GIS Techniques for Floodplain Delineation

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What’s So Important About Floodplains and Floods

GIS for Floodplain Modeling

- **What is it all about?**

“EASY”

BUTTON

but, there is no “easy” button,
just hard work.

Floodplain Definitions

- **“To define a floodplain depends somewhat on the goals in mind. As a topographic category it is quite flat and lies adjacent to a stream; geomorphologically, it is a landform composed primarily of unconsolidated depositional material derived from sediments being transported by the related stream; hydrologically, it is best defined as a landform subject to periodic flooding by a parent stream. A combination of these [characteristics] perhaps comprises the essential criteria for defining the floodplain" (Schmudde, 1968).**

- **“Any land area susceptible to being inundated by flood waters from any source” (FEMA).**

Floodplain Definitions

What's so Important About Floodplains

- **82% of the world's population lives in areas with high flood risk (UNDP, 2004).**

Mortality risk is expressed within a decile range with 10 being the most exposed (Decile 10= est. 300 people/sq. km and decile 9 is around 150 people/sq. km). Source: Mark Pelling, Visions of Risk, UNDP / ISDR, 2004

- **¾ of world population lives within coastal zone**
  - **USA – 16.5 million (5% population) within flood prone coast**
- **½ billion people live within flood prone deltas**

What's so Important About Floodplains

- **Recurring**
  - **Lie, bigger lie, statistics**

- **Increase in % of aid from Feds due to hurricane/flooding (25% -> 70% since 2005)**
  - **Sandy (2nd most costly), Katrina (1st most costly) ~ $200B**

If We Know Where the Floodplain Is …

- **Operations**
  - **Flood prevention (dam and levee operations)**
  - **Emergency management**
  - **Facility management**

- **Planning**
  - **Design**
  - **Insurance (not everywhere)**
  - **Emergency planning**

Principles of GIS Floodplain Delineation

How to Get the Floodplain

- **Observations**
  - Water surface elevations
  - Flows
  - Precipitation (rainfall, snow)
  - “Other” (temperature, soil moisture, E/T, …)

- **Modeling (H&H)**
  - Precipitation-runoff
    - Real-time
    - Planning (design)

Direct Observations (stage/flow)

- Traditionally through gaging station
  - Problems with sensors during floods

- High water marks
  - Not real time

- Remote sensing – airborne/satellite
  - Problem with sensors and cloud cover, cost, timeliness
  - Some new options with UAVs

Modeling

- 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.
- Types of modeling
  - Real-time (operations, forecasting)
  - Long term (planning, design)

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)**
  - **Deterministic/physical modeling ("rainfall/runoff")**
    - **HEC-HMS, SMS, …**

- ***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 Q in space and time.**
- **Input: Terrain geometry with hydraulic characteristics, plus discharge Q and initial water surface level.**

$$\frac{\partial \eta}{\partial t} + \frac{\partial(\eta u)}{\partial x} + \frac{\partial(\eta v)}{\partial y} = 0$$

$$\frac{\partial(\eta u)}{\partial t} + \frac{\partial}{\partial x}\left(\eta u^2 + \frac{1}{2} g \eta^2\right) + \frac{\partial(\eta u v)}{\partial y} = 0$$

$$\frac{\partial(\eta v)}{\partial t} + \frac{\partial(\eta u v)}{\partial x} + \frac{\partial}{\partial y}\left(\eta v^2 + \frac{1}{2} g \eta^2\right) = 0.$$

St.Venant equations

- ***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).***

What Do You Need for H&H Analyses

- Definition of the landscape
  - Terrain
  - Known drainage structures (streams, sinks, lakes)
    - Constructed elements (dams, channels, tunnels, …)
  - Landscape characteristics
    - Land use, soils, vegetation cover, …
- Precipitation
  - Rainfall, snowfall, temperature, …
- Boundary conditions
  - Water levels, soil moisture content, …

Observations For Modeling (precipitation)

- Space and time distribution issues
- Traditional rain gages
- Nexrad
- Satellite
- Needs calibration!!!!

Observations For Modeling (other)

- **Space and time distribution issues**
- **Needs calibration!!!!**

Groundwater levels

Snow pack

Evaporation

Terrain !!!

- Good terrain representation is important for any type of floodplain delineation.
- “Good” is a function of the type of modeling being made and type of terrain morphology (flatter terrains need higher accuracy).

- “Mapping the Zone”, National Research Council, 2009, National Academies Press, Washington, D.C., 122 pp.
- “Elevation Data for Floodplain Mapping”, National Research Council, 2007, National Academies Press, Washington, D.C., 152 pp.

LiDAR – Beauty and the Beast

- Beauty
  - High resolution and density
- Beast
  - Too much irrelevant data
  - What are we really measuring?
  - No explicit breaklines
  - Processing “art”

GIS for Floodplain Modeling

- **So what happened to the “easy” button?**

“EASY”

BUTTON ?

What Can GIS Do for Floodplain Modeling

What Can GIS Do for Floodplain Modeling? – A LOT!

- Centralized data storage
- Data preparation for multiple models
- Postprocessing of modeling results
- Integration of modeling results with other data
- Automation of operations (Map to Map)
- Mobilizing technology (once results are available):
  - Emergency management
  - Notifications
  - Vehicle routing
  - …

GIS Database Development

- Develop digital representation of the landscape – one time process.
  - Quality
  - Precision
  - Labor Intensive

Remote Sensing

Heads-up digitizing

GIS Layers/Data

GIS for Water Resources

GIS as Database for Support of Multiple Models

- **Integrates data formats and model databases into an integrated data and processing system**

We Have the “Blue Blob” – Now What?

- **Leveraging GIS technology (once the results are available):**
  - **Emergency management**
    - **Notifications**
    - **Vehicle routing/road closures**
    - **Evacuation/relief centers**
  - **Recovery planning**
  - **Permitting**
  - **Insurance/risk management**
  - **Flood prevention**
  - **Design**
  - **Policy**
  - **…**

Methods for GIS Floodplain Delineation

Floodplain GIS Artifacts

- **Basic result “stack”:**
  - **Floodplain extent polygon (the “blue blob”)**
  - **Depth of flooding surface (usually raster)**
  - **Water surface elevation surface (usually raster)**
- **The stack can have two domains:**
  - **Temporal (for real-time analysis – e.g. what will the flood extent be today at 16:00)**
  - **Probabilistic (for planning – e.g. what is the 100-year return period flood extent)**
- **Extended “stack” (heavily dependent on the method used):**
  - **Velocities**
  - **Risks**
  - **…**

Methods for GIS Floodplain Delineation

- One size does NOT fit all.
- Depends on the available data and scope of the analysis.
- Anything:
  - From basic topographic analysis
  - To full integration with 2D/3D hydraulic models
  - And anything in between
- A matrix of solutions and tools that have to be assembled into coherent workflows for specific use cases.

Floodplain Delineation Solutions Matrix - Simplest

- **“Flooding out” technique based on DEM only.**
- **Derived stream centerline.**
- **Floodplain stack derived using “flood out” technique for fixed or incremental depth increase along the stream.**

Floodplain Delineation Solutions Matrix - Simple

- **“Flooding out” technique based on DEM, stream centerline, and point data.**
- **Floodplain stack derived using “flood out” technique for fixed depth, incremental depth, observed measurements, or modeled flows at points with WSE interpolated along the stream.**

Floodplain Delineation Solutions Matrix – Less Simple

- **“TIN” technique based on DEM, stream centerline, and cross-section data (points are optional).**
- **Floodplain stack derived using “TIN” technique for fixed depth, incremental depth, observed measurements, interpolated, or modeled flows at cross-sections.**

Cross-sections allow control of lateral distribution of water surface elevations into the floodplain

Floodplain Delineation Solutions Matrix – Complex

- Need H&H models. The complexity in implementation is in derivation of H&H models, not necessarily in floodplain delineation based on the model results.
- Some of the floodplain delineation is the same as in previous examples, once the model results are imported into GIS.
  - Some require a combination of approaches (e.g. ICPR 3)
- 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

“Flood Out” Technique

- This technique can be used when reliable cross-sections are not available.
- Use the water surface elevation along the stream line and “push out” that elevation away from the stream.
- Neighboring cells get the WSE of the nearest cell along the stream.
- Uses Spatial Analyst nibble function.
- Technique first builds an unrestricted WSE “water” surface ignoring the presence of the terrain.
- Then the difference between the water WSE and terrain elevation is taken and all negative values are eliminated. This defines the depth of flooding.
- The extent of depth of flooding is converted to a polygon and that defines the floodplain polygon in the flood stack.

“TIN” Technique

- This technique can be used when reliable cross-sections are available.
- Use cross-sections as hard breaklines with water surface elevation as values. Build a TIN using the stream and cross-sections.
- The “water” TIN is limited only by the extent of the cross-sections (ignoring the presence of the terrain).
- Water TIN is converted into raster of same resolution as DEM.
- Then the difference between the water WSE and terrain elevation is taken and all negative values are eliminated. This defines the depth of flooding.
- The extent of depth of flooding is converted to a polygon and that defines the floodplain polygon in the flood stack.

WSE Longitudinal Interpolation Technique

- Often, WSE is know at few (sometimes none) points along the stream (based on observed or modeled locations).
- Special tool to perform linear interpolation of WSE along the stream line (“Create 3D Stream WSE Line” and “Create 3D WSE Stream Line Grid”).
- Interpolation is performed linearly between points with known WSE on a reach by reach basis.
- Special cases for dealing with:
  - No points on the reach
  - One point on the reach
  - Confluences (adjustment or no adjustment of WSE from connected streams)

Custom Solutions: Leverage Existing Model Interfaces

- **Many H&H models have GIS interfaces that can be used to generate the floodplain stack.**
- **Always use these interfaces if at all possible.**
- **Maintaining custom model interfaces is a “never ending” job – have someone else do it – it is worth every $.**

“Flood” Tools
(Arc Hydro)

Tools Purpose

- 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
  - Models

Real-time Observations

- Leverage WaterML 1.1 and 2.0 standards
- Arc Hydro WaterML time series download tool
  - Populate standard Arc Hydro time series tables

Landscape Characterization for Hydraulic Analysis

- **Streams**
  - DEM alignment and thalweg adjustment
  - Longitudinal WSE interpolation based on point values
- **Cross-sections**
  - 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

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

- Points (“flood out” technique)
  - WSE at points along streams (observed, modeled through Q)
- Cross-sections (TIN technique)
  - WSE at cross-sections (observed, modeled through Q)
- Models
  - 1D (HEC-RAS, ICPR 3)
  - 2D (ICPR 4)

Arc Hydro Tools

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

Delineation Workflows

Process Implementation

- Workflows for piecing solutions together as a function of available input data
- Increasing complexity of possible solutions as a function of data availability:
  - Minimal (DEM only)
  - Medium (DEM and some additional data)
  - Full (GIS + H&H modeling)
  - … and anything in-between
- Comprehensive process documentation in initial phase
  - Matrix of use cases
  - Workflows and tools to support them
  - Similar to terrain processing doc

	Deranged			Combined			Dendritic		
Function \ Use Case	UC1	UC2	UC3	UC4	UC5	UC6	UC7	UC8	UC9
Sink Evaluation	X	X		X					
Create Sink Structures	X	X	X	X	X	X			
Flow Direction	X	X	X	X	X	X	X	X	X
Adjust Flow Direction in Sinks	X	X	X	X	X	X			
Sink Watershed Delineation	X	X	X	X	X	X			
Append Coastal Catchments	X	X	X	X	X	X	X	X	X
Assign CatType Attribute to	X	X	X	X	X	X	X	X	X

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

Comparison of Floodplain Delineation Techniques

Methodology

- Tuolumine River – Modesto, CA
- Fully developed RAS model (Baxter)
- 50-year event
- Benchmark are depths developed through GeoRAS postprocessing
- Comparison with “flood out” technique
  - Take WSE developed at CS by RAS
  - Assign them to points on the stream where CS intersects the stream
  - Use the “flood out” technique to get the floodplain/depths
  - Calculate difference between GeoRAS and “flood out” depths
  - Incrementally reduce the number of points (“all”, “some”, “2”, “1 up”, “1 dwn”)

Area of Interest

Blue Gum Ave
Woodland Ave
Kansas Ave
Maze Blvd
Modesto
Needham St
Yosemite Blvd
California Ave
Paradise Rd
W Hatch Rd
E Hatch Rd
W Whitmore Ave
E Whitmore Ave
Ceres
Hughson
Keyes
W Grayson Rd
Garst Rd
Santa Fe Ave
Scenic Dr
Tenaya Dr
River Rd
Reeding Rd
E Hackett Rd
Tully Rd
Faith Home Rd
Mountain View Rd
Pioneer Rd
Washington Rd
Central Ave
Mitchell Rd
Crows Landing Rd
Carpenter Rd
Roselmore Ave
Kansas Ave
Pontiac Ave
Grimes Ave
Stone Ave
Young Rd
Vivian Rd
Jennings Rd
Geer Rd
Hackett Rd
Claus Rd
Church St
Walnut Rd
Lakewood Ave
Vista Ave
Sutter Park
Acacia Memorial Park
Modesto City-County Airport
Dryden Park Golf Course
Junior College-West
Tully Rd
Coffee Ave
McHenry Ave
Sunrise Ave
Orangeburg Ave
Dry Creek
Tuolumne Ave
Kansas Ave
Elm Ave
Pontiac Dr
Lakewood Ave
Claus Rd
Garst Rd
Walnut Rd
Santa Fe Ave
Mitchell Rd
Central Ave
Faith Home Rd
Reeding Rd
Washington Rd
Pioneer Rd
Mountain View Rd
Tully Rd
Hackett Rd
Geer Rd
Jennings Rd
Vivian Rd
Young Rd
Stone Ave
Grimes Ave
Pontiac Ave
Roselmore Ave
Carpenter Rd
Crows Landing Rd
Tully Rd
Coffee Ave
McHenry Ave
Sunrise Ave
Orangeburg Ave
Blue Gum Ave
Junior College-West
Needham St
Yosemite Blvd
Maze Blvd
Paradise Rd
W Hatch Rd
E Hatch Rd
W Whitmore Ave
E Whitmore Ave
Ceres
Hughson
Keyes
W Grayson

Area of Interest

Area of Interest

GeoRAS Inundation Depths (ft)

GeoRAS – “all” Difference (ft)

GeoRAS – “some” Difference (ft)

GeoRAS – “2” Difference (ft)

GeoRAS – “1 up” Difference (ft)

GeoRAS – “1 dwn” Difference (ft)

Side-by-side Comparison

GeoRAS Depth

GeoRAS – “all” diff

GeoRAS – “some” diff

GeoRAS – “2” diff

GeoRAS – “1 up” diff

GeoRAS – “1 dwn” diff

Summary

Summary

- GIS has many tools to facilitate floodplain delineation
- Data are the key to quality results
- While the GIS tools are “easy” to use, it is also “easy” to produce non-sensical results
- Ability to “see” results enable easier quality control
- GIS as framework for automation of complex floodplain analyses
- Easy mobilization of GIS technology once the “blue blob” is obtained

Floodplain Discontinuity

Floodplain Discontinuity (cont.)

Cross-Section Interpolation

Summary

- **GIS as framework for automation of complex floodplain analyses**

Map To Map to Automate Rainfall-Runoff-Flood Modeling

- Complex Alterative Evaluations
- Climate Change
- Landuse Development
  - Deforestation
  - Urbanization
  - …
  - …
- Real-time operations
  - Check out NFIE presentation on Thursday

Summary

- **Easy mobilization of GIS technology once the “blue blob” is obtained**

Impact Summary App

Impact Summary App: This web application highlights an area and displays a summary of data related to its location. Areas can be enriched with demographic, infrastructure, or landscape data to later be analyzed and shared. The map is dynamic and interactive to provide real time situational updates. In the example above, the inundation levels have been enriched with population data of those who are over 65, living under the poverty line, or lacking access to transportation.

Public Information App

Public Information App: This web app is fully configurable for public facing maps that allows authoritative data feeds to be shared to the public. In this example, road closures, evacuation routes, points of interest, low water crossings, and bridges are all shown for public information sharing. Emergency shelters can also be added to the map as they open to inform the public on where to seek help.

Social Media App

Social Media App: This web application provides configurable templates to display geolocated content from Flickr, Youtube, and Twitter. Resulting content can be analyzed as clusters or heat maps. This app is also configurable with emergency alert systems or emergency assistance registries. Also displayed in this example, are low water crossings evacuation routes and bridges within the effected area.

Map Comparison App

Map Comparison App: This application allows the examination of 3 web maps simultaneously to detect changes or relationships. This app is useful to display data over time to visualize changes and patterns in the data. This example shows how the inundation levels of the creek change over time based on predicative modeling.

3D Viewer

Esri CityEngine: This modeling software allows the transformation of 2D GIS Data into interactive 3D Models. The example above shows the October flooding at multiple levels in the Onion Creek Area. This model also allows for the assessment of infrastructure damage and potential areas in need of emergency response.

3D Viewer

Esri CityEngine: The example above shows water depths for the 100-year and 25-year flooding events in relation to people and buildings.

Flood Response Run Book

Flood Response Run Book: Along with web maps and apps, Flood Response Run Books can also be created to provide hard copy references to emergency responders in the field. In this example, the area is divided by UTM Gridlines. It is also possible to split the area by emergency response zones and by right and left side of the river. These pages would be indexed to critical infrastructure in each grid along with streets and points of interest.

GIS for Floodplain Modeling

- **Maybe not “easy” yet, but it isn’t mystery.**

“EASY”

BUTTON

Thank You…

- Questions?

- Please fill out the session survey in your mobile app
- Select “GIS Techniques for Floodplain 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

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