New Developments in River Valley Floodplain Mapping Using DEMs: A Survey of FLDPLN Model Applications

Jude Kastens | Kevin Dobbs | Steve Egbert
Kansas Biological Survey
ASWM/NFFA Webinar | January 13, 2014

Kansas River Valley between Manhattan and Topeka
This DEM was created using LiDAR data.

Shown is a portion of the river valley for Mud Creek in Jefferson County, Kansas.

Unfilled DEM (shown in shaded relief)
Terrain Processing: *Filled (depressionless) DEM*

This DEM was created using LiDAR data.

Shown is a portion of the river valley for Mud Creek in Jefferson County, Kansas.

*Filled DEM* (shown in shaded relief)
Each pixel is colored based on its **flow direction**.

Navigating by flow direction, every pixel has a single **exit path** out of the image.

**Flow direction map** (gradient direction approximation)
Terrain Processing: *Flow Direction*

Each pixel is colored based on its *flow direction*.

Navigating by flow direction, every pixel has a single *exit path* out of the image.

*Flow direction map* (gradient direction approximation)
Flow accumulation map (streamline identification)

Terrain Processing: Flow Accumulation

The flow direction map is used to compute flow accumulation.

*flow accumulation* = *catchment size* = the number of exit paths that a pixel belongs to
Terrain Processing: **Stream Delineation**

Using pixels with a flow accumulation value $>10^6$ pixels, the **Mud Creek** streamline is identified (shown in blue).

“Synthetic Stream Network”
The 10-m floodplain was computed for Mud Creek using the FLDPLN model. FLDPLN is a static, 2D hydrologic model that requires only DEM data as input. Using simple surface flow properties, FLDPLN identifies the depth-varying floodplain in reference to the input stream network (floodwater source).
Amazon River in Brazil (1700 km). 90-m SRTM DEM data were used.

Amazon surface elevation drop in study area: 17 m

1 m per 100 km!
Example: Delaware River Basin above Perry Lake in northeast Kansas
Example: Walnut River Basin in southeast Kansas

Each colored stream segment has its own inundation library

Merged library
The FLDPLN ("Floodplain") Model—
There are two ways that point \( Q \) can be flooded by water originating from point \( P \):

- **Backfill Flooding**
  - "Water seeks its own level"
  - Uphill flow (swelling)

- **Spillover Flooding**
  - "Water flows downhill"
  - Downhill flow (overland flow)
Backfill Flooding—accounts for floodwater expansion due to swelling processes

Water surface

Flood depth

Ground surface

Flow directions

Flow divide

Dry

Dry

Dry

Pixel on ridgeline

Floodwater source pixel over here
Spillover Flooding—accounts for floodwater rerouting (alternative flow path development)
PLAN VIEW illustrating backfill and spillover flooding

- Tributary channel
- Watershed boundary
- Flow divide
- Depth To Flood (DTF) Contour

Spillover flooding meets backfill flooding
Ground

Inflowing Channels

Longitudinal Floodplain Cross Section

Flood Stage 1 → DTF Contour 1
Flood Stage 2 → DTF Contour 2
Flood Stage 3 → DTF Contour 3
Flood Stage 4 → DTF Contour 4

FLDPLN Model Solution Profile

Overhead view

Side-channel flow back into the main channel results in depth decay
Seamless modeling with FLDPLN

*Works for depth grids. Multi-segment merged DTF maps require minimum value compositing.
Seamless modeling with FLDPLN
Arghandab – 5m floodplain
West trib – 5m floodplain
Now let’s see some **actual** flood extent mapping...
Flood Extent Estimation (Example 1)

Flooding along the Osage River in Missouri

July 2007
June 13, 2008

Flooding on the Cedar River crested more than 11 ft above the historic record in Cedar Rapids, Iowa
Example 3:
1938 Texas Flood Study Area

adapted from Burnett (2008)
Analyzed Stream Segments

FLDPLN can be applied using any stream segmentation.

For this analysis, the study reach was initially partitioned at all confluences with tributary catchments > 2 sq mi. All spans > 5 km in length were further subdivided at maximum flow accumulation change points.
NED Elevation

10-m Elevation data from USGS National Elevation Dataset (NED)
Additionally, LiDAR elevation data were provided by TNRIS. Intermap also kindly provided IfSAR elevation data to improve the analysis. Both were downsampled to the 10-m NED grid before processing.
Wetted Extent Correspondence

Intermap vs. NED-LiDAR (entire study area)

79.4% agreement

NED-LiDAR wetted extent is 2.1% larger
Wetted Extent Correspondence

Intermap vs. LiDAR vs. NED (LiDAR area only)

<table>
<thead>
<tr>
<th></th>
<th>Intermap agreement:</th>
<th>LiDAR agreement:</th>
<th>NED agreement:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>82.8% [L-N union]</td>
<td>80.8% [Lidar]</td>
<td>76.5% [NED]</td>
</tr>
<tr>
<td></td>
<td>77.2% [I-N union]</td>
<td>72.7% [NED]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75.4% [I-L union]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example 3 – Verification

Oblique aerial photo over **San Saba, Texas**, during a record flood that occurred in **July 1938**.

High water marks collected by the USACE in 1938 were used to model this event.

**FLDPLN floodwater surface estimates using different elevation datasets**
Example 3 (continued)

Oblique aerial photo of San Saba during the 1938 flood (not necessarily at crest).

Note the locations of the water tower & the courthouse (green dots).

“Reports and pictures in the Dallas Morning News, The Saba News and Star, and the Wichita Falls Record News show that in the City of San Saba, flood waters from the river spread through a great part of the business district and around the courthouse and spread over more than one-third of the City.”

Recent photo of Mission Theatre (Menard, TX)

Both Intermap and NED 1938 flood simulations indicate a flood depth of 2-3 ft in Mission Theatre.

Water reached a depth of five feet in the Mission Theater and one foot in the Bevans Hotel in Menard.
Example 4:

Reconstructing the 1993 Missouri River Flood in Kansas*

*KDEM request for 2011 floods
St. Joseph
Atchison
Leavenworth
Kansas City
Sibley
Rulo
The Missouri River reach was partitioned into 60 segments (with breaks at major confluences) for FLDPLN processing.
Example 5: Susquehanna River
Susquehanna River Water Surface Elevations

Gage heights represent 9/8/11 flood crest

From existing hydraulic model

Elevation (ft)

River miles from upstream start

500-yr
100-yr
50-yr
10-yr
Filled DEM

CKLN6
BNGN6
VSTN6
Estimated Flood Depth, September 2011
(from FLDPLN model)

29.56 ft
0.01

USGS stream gage
modeled stream reach

Chenango River
Susquehanna River
This floodplain database (called a Segmented Library of Inundation Extents, or SLIE) was developed for 339 stream segments in eastern Kansas.

Using river stage information from gages and observers, the SLIE is used to produce current and predicted flood extents during severe flooding to improve situational awareness for disaster response personnel.

Website: http://www.kars.ku.edu/geodata/maps/depth-flood-eastern-kansas/
Also available as a web mapping service for ArcMap and Google Earth (KML)

www.kars.ku.edu
Kansas SLIE: Expansion and LiDAR update
Conceptual Framework

Data Prep
- DEM input
  - NED
  - LiDAR
  - InterMap
  - SRTM
  - other
- DEM Conditioning (ex. NLD, NID)
- Arc Hydro Tools & Stream Segmentation

Database / Server
- FLDPLN Model (MATLAB)
- SLIE Database Segmented Library of Inundation Extents
- GIS Server
- Custom Extent Map / Depth Grid

Implementation
- “SLIE Selectors” Observed (point)
  - Gauge Data
  - HWM Library
  - Ground Observer
- Satellite (raster)
  - GFDS (low res)
  - DFO (mod res)
  - Other
- Modeled
  - HEC-RAS
  - HAZUS
  - Other
- Client Applications
Other Applications for the FLDPLN Model
Flood scenario modeling for training exercises – HWM targeting and estimation of flood depth grid

Ottawa, KS

Flood Depth

14.9 m

0.1 m

stream gage

Marais des Cygnes River

levee
River typing and morphology studies – valley identification and floor width estimation

- Valley floor width
- Valley top width
- Valley boundary
River valley boundary delineation – masking for identification of floodplain wetlands
Identifying potential wetland locations & wetland boundary refinement
Identifying Riparian Forested Areas for Preservation or Restoration
Assessing Wetland Hydrologic Connectivity

• DTF value extracted for each site.

• Provides a **hydrologic connectivity index (HCI)**.

• HCI indicates relative frequency of connection (via floodwaters) of a floodplain location to the river.

• \( \uparrow \text{DTF} = \downarrow \text{HCI} \)
Assessing Wetland Hydrologic Connectivity

- DTF value extracted for each site.
- Provides a hydrologic connectivity index (HCI).
- HCI indicates relative frequency of connection (via floodwaters) of a floodplain location to the river.

\[ \uparrow \text{DTF} = \downarrow \text{HCI} \]
Levee Effects on Wetland Hydrologic Connectivity

- XYZ levee data obtained from KC USACE.

- Acquired as part of the National Levee Database (NLD) effort.

- Some levees are absent*

*Many of these are included in the latest version of the NLD.
Levee Effects on Wetland Hydrologic Connectivity

30-m DEM data backdrop.
Without levee data

- FLDPLN
- No levee data.
- $\uparrow{\text{DTF}} = \downarrow{\text{HCl}}$
With levee data

- DTF values increased more than 4 m, indicating much less frequent reconnection to the river.

**Next Step:**
Relate stage to frequency

*Note:* A non-hydrologic connectivity index, such as distance-to-stream, will not pick up levee effects.
DTF maps provide a useful guide when specifying cross sections for hydraulic modeling.
Thanks for Listening...

Any Questions?

Email: jkastens@ku.edu