Floodplain Modeling and Mapping with GIS

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City of RAMSEY

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University of Minnesota
Building community-university partnerships for sustainability

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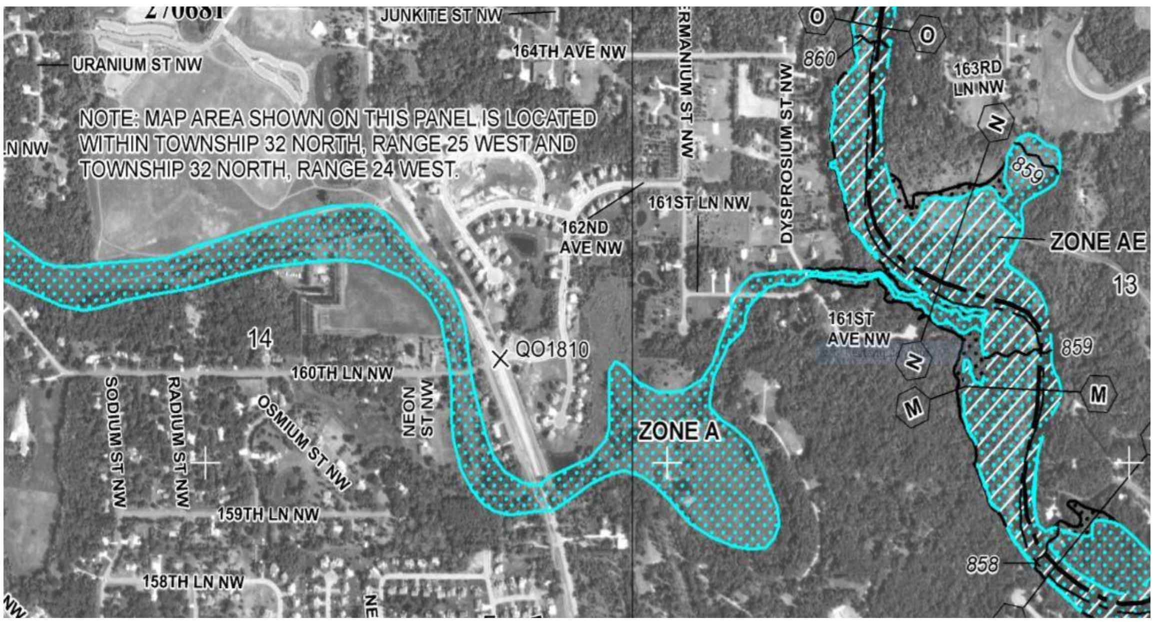

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GEOG 5564

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1. Introduction

FEMA Flood zone maps delineate the boundaries of the 100-year base flood elevation (BFE) of a water body. This translates to a one percent chance of flooding to this level in any given year, and is used by FEMA as the standard threshold of risk beyond which houses are considered to be in danger of flooding. Homeowners in these areas must pay for expensive flood insurance. Many flood zones in the City of Ramsey were approximated by FEMA using 2011 data, which used older, low-resolution spatial data and lacked the accuracy of a detailed hydrological study. The City of Ramsey is naturally interested in making these flood zones more precise to lessen the burden on property owners, who must often individually hire surveyors to inspect their property in an effort to determine if it is necessary for the homeowner to purchase flood insurance.

To address this issue, the City of Ramsey tasked us with using more accurate spatial data and GIS methods to produce a more accurate flood zone delineation in the areas where flood zones were approximated. Traditionally, flood zones are modeled based upon either previously observed flood event data or using detailed engineering studies, but these methods were not feasible to conduct given the lack of previous engineering data for these areas.[1] Additionally, using GIS provides an alternative methodology that can highlight the importance of certain modeling parameters. Given the enormous complexity of water dynamics it is difficult to precisely model the behavior of flooding water, but we aimed to use high-resolution remotely sensed data to provide a more accurate depiction of where flood water will likely go during flood events.[1]

This report discusses the methodology we used to model flood zones, as well as the rationale behind these decisions. To maximize the ability to replicate our results, a write-up for each step in this process is provided. We then cover the results of this model, how they can be interpreted, and the benefits and limitations of our approach.

2. Objectives

The main objective of the project is to provide a floodplain delineation data model for approximate flood zones in the City of Ramsey using the techniques and tools of GIS. We aim to build a user-friendly model using ModelBuilder in ArcMap. This model will enable one to study the impact of changes in different parameters, e.g. elevation level, floodplain delineation. Validation of the data model will be conducted by testing it using detailed study area cross-sections from the FEMA NFHL dataset and comparing the results generated by the model

[1]Liu, Y.B., & Smedt, F.D. (2005). Flood Modeling for Complex Terrain Using GIS and Remote Sensed Information. *Water Resources Management, 19*(5), 605-624. https://doi.org/10.1007/s11269-005-6808-x

to the existing detailed study floodplain delineations. The model will then be applied using our generated mapping cross-sections in approximate study areas.

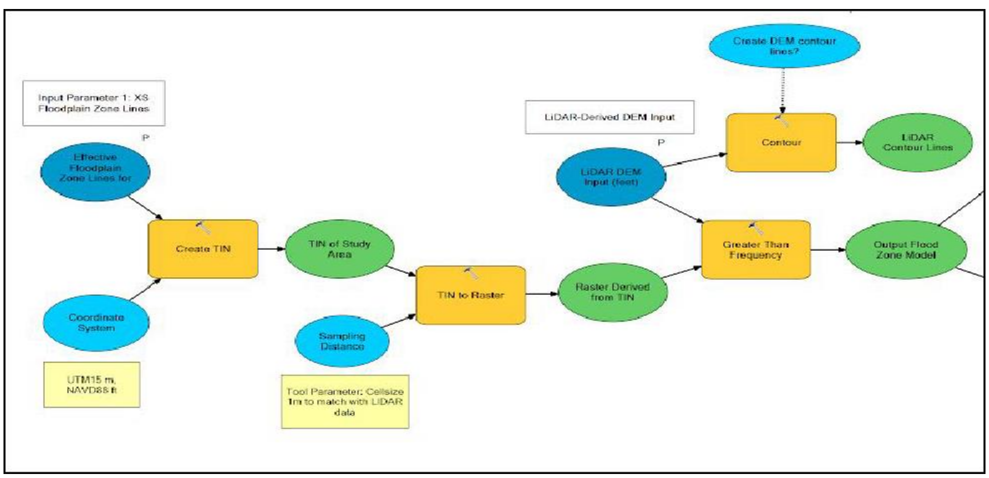
3. Data and Methods

Our study area included the entire City of Ramsey. The focus areas examined were the Ramsey flood zones, which includes both the approximate and the well-defined flood zone boundaries. We used high-resolution 2012 LIDAR data to process a DEM with a 1-meter resolution, and used this as the primary data source with which to carry out our analysis. This is justified by the importance of accurate DEMs modeling flooding effects, as accurate elevation and terrain data has been shown to be important in creating these models.[2] Data was obtained from the following source:

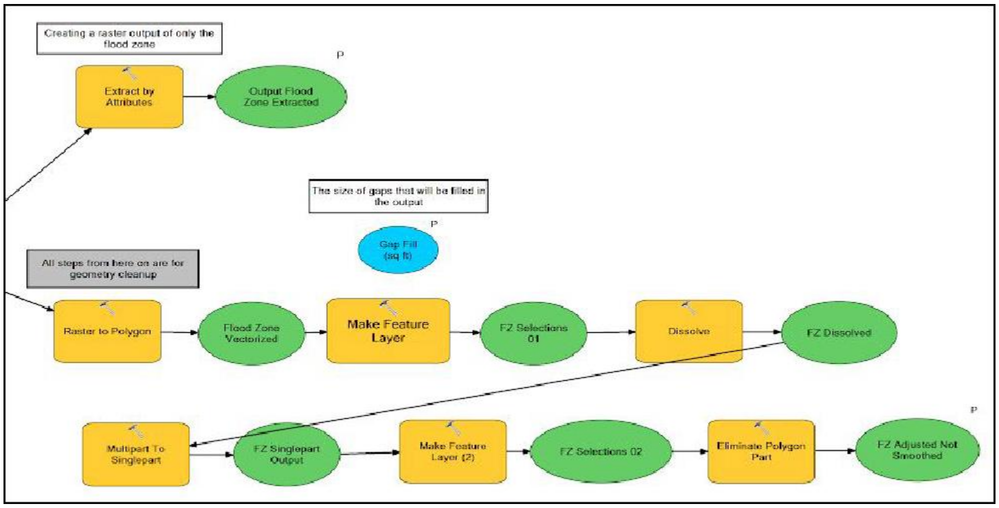
- "LiDAR Elevation Data for Minnesota". *Minnesota Geospatial Information Office.* http://www.mngeo.state.mn.us/chouse/elevation/lidar.html#data

3.1 Model

The following two-part diagram is an overview of the ArcMap model we used to create the base flood zone output results. The details of each step in this process are covered below.



2 Sanders, B.F. (2007). Evaluation of on-line DEMs for flood inundation modeling. *Advances in Water Resources, 30*(8), 1831-1843. https://doi.org/10.1016/j.advwatres.2007.02.005



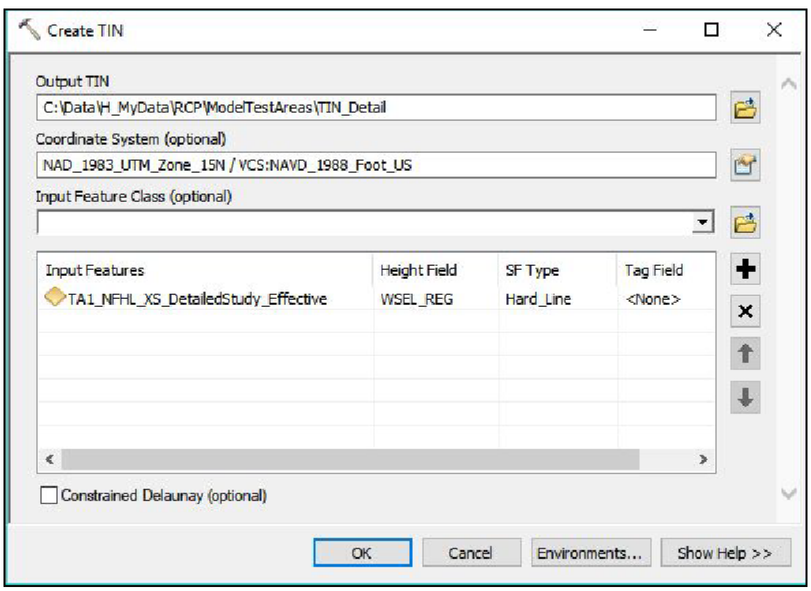
3.2 Description of Tools Used in the Model

(1) 3D Analyst Toolbox License

(1.1) Create TIN

[3D Analyst Tools > Data Management > TIN > Create TIN]

It creates a triangulated irregular network (TIN) dataset.



Output TIN
The TIN dataset that will be generated.

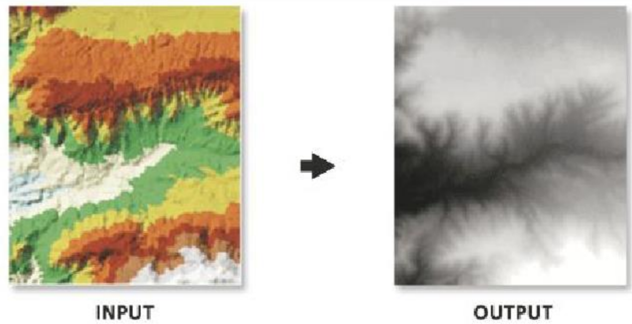
Coordinate System (optional)
The spatial reference of the output TIN should be set to a projected coordinate system. (Geographic coordinate systems are not recommended)

Input Feature Class (optional)
The input features and their related properties that will contribute to the definition of the TIN.

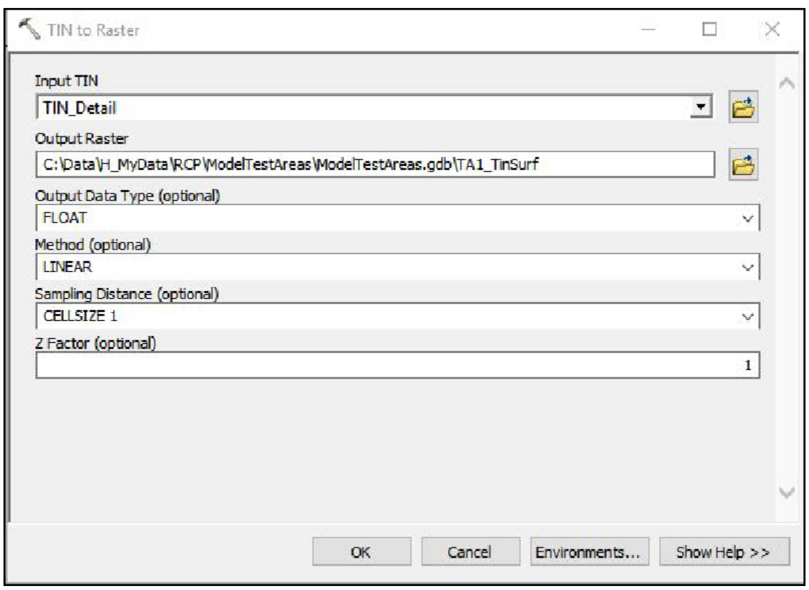
(1.2) TIN to Raster

[3D Analyst Tools > Conversion > From TIN > TIN to Raster]

It creates a raster by interpolating its cell value from the elevation of the input TIN at the specified sampling distance.



Source:
http://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-tin-to-raster-3d-analyst-works.htm



Input TIN
The TIN dataset to process.

Output Raster
The location and name of the output raster. When storing a raster dataset in a geodatabase or in a folder such as an Esri Grid, no file extension should be added to the name of the raster dataset.

Output Data Type (optional)
The data type of the output raster can be defined by the following keywords:

- FLOAT
- INT

Method (optional)
The interpolation method used to create the raster.

- LINEAR
- NATURAL_NEIGHBORS

Sampling Distance (optional)
The sampling method and distance used to define the cell size of the output raster

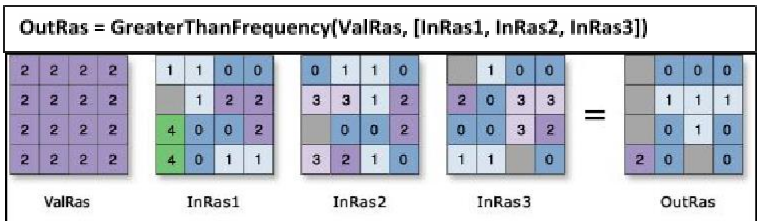
Z Factor (optional)
The factor by which Z values will be multiplied. This is typically used to convert Z linear units to match XY linear units. The default is 1.

(2) Spatial Analyst Toolbox License

(2.1) Greater Than Frequency

[Spatial Analyst Tools > Local > Greater Than Frequency]

It evaluates on a cell-by-cell basis the number of times a set of rasters is greater than another raster.



Source: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/greater-than-frequency.htm

Input value raster
For each cell location in the input value raster, the number of occurrences (frequency) where a raster in the input list has a greater value is counted.

Input rasters
The list of rasters that will be compared against the value raster.

Output raster
For each cell in the output raster, the value represents the number of times that the corresponding cells in the list of rasters is greater than the value raster.

(2.2) Contour

[Spatial Analyst Tools > Surface > Contour]

It creates a line feature class of contours (isolines) from a raster surface.

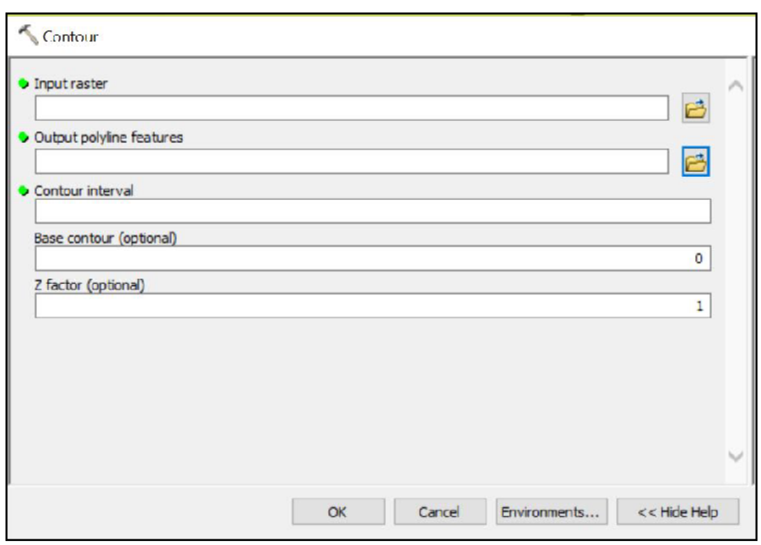
Input raster
The input surface raster.

Output polyline features
The output contour polyline features.

Contour interval
The interval, or distance, between contour lines. It can be any positive number.

Base contour (optional)
The base contour value.
Contours are generated above and below this value as needed to cover the entire value range of the input raster. The default is zero.

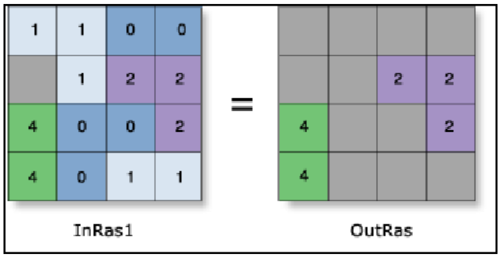
Z factor (optional)
The unit conversion factor used when generating contours. The default value is 1.



(2.3) Extract by Attributes

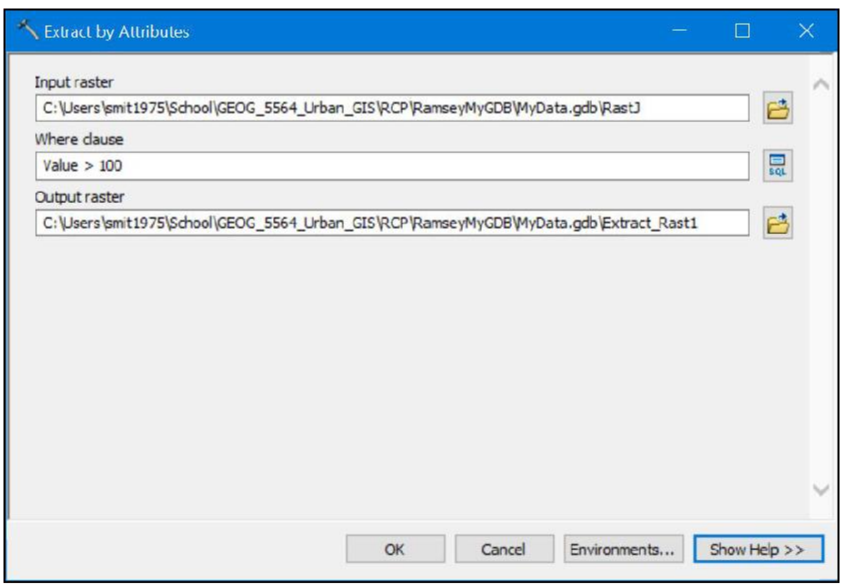
[Spatial Analyst Tools > Extraction Toolset]

It extracts the cells of a raster based on a logical query.



Source: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/greater-than-frequency.htm

OutRas = ExtractByAttributes(InRas1, "Value >= 2")



Input raster
The input raster from which cells will be extracted.

Where clause
A logical expression that selects a subset of raster cells.

The Where clause follows the general form of an SQL expression.It can be entered directly, for example, VALUE > 100. To use a text attribute field, use single quotes around the values, for example, landuse = 'urban'. It can also be created in the Query Builder dialog box that results from clicking on the SQL button.

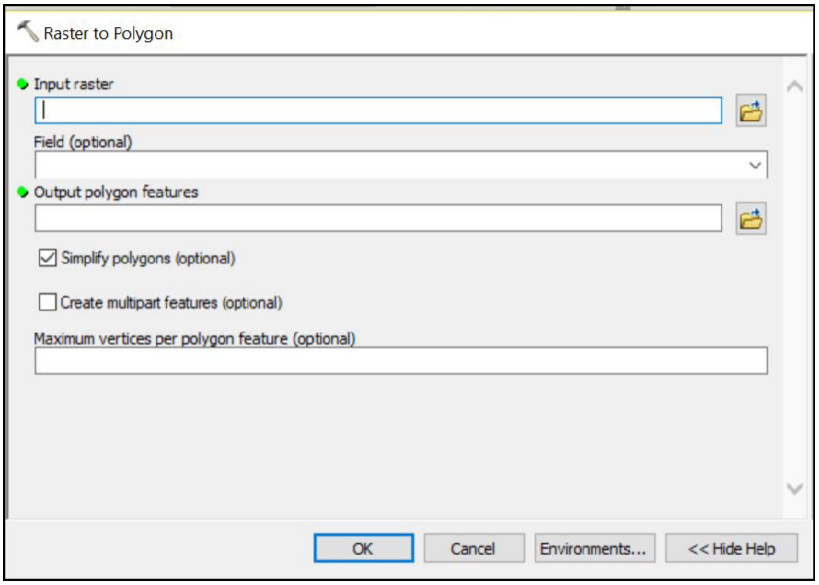
Output raster
The output raster containing the cell values extracted from the input raster.

(3) Conversion Toolbox License

(3.1) Raster to Polygon

[Conversion Tools > From Raster > Raster to Polygon]

Converts a raster dataset to polygon features.



Input raster
The input raster dataset. The raster must be integer type.

Field (optional)
The field used to assign values from the cells in the input raster to the polygons in the output dataset. It can be an integer or a string field.

Output polygon features
The output feature class that will contain the converted polygons.

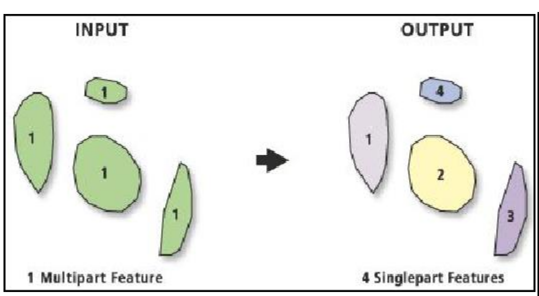
Maximum vertices per polygon features (optional)
The vertex limit used to subdivide a polygon into smaller polygons. If left empty, the output polygons will not be split. The default is empty.

(4) Data Management Toolbox License

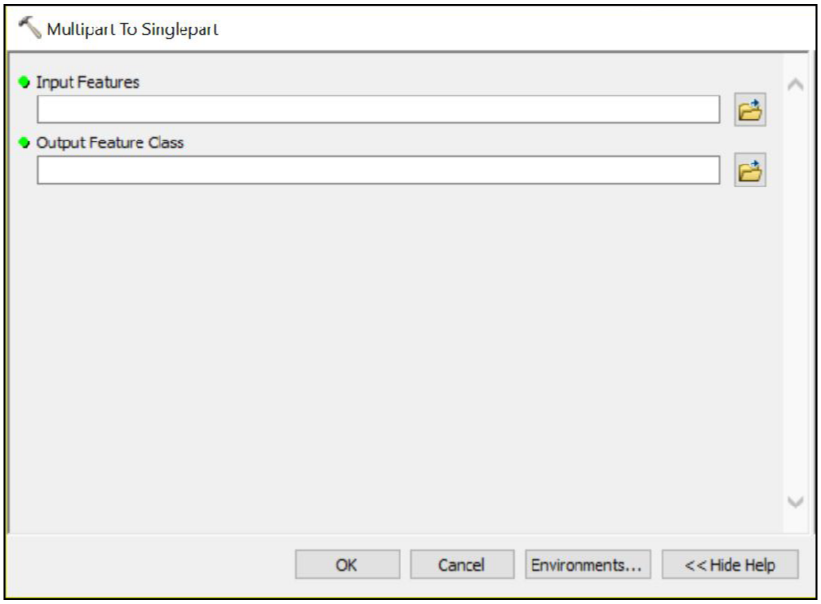
(4.1) Multipart to Singlepart

[Data Management Tools > Features > Make Feature Layer]

Creates a feature class containing singlepart features generated by separating multipart input features.



Source: http://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/multipart-to-singlepart.htm



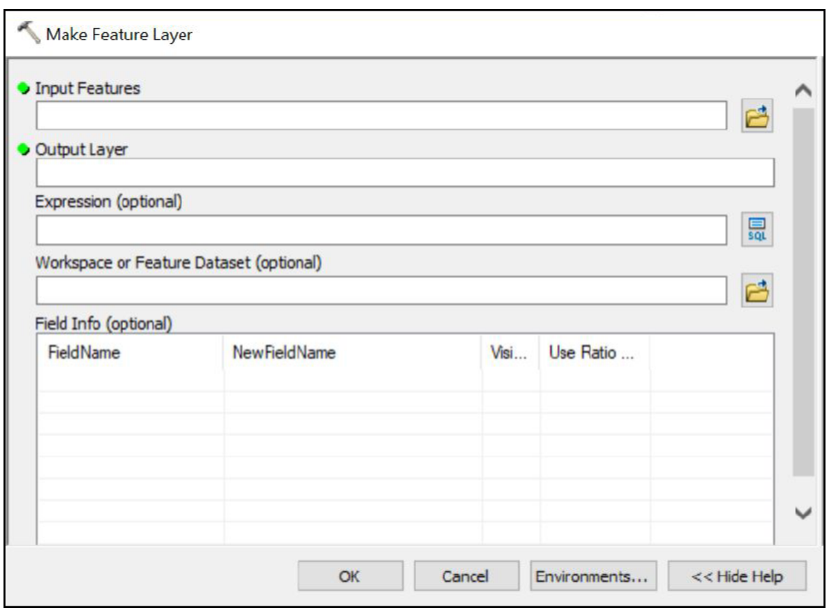
Input Features
The input features that can be any feature type.

Output Feature Class
The output feature class containing features that vary with input feature type.

(4.2) Make Feature Layer

[Data Management Tools > Layers and Table Views > Make Feature Layer]

Creates a feature layer from an input feature class or layer file. The layer that is created by the tool is temporary and will not persist after the session ends unless the layer is saved to disk or the map document is saved.



Input Features
The input feature class or layer from which to make the new layer. Complex feature classes, such as annotation and dimensions, are not valid inputs to this tool.

Output Layer
The name of the feature layer to be created.

Expression (optional)
An SQL expression used to select a subset of features.

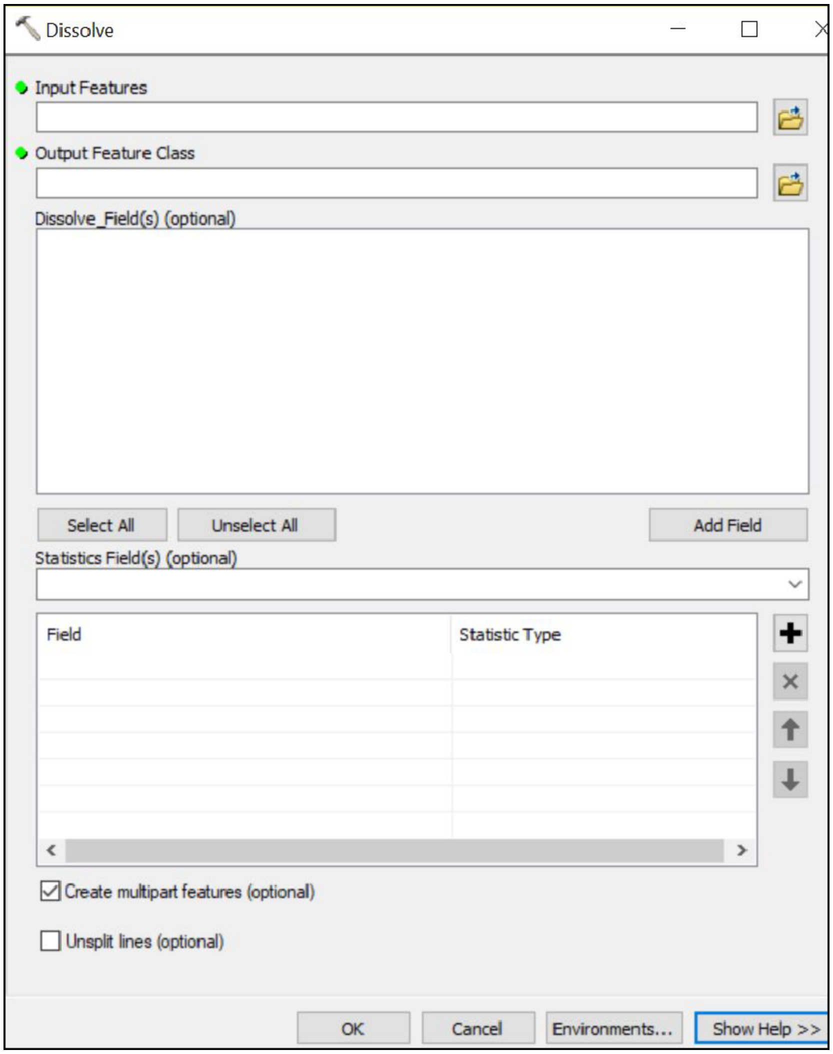
Workspace or Feature Dataset (optional)
The input workspace used to validate the field names.

Field Info (optional)
Can be used to review and alter the field names and hide a subset of fields in the output layer.

(4.3) Dissolve

[Data Management Tools > Generalization > Dissolve]

Aggregates features based on specified attributes.



Input Features
The features to be aggregated.

Output Feature Class
The feature class to be created that will contain the aggregated features.

Dissolve_Fields (optional)
The field or fields on which to aggregate features.

The Add Field button, which is used only in ModelBuilder, allows you to add expected fields so you can complete the dialog box and continue to build your mode

Statistics Field(s) (optional)
The numeric field containing attribute values used to calculate the specified statistic. Text attribute fields can be summarized using first and last statistics.

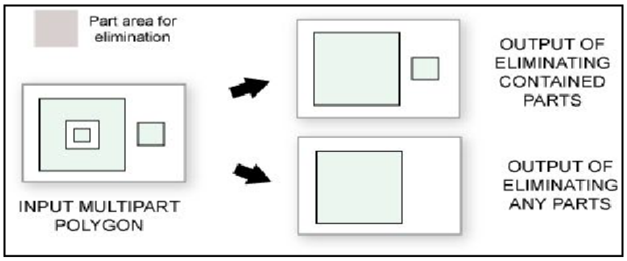
Available statistics types are as follows:

- SUM
- MEAN
- MIN
- MAX
- RANGE
- STD
- COUNT
- FIRST—Finds the first record in the input and uses its specified field value.
- LAST—Finds the last record in the input and uses its specified field value.

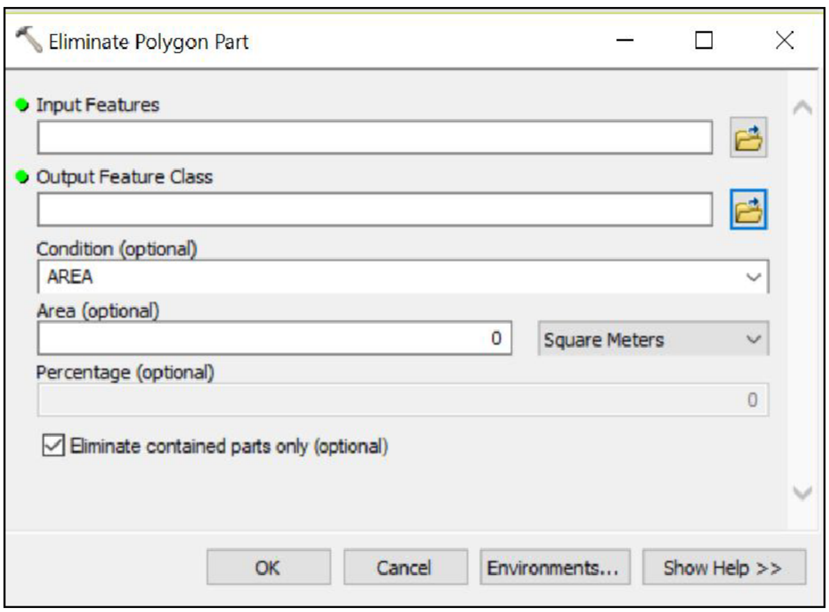
(4.4) Eliminate Polygon Part

[Data Management Tools > Generalization > Eliminate Polygon Part]

Creates a new output feature class containing the features from the input polygons with some parts or holes of a specified size deleted.



Source: http://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/eliminate-polygon-part.htm



Input Features
The input feature class or layer whose features will be copied to the output feature class, with some parts or holes eliminated.

Output Feature Class
The output polygon feature class containing the remaining parts.

Condition (optional)
Specify how the parts to be eliminated will be determined.

- AREA—Parts with an area less than that specified will be eliminated.
- PERCENT—Parts with a percent of the total outer area less than that specified will be eliminated.
- AREA_AND_PERCENT—Parts with an area and percent less than that specified will be eliminated. Only if a polygon part meets both the area and percent criteria will it be deleted.
- AREA_OR_PERCENT—Parts with an area or percent less than that specified will be eliminated. If a polygon part meets either the area or percent criteria, it will be deleted.

Results

The approximate floodplain delineations generated by this study found that the effective FEMA A Zones from the December, 2015 FIS Study and floodplain maps do not closely follow the 2012 LiDAR derived elevation contours. As a result, many properties and existing structures lie within the 100-yr flood event delineation though they are several feet above the elevation of the actual flooding area.

The data geo-processing model produced a floodplain delineation result that correlated well and closely matched the existing effective floodplain delineation. The model was tested on a portion of Trott Brook that was studied by FEMA with detailed hydraulic and hydrologic methods. Validation of the modeling results for the test area was the impetus to move forward with using the floodplain delineation analysis model on the targeted approximate floodplain study areas of Ramsey.

The modeling results for approximate study areas produced floodplain delineations that largely removed structures from the 100-year inundation zone. However, the modeling results also highlighted other large areas near approximate study flooding sources that are not in any effective flood zone but may be inundated during a significant flooding event.

Extensive literature across time and countries shows that other explanatory variables like drainage basin, storage area, soil type, etc. are significant in the floodplain regression analysis. [3] [4] In this model, we primarily consider the elevation data and not the other variables which are present in the true model. This leads to underfitting of model. Statistical theory shows that underfitting in multiple linear regression models creates biased estimates of the coefficients of the explanatory variables. Hence, in this case, it is expected that multiple linear regression will provide biased estimates.

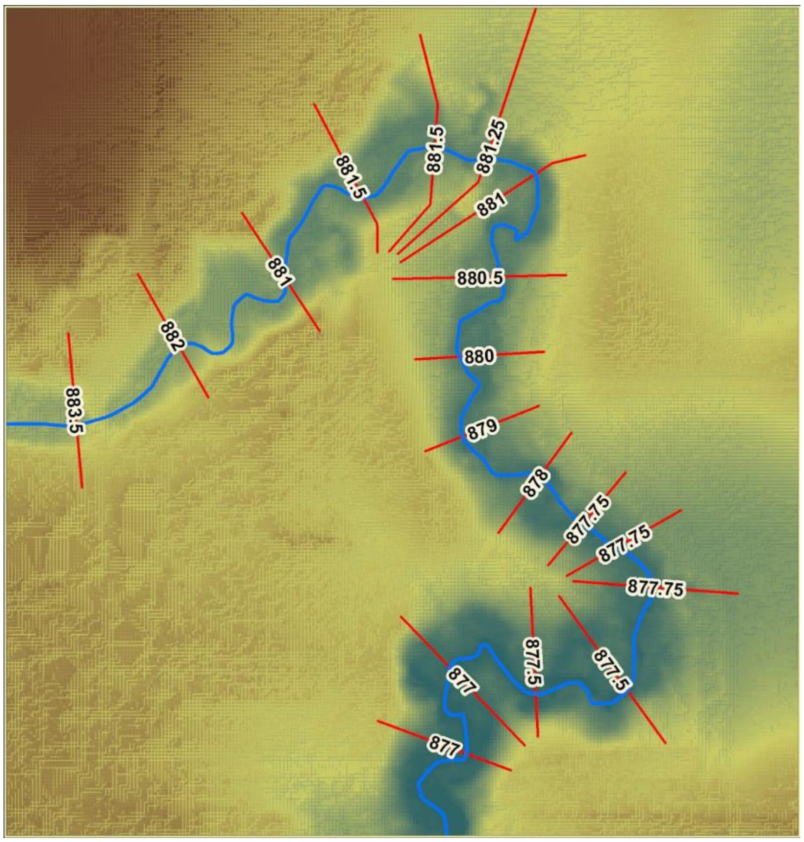
[3] Tehrany, M.S., Shabani, F., Jebur, M.N., Hong, H., Chen, W. & Xie, X. (2017) GIS-based spatial prediction of flood prone areas using standalone frequency ratio, logistic regression, weight of evidence and their ensemble techniques. *Geomatics, Natural Hazards and Risk*, *8*(2), 1538-1561, https://doi.org/10.1080/19475705.2017.1362038

[4] Kim, Y.O., Seo, S.B. & Jang, O.J. (2012) Flood risk assessment using regional regression analysis. *Natural Hazards*, *63*(2), 1203-1217. https://doi.org/10.1007/s11069-012-0221-6

Mapping Results

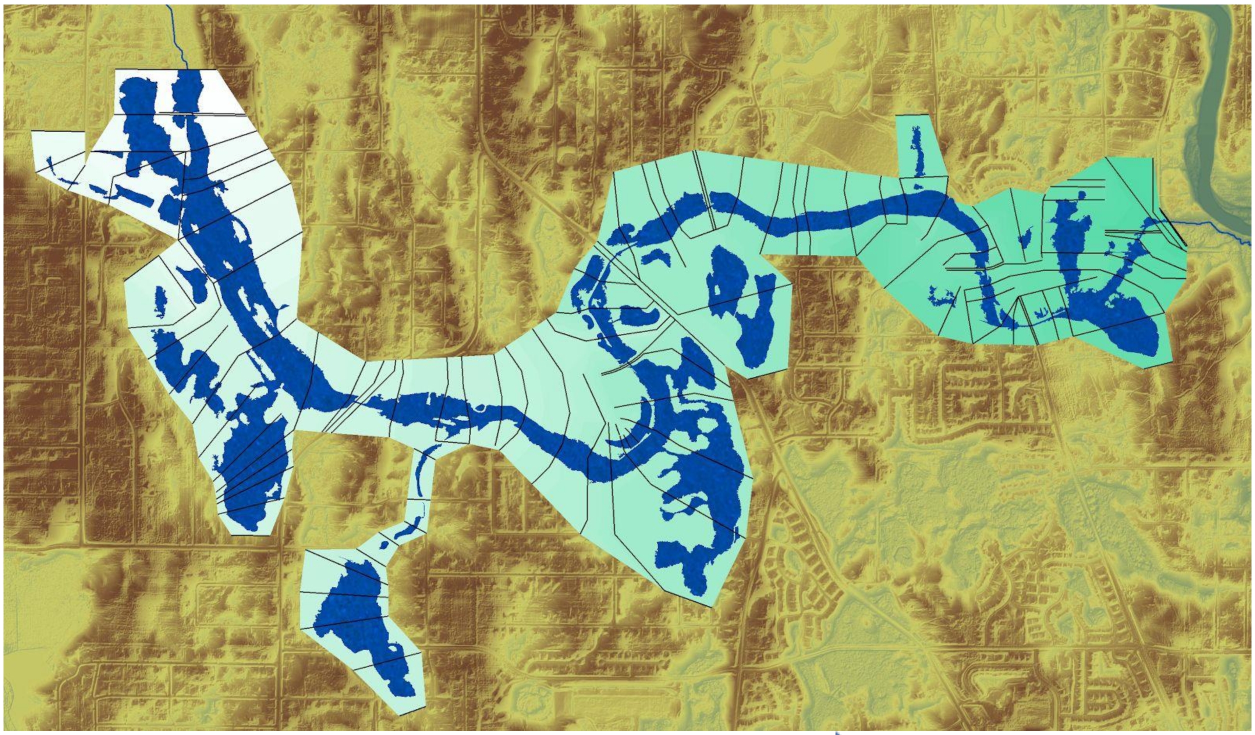
This graphic illustrates how mapping cross-sections are shaped. From FEMA Floodplain Mapping Guidelines and Specifications[5]:

- Cross-Sections should be placed close enough to provide reasonable approximation of the flooding source's profile based on terrain.
- Additional Cross-Sections should be placed at major changes in the width of the 1% annual-chance floodplain.
- Typically, cross-sections are placed perpendicular to the stream centerline.
- This approach generally works well and produces reasonable results, except where streams are highly sinuous or have multiple branches.

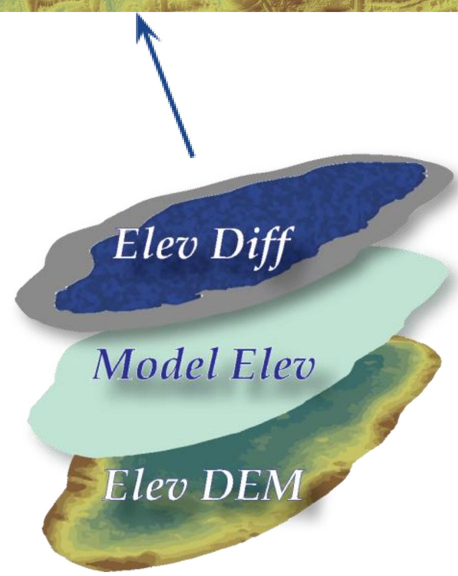


[5] FEMA (2016) Guidance: Automated Engineering. *Guidelines and Standards for Flood Risk Analysis and Mapping.* https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping

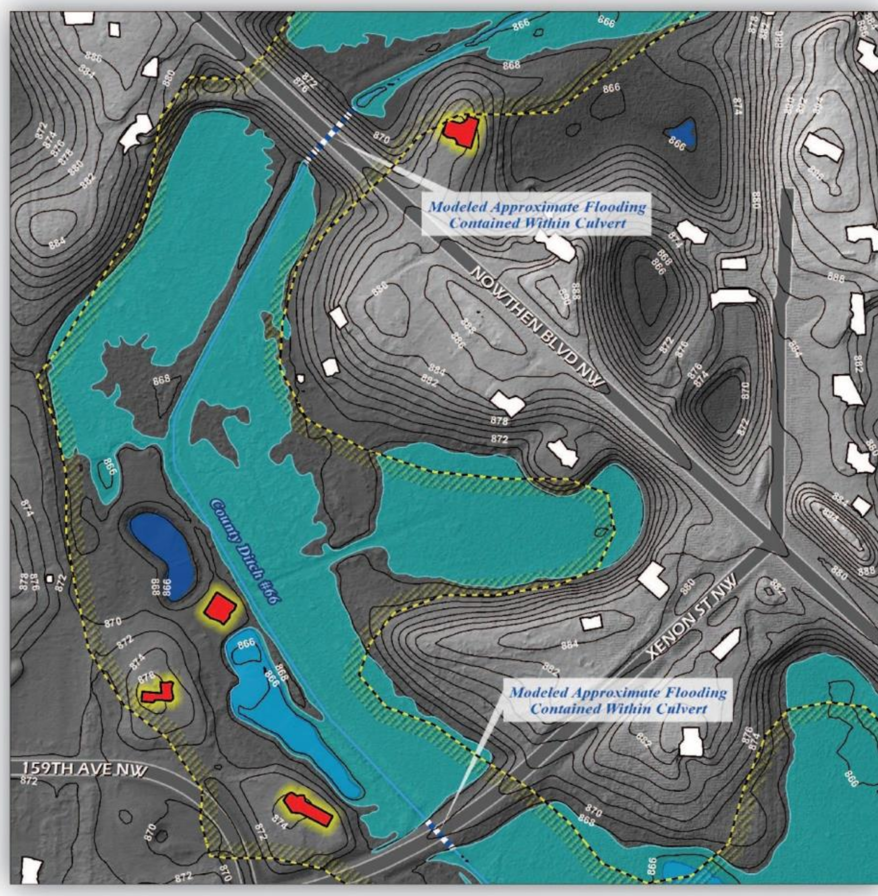
This map depicts a modeled TIN over the LiDAR derived DEM. The mapping cross-section (black lines) elevations were shaped and assigned elevations. The blue areas are the 100-yr floodplain generated from the cut/fill analysis between the TIN and DEM.

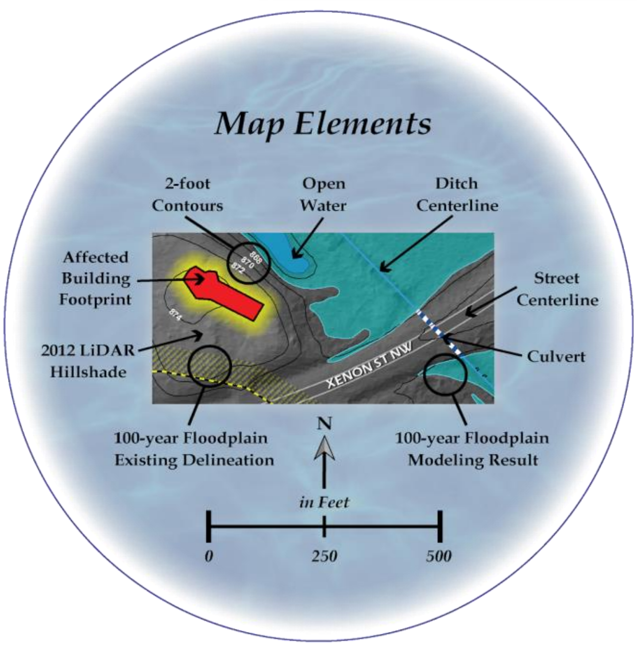


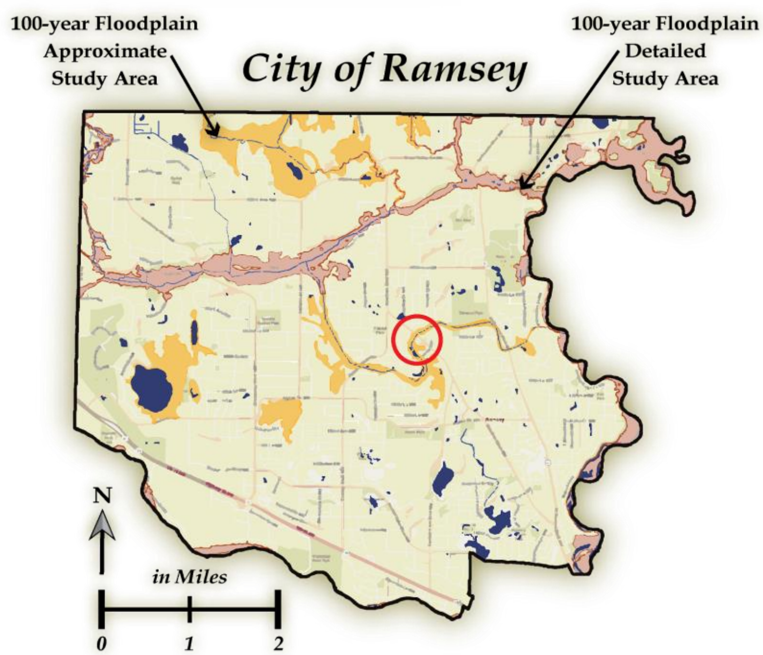
The modeling approach is illustrated here. The DEM raster landform elevation is the basis for the analysis (bottom layer). The modeled TIN is converted to a raster (middle layer). The raster analysis produces the floodplain result (top layer).



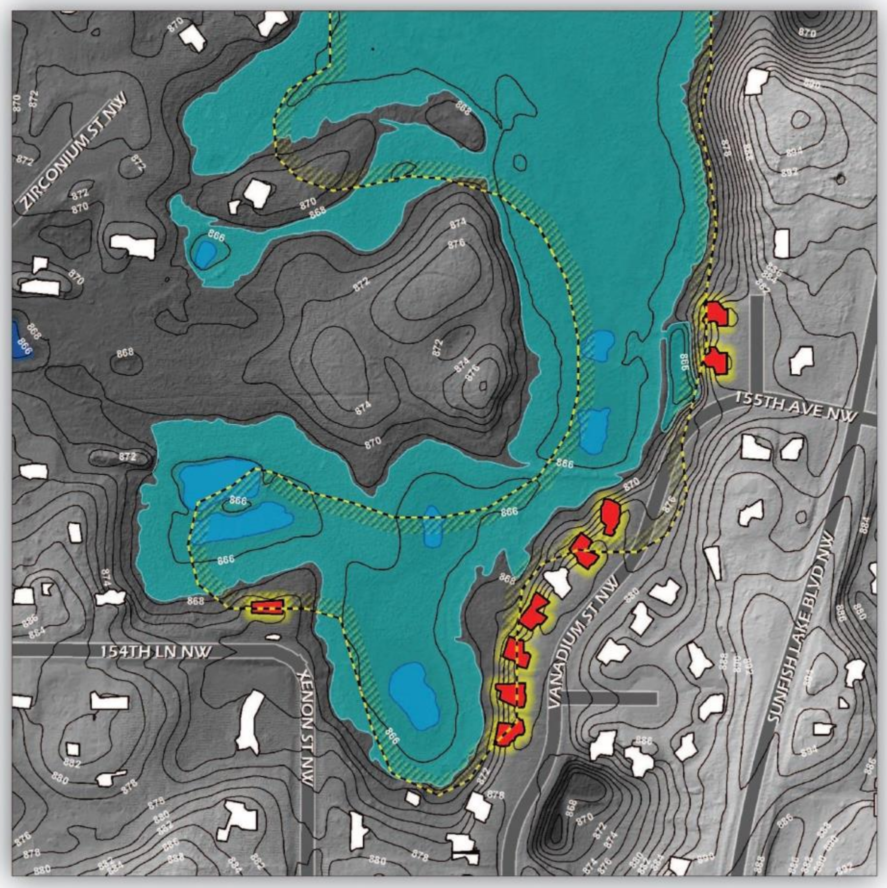
Map depicting typical modeling results along portions of County Ditch #66, an approximate floodplain area in the 2015 floodplain study.

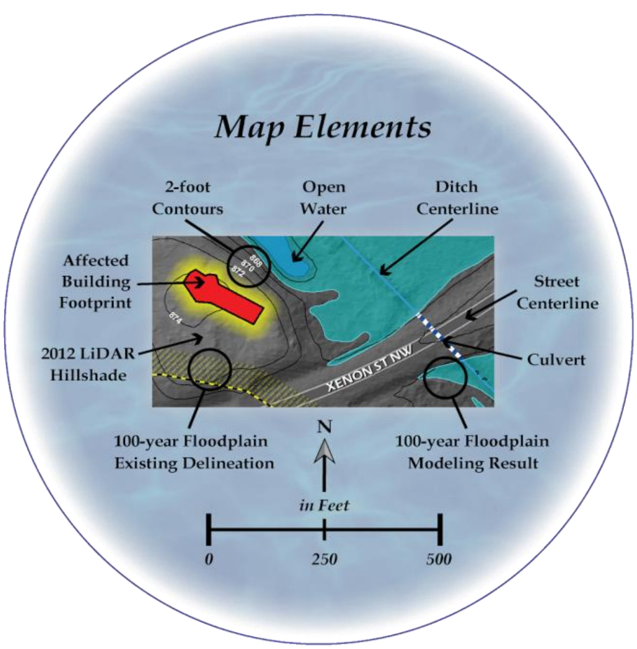


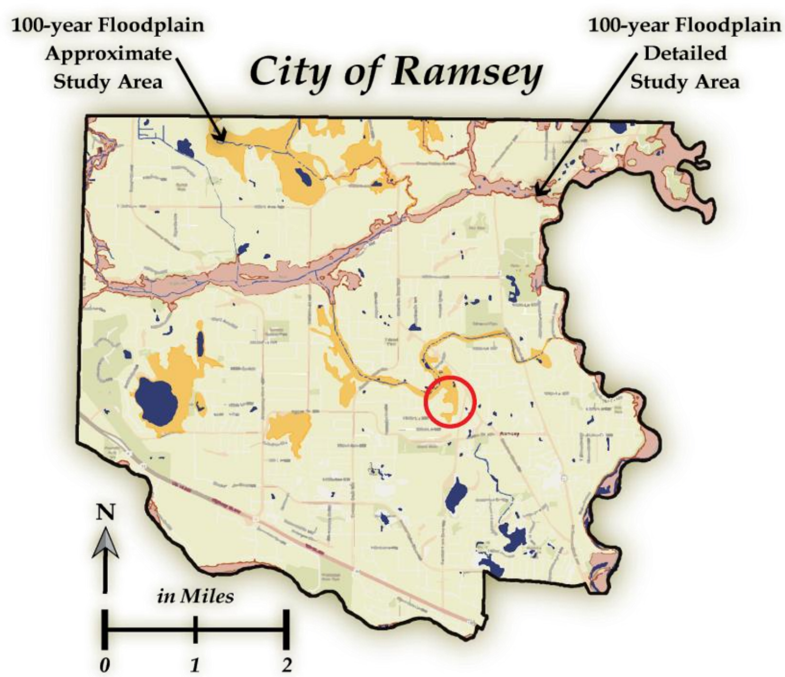




Map showing minor floodplain delineation changes impacting existing structures along a backwater to County Ditch #66.







Conclusion

We found that improved elevation data allows for more accuracy for floodplain delineations. We created a type of cut-fill model, as well as a modeling tool for easy replication, that used this LIDAR data to create flood zones for approximate areas. We tested this model on detailed flood zone areas and found that our model closely matches the result of detailed zones.

Flood zones have a large impact on property owners. We used GIS methods to provide an alternative model of approximate flood zones, and used high-resolution elevation data to provide more accurate zones in these areas. Elevation was a strong predictor of flood zones, and our results matched well when compared to detailed flood zones. However, due to a lack of validation data, further engineering work is needed to confirm the accuracy of our modeled flood zones and identify any site-specific factors not considered in our model. Even without such validation, our study emphasizes the need for revisions of the approximate flood zones and provides a tool that will allow the City of Ramsey to easily explore the effect of elevation on flood zones. The next appropriate steps are to complete a new detailed Letter of Map Revision for problematic approximate floodplain delineation areas and apply engineering methods to analyze the effectiveness of this new study in delineating flood zones.