEM conditioning

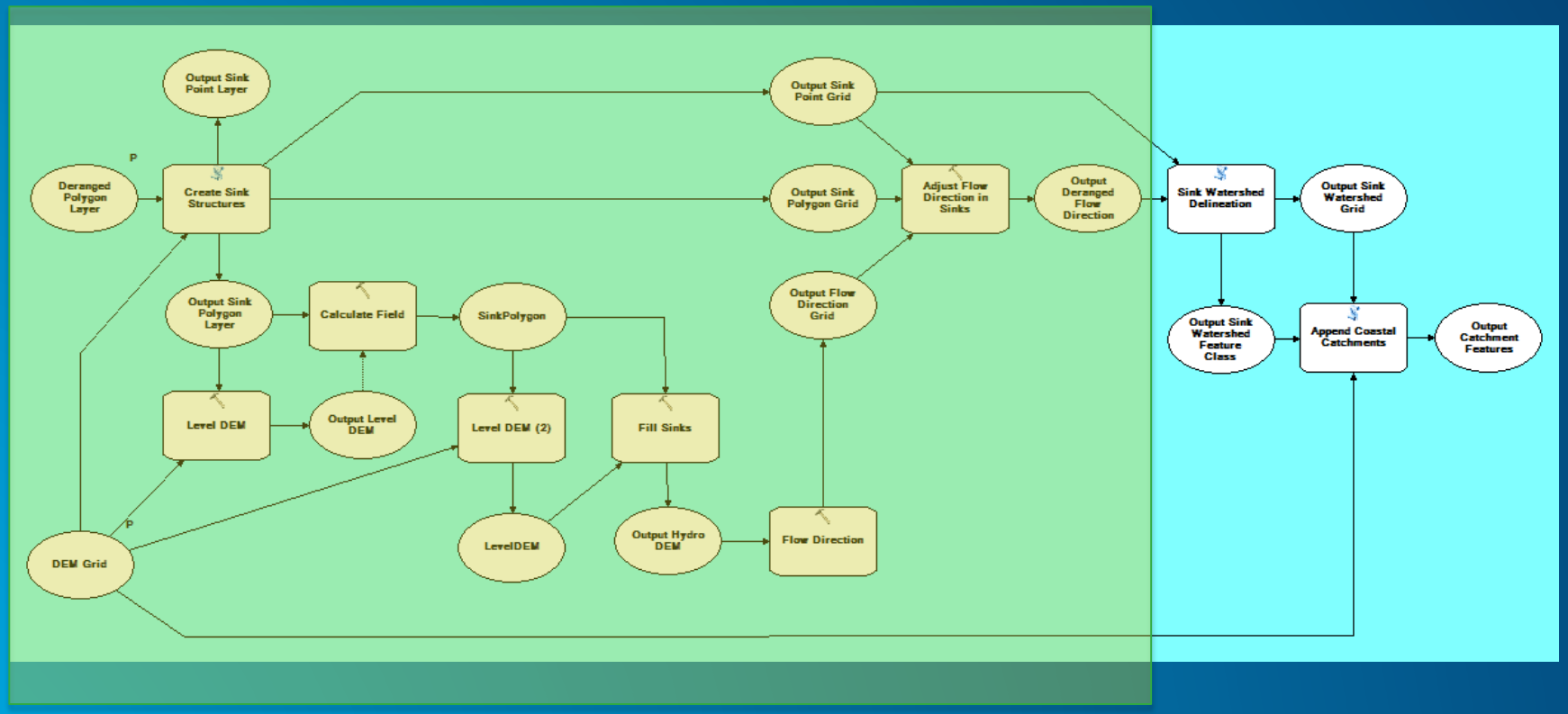
## Within terrain preprocessing workflows captured in Model Builder models



# Automating hydro DEM conditioning

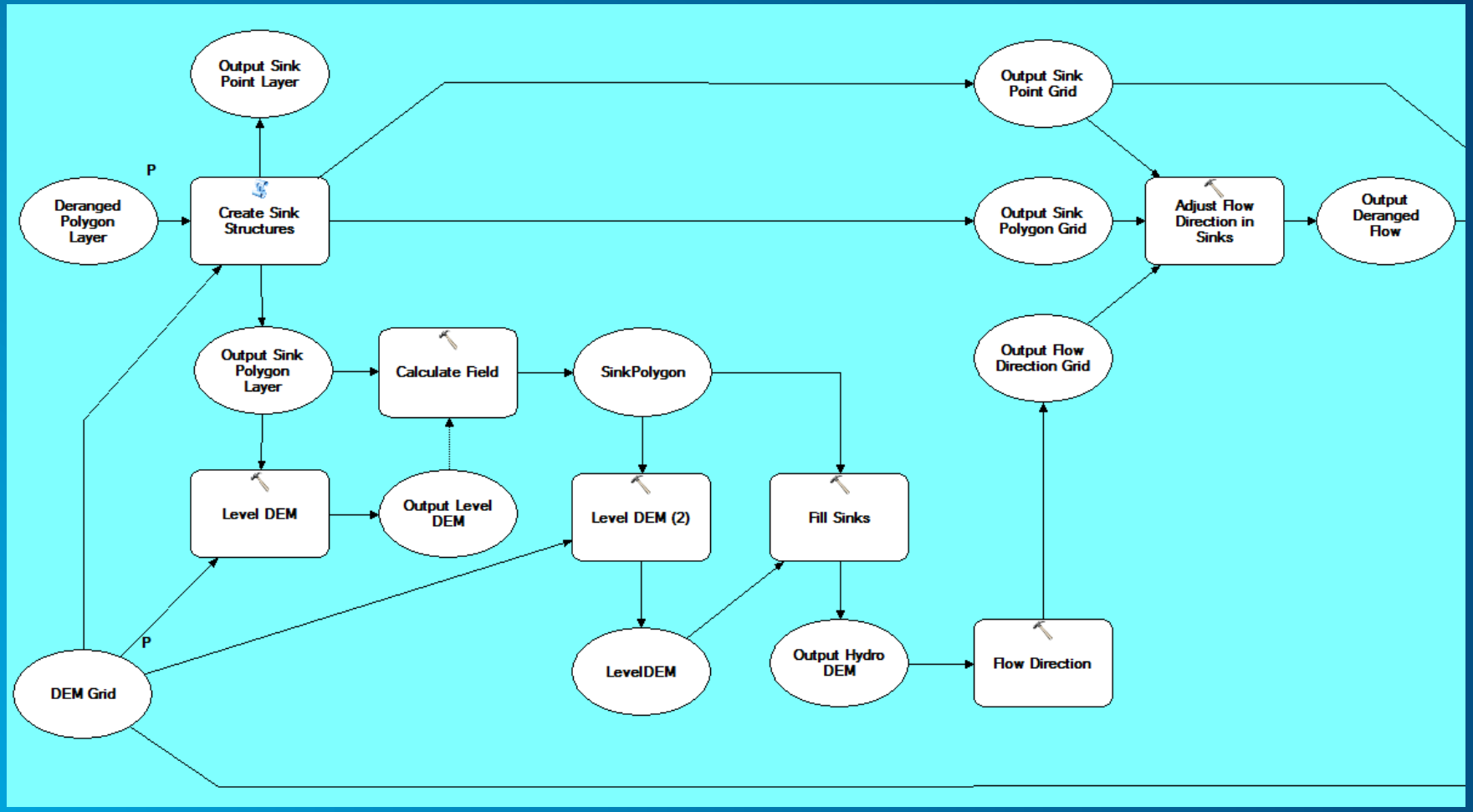
## Details (Known Sink Location And Some Filling)




**Portion of the overall model dealing with development of hydro DEM and flow direction**

# Automating hydro DEM conditioning

## More details (Known Sink Location And Some Filling)




**… and this is one of the medium complexity processes**

# Using hydro DEM/flow direction

# Using hydro DEM/flow direction

- Once correct flow direction is established, other raster and vector functions can be applied to determine important drainage pattern elements (drainage lines, catchments, watersheds, watershed characteristic, …).
- Many of these are captured in Arc Hydro tools and terrain preprocessing workflows.

# Using hydro DEM/flow direction

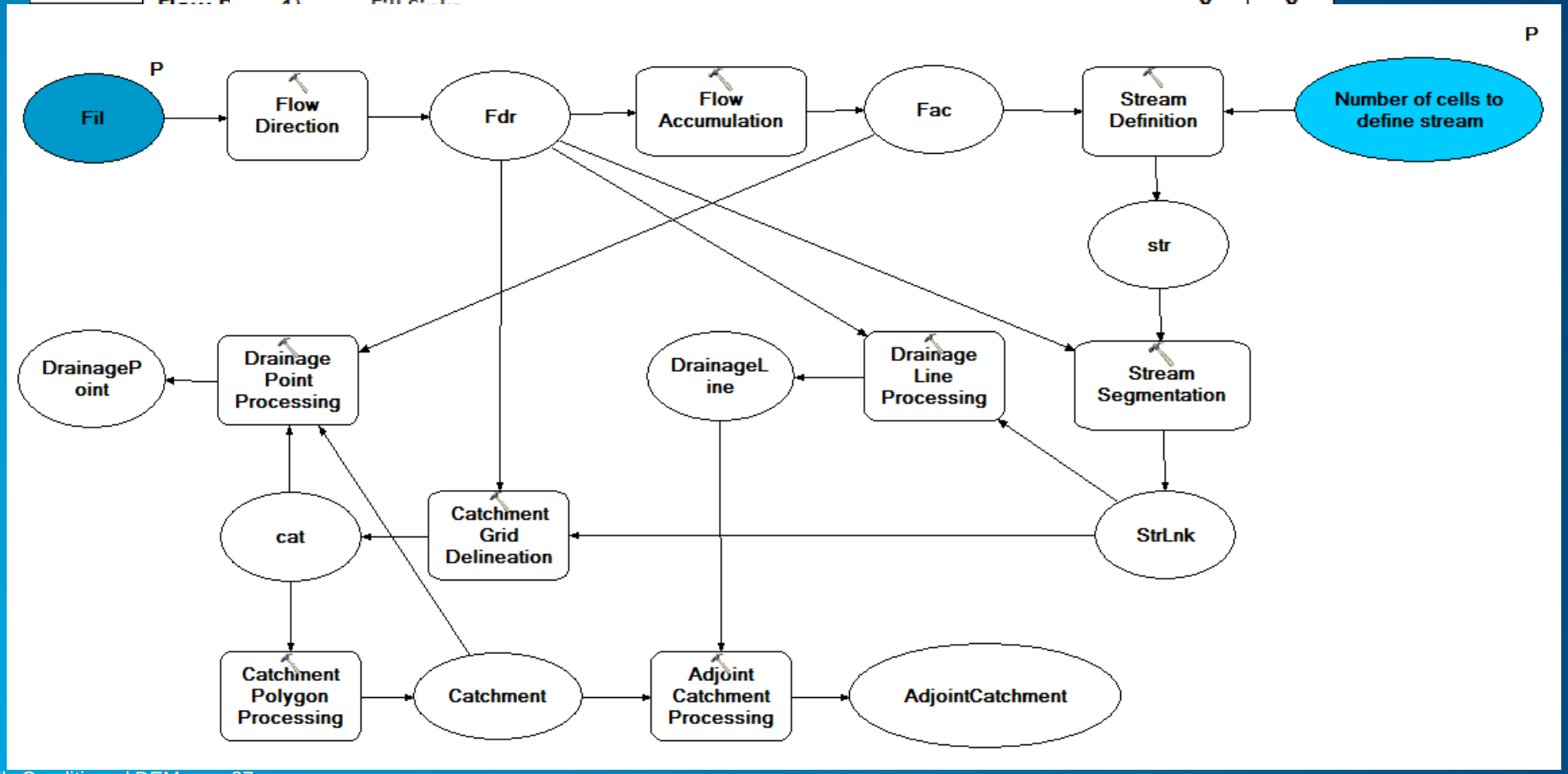
## Example terrain preprocessing workflow (UC4 – combined with unknown sinks and streams)

1. Sink Evaluation.
2. Selection of sinks process.
3. Create Sink Structures.
4. Fill Sinks.
5. Flow Direction.
6. Adjust Flow Direction in Sinks.
7. Adjust Flow Direction in Lakes.
8. Sink Watershed Delineation.
9. Flow Accumulation.
10. Stream Definition.
11. Stream Segmentation.
12. Combine Stream Link and Sink Link.
13. Drainage Line Processing.
14. Catchment Grid Delineation.
15. Catchment Polygon Processing.
16. Adjoint Catchment Processing.
17. Append Coastal Catchments.
18. Assign CatType Attribute to Catchment FC.

# Terrain preprocessing workflows and tools - workflows

| | Deranged | | | Combined | | | Dendritic | | |
|---|---|---|---|---|---|---|---|---|---|
| Function \ Use Case | UC1 | UC2 | UC3 | UC4 | UC5 | UC6 | UC7 | UC8 | UC9 |
| Sink Evaluation | X | X | | X | | | | | |
| Create | | | | | | | | | |
| Flow | | | | | | | | X | X |

Use case 7: Completely dendritic terrain with unknown stream locations



# Automated global processing (1)

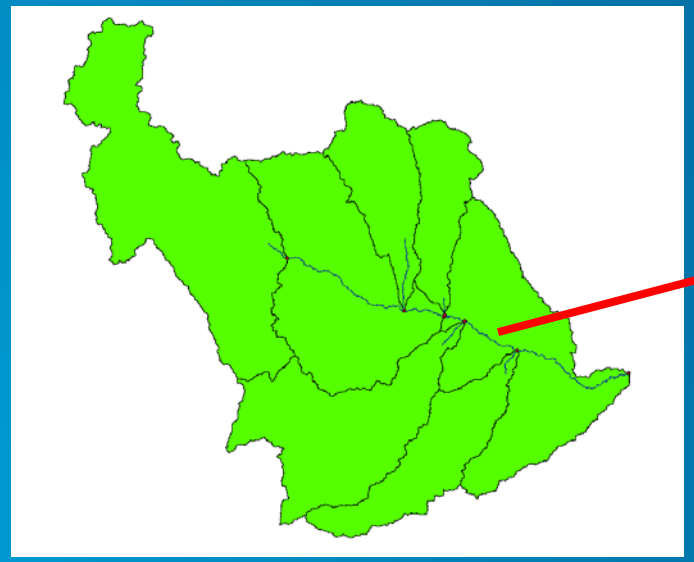
## Work in progress …

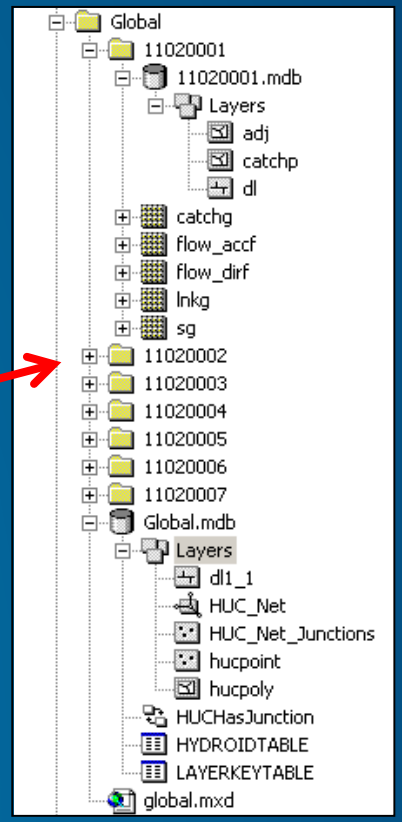
- **Inputs:**
  - **Start with DEM in a mosaic dataset**
    - **Scalable!**
  - **Have your “clean” vector data**
  - **Have your terrain preprocessing workflows in a model builder/python script**

# Automated global processing (2)

## Work in progress …

- **Outputs:**
  - **Fully processed Arc Hydro global dataset (ready for use in tools/services)**
    - **Global network and processing units**
    - **AH processed individual PUs**

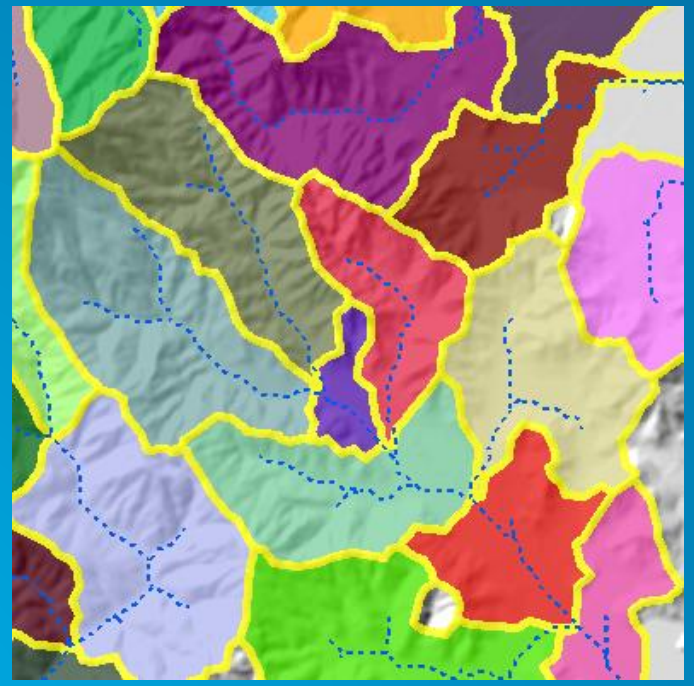




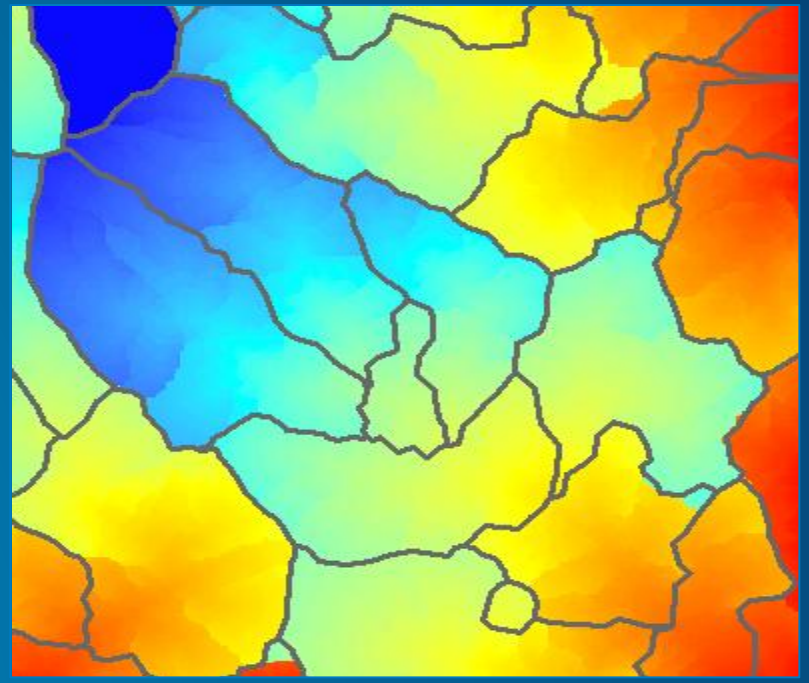
# Using hydro DEM/flow direction

## Interactive analyses

- **Watershed delineation (interactive or batch)**



- **Watershed characterization (e.g. flow path length)**



# Summary

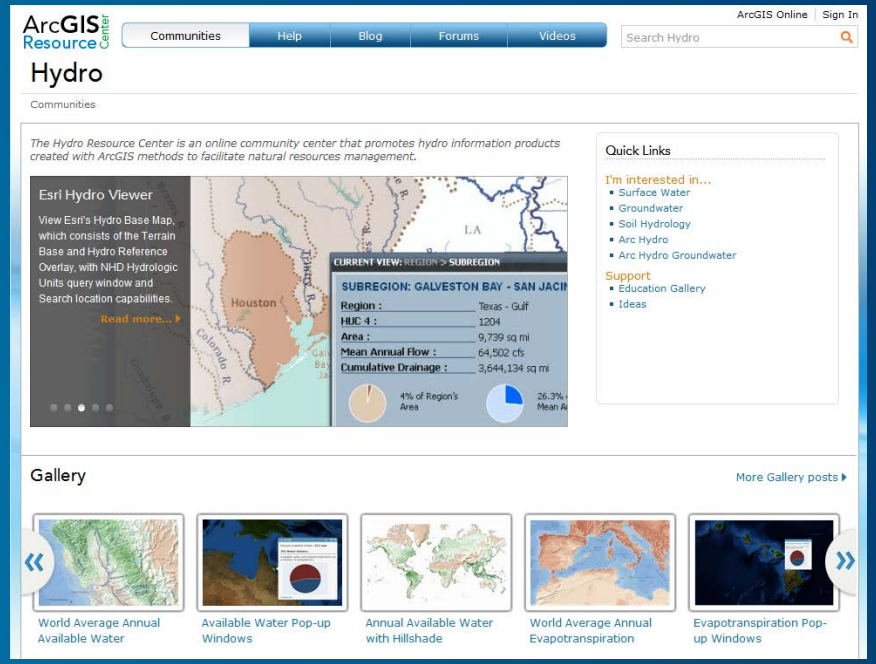
# Summary

- Hydrologically correct DEM's role is derivation of proper flow direction grid which in turn is the foundation for hydro analyses.
- Same extent can have several hydro DEMs, depending on the analysis type.
  - Hydro DEM is derived with analysis in mind.
- There are few core techniques for "correcting" DEM, but many permutations of how to use them depending on the available data and terrain morphology.
- Development of hydro DEM can be iterative process.
- Be patient and know your "dirt".

# Where is this functionality?

- Tools in the Spatial Analyst Toolbox
- Tools in Arc Hydro
- Sample tools, models, and workflows are available in ArcGIS Online
  - Hydro Resource Center

    resources.arcgis.com/en/communities/hydro
  - Analysis and Geoprocessing Tool Gallery
- Arc Hydro forum



# Using the tools

# Thank you…

- **Questions ?**


Understanding our world.