Flood Forecast

Term Project

NFIE-River:

Building a national stream addressing system

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Introduction

From September 2014 to August 2015, the National Weather Service, the academic community, and their respective government and commercial partners will undertake an ambitious collaboration dubbed the National Flood Interoperability Experiment (NFIE). The NFIE will demonstrate a transformative suite of science and services for the next generation of national flood hydrology and emergency response.

This project will create a geospatial data infrastructure for hydrology, containing several water-related, interconnected layers (rivers, catchments, gages, reservoirs, forecast points, inundation polygons, etc.). This data infrastructure will comprise a next-generation national hydrologic geospatial fabric. Based on this fabric, a national hydrologic simulation framework, including an atmospheric model for precipitation forecast, a land surface model for flood runoff calculation, and a flood routing model, will be set up. Using the forecast flow data, detailed river hydraulic modeling and flood inundation mapping will be implemented for selected communities and regions. This information will be further developed to improve community resilience and local flood response. If successful, the NFIE will increase the spatial density of flood forecasting locations from approximately 3600 (the present NWS river forecasting system) to about 2.67 million. The increase would transform real-time flood information in the United States. (Maidment, 2015)

An essential part of NFIE is translating a forest discharge to its corresponding water surface elevation in river channels over the floodplain. Water elevation information is both more understandable and operable to local communities and emergency response organizations. Flood inundation mapping over the floodplain also needs to rely on the translation. In order to realize this translation, two approaches could be considered. One is the experience-based hydrologic approach using the rating curve, a figure or table describing the relationship between water elevation and discharge. Rating curves can be acquired with measured gage height-discharge pairs from stream stations or computed water depth-discharge pairs from hydraulic models. The other option is the physics-based hydraulic approach. In this scenario, hydraulic models are built using classic fluid mechanic equations. For both approaches, information about river channel is needed. The basic unit to organize river channel data is cross section. For each cross section, three kinds of information are needed to represent it completely both in the geographic information system (GIS) and the hydraulic model. They are the geographic coordinates, the cross section geometry, and the discharge-elevation relationship. However, at this moment, there is no data model available to store these three types of data in an integrated way.

So the purpose of this research is to develop an information framework for river channel cross section data, named Hydraulic Fabric. The principle that directs the design of Hydraulic Fabric is that it should become a data model of national cross section repository. Cross section data come from different platforms will be stored in Hydraulic Fabric in a consistent way. In Hydraulic Fabric, all these three kinds of data used to describe cross section features, geographic coordinates, geometry, rating curve, are available, and the exchange among them are easy to realize as Figure 1.

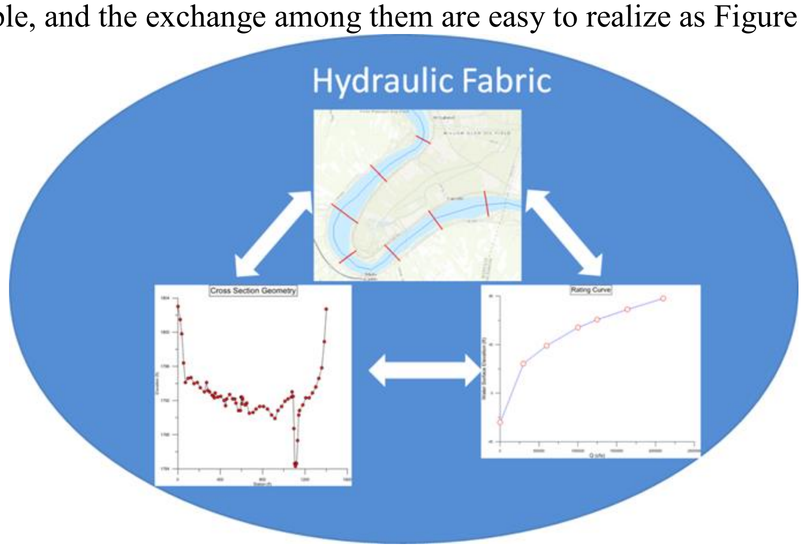


Figure 1 The Role of Hydraulic Fabric

Methodology

DATA MODEL

The Hydraulic Fabric is designed based on GIS concepts. The whole information framework is stored as a geodatabase. The data dictionary of the Hydraulic Fabric is shown as Figure 2. Four feature classes and one table are stored in the geodatabase, namely, **Flowline**, **XSLine**, **XSIntersection**, **XSPoint**, and **XSRating**. Four relationships, **FlowlineIntersectsXSLine**, **XSLineHasXSIntersection**, **XSLineHasPoint**, and **XSLineHasRating**, establish connectivity between the feature classes and the table.

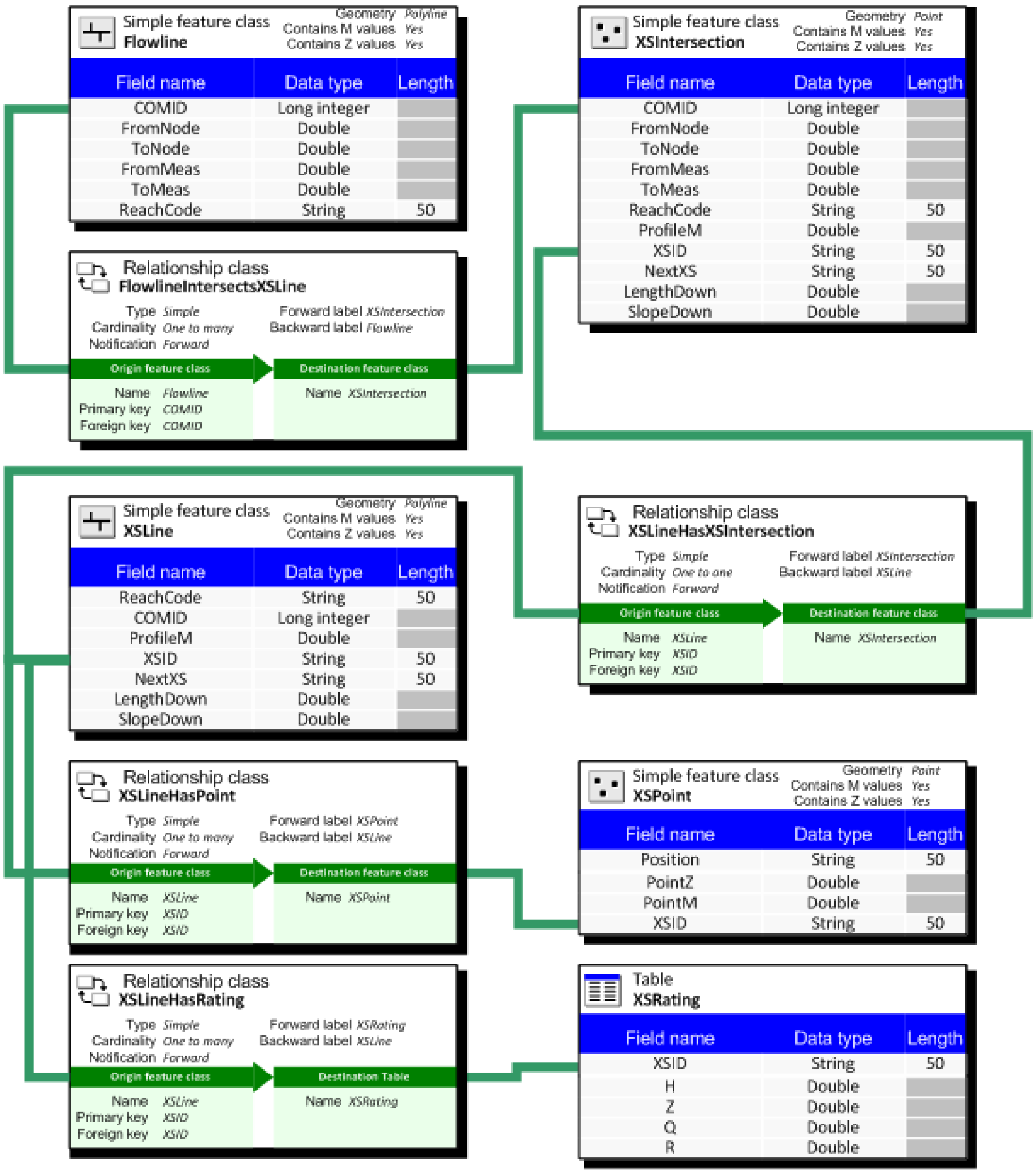


Figure 2 Hydraulic Fabric Data Dictionary

Flowline

Description: Lines representing the river network as shown in plan or map view

Note: Flowlines are similar in concept to a river segment or reach. A reach could be comprised of a single flowline. However, it is also possible for several flowlines to be included in a single reach. Then several features may have the same ReachCode. Thus, a reach is an organizing unit whose definition depends upon the dataset or application. For example, in the National Hydrography Dataset, a reach is “a continuous piece of surface water with similar hydrologic characteristics” (http://nhd.usgs.gov/nhd_faq.html#q106). Flowlines include route measure values to enable linear referencing. The route measure value is 100 at the upstream end of a reach, and 0 at the downstream end of a reach.

Table 1 Flowline Fields

Field Name	Description
COMID	Unique identifier of the feature
ReachCode	Identifies the reach to which the feature belongs
FromNode	Unique identifier for the upstream end of the feature
ToNode	Unique identifier for the downstream end of the feature
FromMeas	Route percentage measure (m-value) at the downstream end of the feature
ToMeas	Route percentage measure (m-value) at the upstream end of the feature

Table 1 shows fields within the Flowline feature class. FromNode and ToNode define the topology relationship between different Flowlines. If the ToNode attribute of one Flowline feature shares the data value with the FromNode attribute of another Flowline, connectivity and flow direction between these two Flowlines is established.

XSLine

Description: The cross section lines on river channels as shown in plan or map view

Note: Cross section lines are normally drawn transverse to the flow. Each cross section line can only intersect one Flowline and only cross the Flowline once.

Table 2 XSLine Fields

Field Name	Description
COMID	Identifier of the Flowline feature on which the cross section is located
ReachCode	Identifies the reach to which the Flowline feature belongs
XSID	Unique identifier of the XSLine feature
NextXS	XSID of next downstream XSLine feature
ProfileM	Route percentage measure (m-value) at the intersection between the XSLine feature and the Flowline feature
LengthDown	River length between the XSLine feature to its next downstream XSLine feature
SlopeDown	Bed slope of the river segment between the XSLine feature to its next downstream XSLine feature

The key point of the XSLine feature class is using the intersection between cross section and Flowline to identify cross section location on river network. The shared COMID achieved from the intersected Flowline defines which reach the cross section is location on. Route measure value of the intersection along the intersected Flowline combined with the ReachCode decides the exact position of the cross section on that reach. It is displayed in a 0 to 100 percentage format so that it will be consistent with the linear referencing measure system of Flowline feature class. The premise of this point, the uniqueness of the intersection, must always be satisfied. By giving the NextXS attribute to each cross section, the topologic relationship between cross sections is established. Important river network parameters, river length and river bed average slope between adjacent cross sections, are also provided to facilitate hydraulic modelling.

XSIntersection

Description: Intersection points between Flowlines and cross section lines as shown in plan or map view

Note: Intersection point feature inherits all the attributes from both intersected Flowline and cross section line. It is a marker for information attached on the Flowline and the cross section line.

Table 3 XSIntersection Fields

Field Name	Description
COMID	Unique identifier of the feature
ReachCode	Identifies the reach to which the feature belongs
FromNode	Unique identifier for the upstream end of the feature
ToNode	Unique identifier for the downstream end of the feature
FromMeas	Route percentage measure (m-value) at the downstream end of the feature
ToMeas	Route percentage measure (m-value) at the upstream end of the feature
XSID	Unique identifier of the XSLine feature
NextXS	XSID of next downstream XSLine feature
ProfileM	Route percentage measure (m-value) at the intersection between the XSLine feature and the Flowline feature
LengthDown	River length between the XSLine feature to its next downstream XSLine feature
SlopeDown	Bed slope of the river segment between the XSLine feature to its next downstream XSLine feature

XSPoint

Description: The points on cross sections, i.e., stations

Note: The starting end of the cross section is defined on the left, where left is interpreted by looking in the downstream direction of flow in the channel.

Table 4 XSPoint Fields

Field Name	Description
XSID	Identifier of the XSLine feature on which the XSPoint is located
PointZ	Z coordinate of the point
PointM	The distance along the cross section line from the beginning of the line to the XSPoint
Position	The profile the point is on, left bank, right bank or centerline

Table 4 describes fields in the XSPoint feature class. PointM and PointZ are provided to express the point location in a station-elevation table which is widely used in hydraulic modelling. The position field provides the profile information about the cross section point. The possible value of this field can only be “left” (left bank), “center” (thalweg), "right" (right bank), or NULL. In that way, if the points with the same attribute "center" are connected from upstream to downstream, the thalweg profile of the river is generated. Similar procedure can be repeated for the left bank and right bank.

XSRating

Description: A table containing the rating cures for all cross sections indexed by XSID

Table 5 Hydraulic Fabric-Rating Table Fields

Field Name	Data Type	Description	Minimum Value Required
XSID	String	Unique identifier of the XSLine feature	--
H	Double	Water surface elevation above river bed (gage height)	Zero
Z	Double	Water surface elevation above geodetic datum (mean sea level)	No limit
Q	Double	Discharge	Zero
R	Double	Return Period	--

To link the rating component to the geospatial component, XSID is adopted as the rating table name. There are four fields in the table. Two kinds of vertical elevation are kept in this table. Gage height (water surface elevation above river bed) is useful for local flood warning and flood damage evaluation, while water surface elevation above geodetic datum (mean sea level) is useful for flood inundation mapping over a large area. Return period is also added here to connect water surface elevation and discharge together with hydrologic frequency analysis results, and help people have a better understanding of the flood scale they are facing. Gage height and discharge data are required to start from zero so that the lower boundary of the interpolation is fixed, and unreasonable values can be avoided.

LOCATING CROSS SECTION LINE WORKFLOW

Cross sections are usually given as lines along a river segment. Both straight lines and polylines are possible forms. To use Hydraulic Fabric, users need to provide geospatial information about their cross sections including the coordinate system and coordinates for each line.

To locate a cross section on a river network, the first step is to intersect the cross section line with the river flowline. This generates the XSIntersection point feature class. For each cross section, only one intersection is allowed to be stored in the intersection dataset.

While it is possible in hydraulic modelling practice such as HEC-RAS that a cross section may have more than one intersection with one or more flowlines, the existence of multiple intersections will cause ambiguity to identify the cross section location. When multiple intersections appear, excess ones must be removed from the XSIntersection feature class. This removal is likely to be a manual process due to the higher level decision making involved in choosing the best intersection point.

Then flowlines along the path from the most upstream cross section to the most downstream cross section will be selected from the original river flowline dataset and written into the Hydraulic Fabric Flowline feature class. In other words, only the subset of river features pertinent to establishing connectivity between cross sections is retained. A percentage curvilinear axis, which is called a route in linear referencing, will be set up along every feature. The coordinates of the start point and end point are assumed to have already been assigned for every Flowline feature. The next step is to locate the intersection of each XSIntersection point along that route and to get its coordinate.

Finally, by joining the XSLine table and XSIntersection table using the same XSID, the COMID of the intersected flowline and the measure value of the intersection will be written to the XSLine table as COMID and ProfileM. At this point, the location of the cross section on the river network has been identified clearly. A flowchart of the whole process is shown as Figure 3.

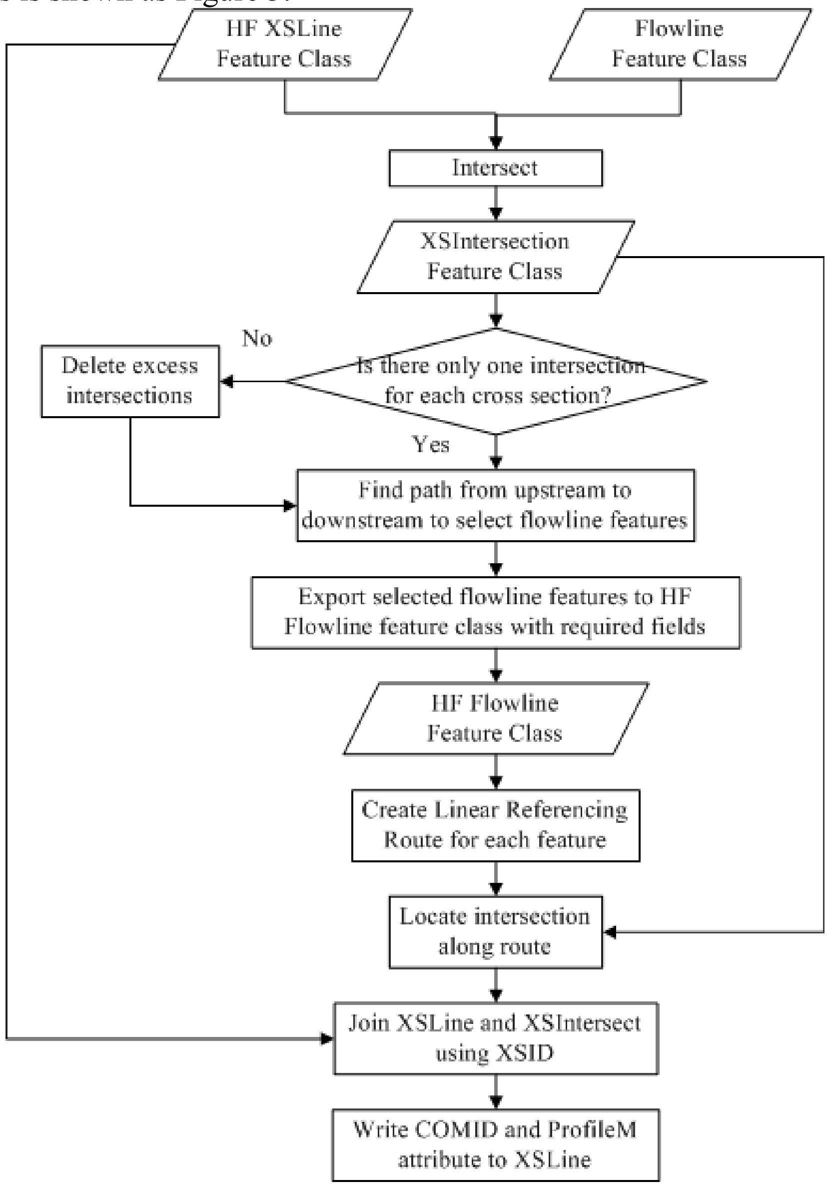


Figure 3 Flowchart of Locating XSLine

Case Study

Study Area and Dataset

A cross section polyline feature class containing 17637 features is given by Solomon Vimal from University of North Carolina. This dataset is created by integrating cross section data in hydraulic models or field surveys from different sources. Figure 4 shows the distribution of these cross sections.

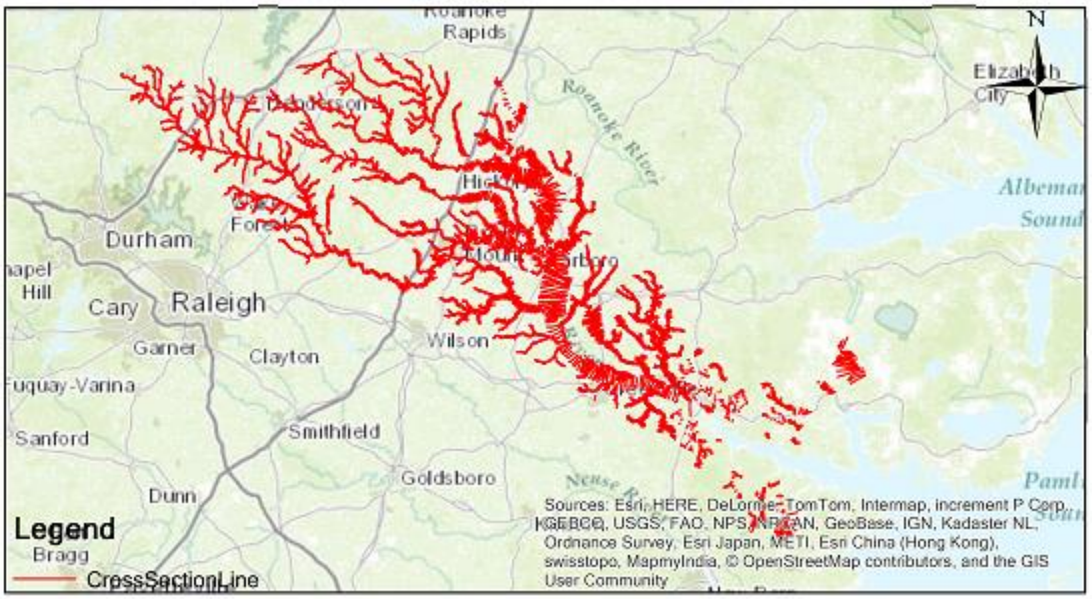
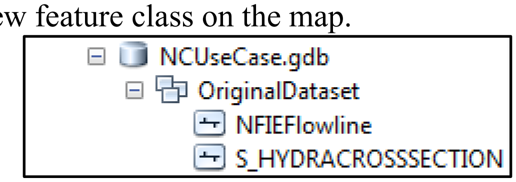
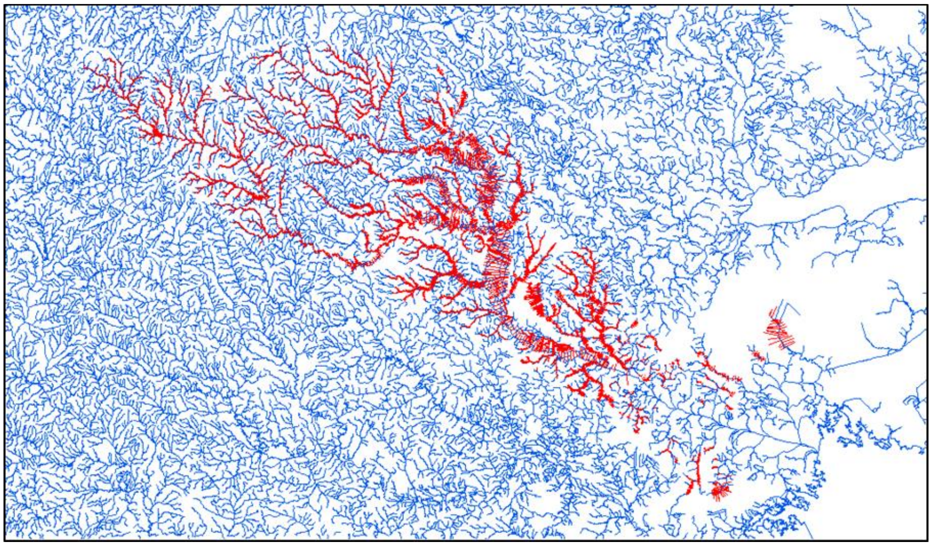


Figure 4 Cross Sections From North Carolina Dataset

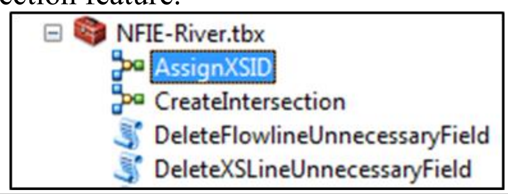
Implementation Process

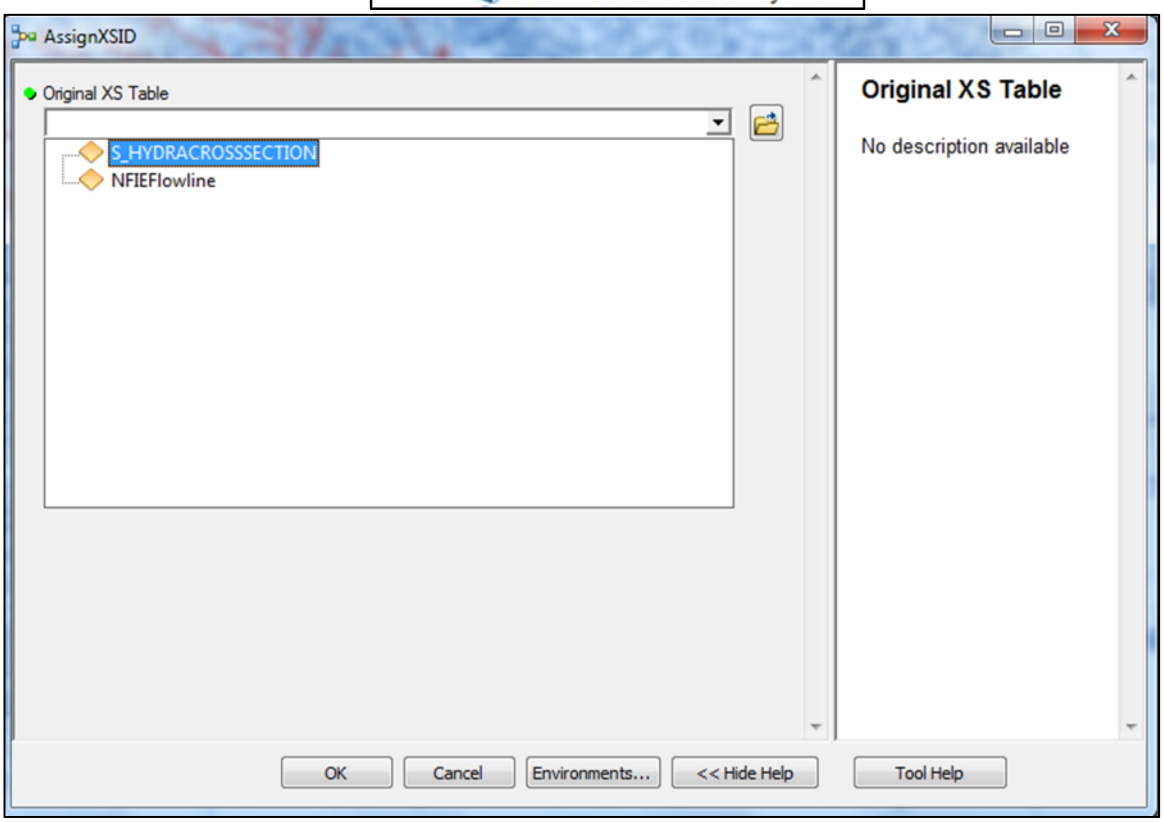
1. Build a new geodatabase, create a feature dataset, set its coordinate system as the same as that of the cross section feature class, and import cross section feature class and NFIE-Geo feature class into this feature dataset. Show the new feature class on the map.

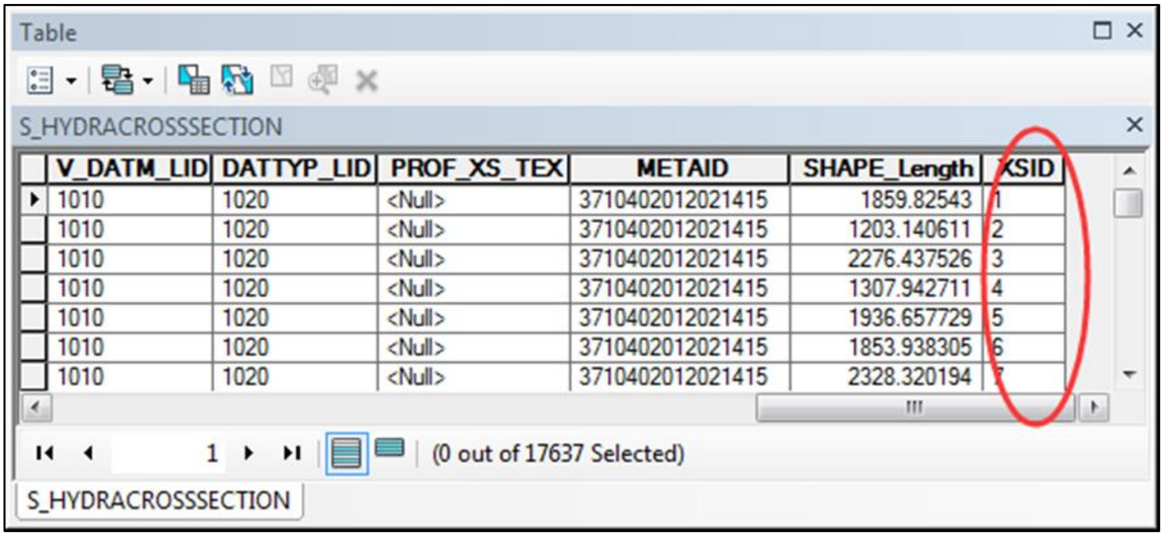




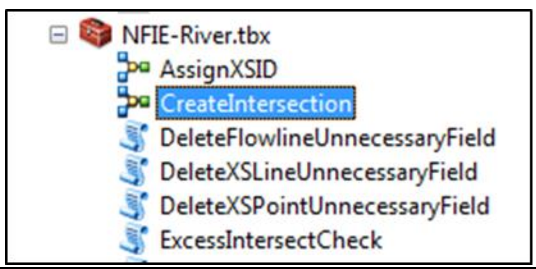
2. Run the AssignXSID tool in NFIE-River toobox using cross section feature class as the input to assign a unique identifier named XSID to every cross section feature.

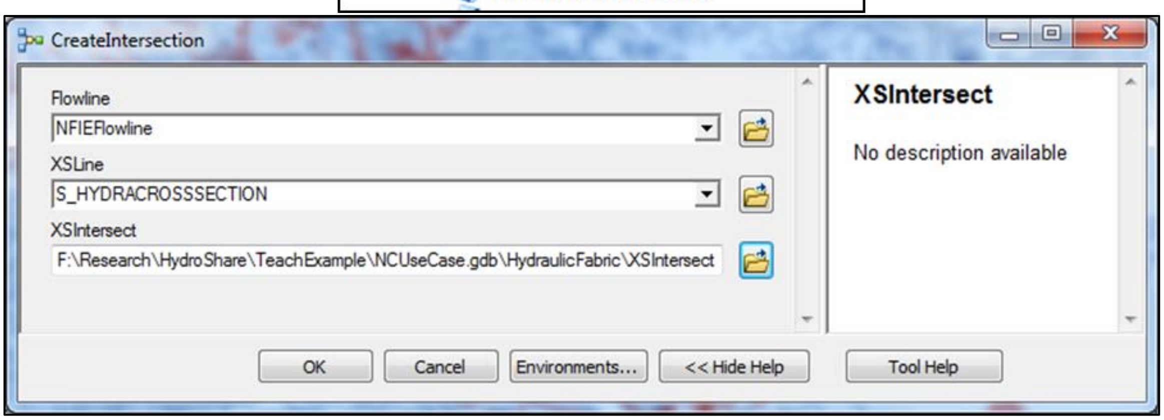




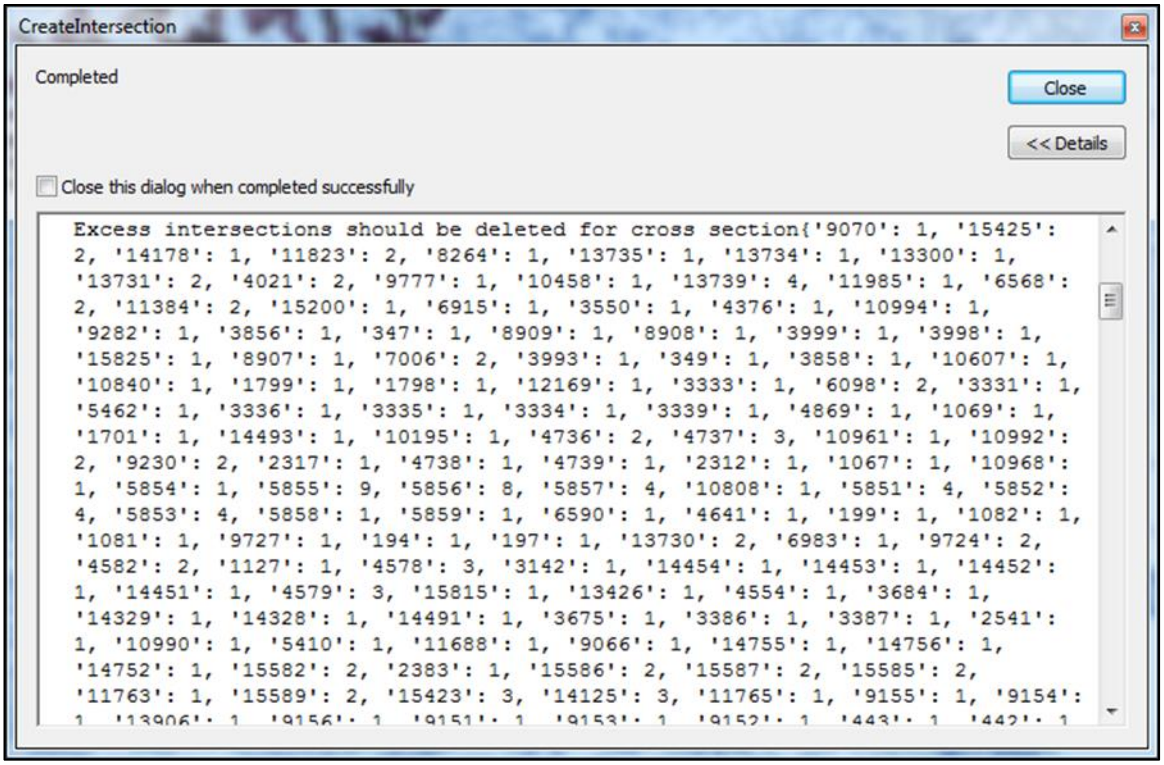


3. Create a new feature dataset in the geodatabase you just created, and name it as HydraulicFabric. Run the CreateIntersection tool to create intersections between cross sections and flowlines. Store the intersections as a new feature class named XSIntersect in HydraulicFabric feature dataset.

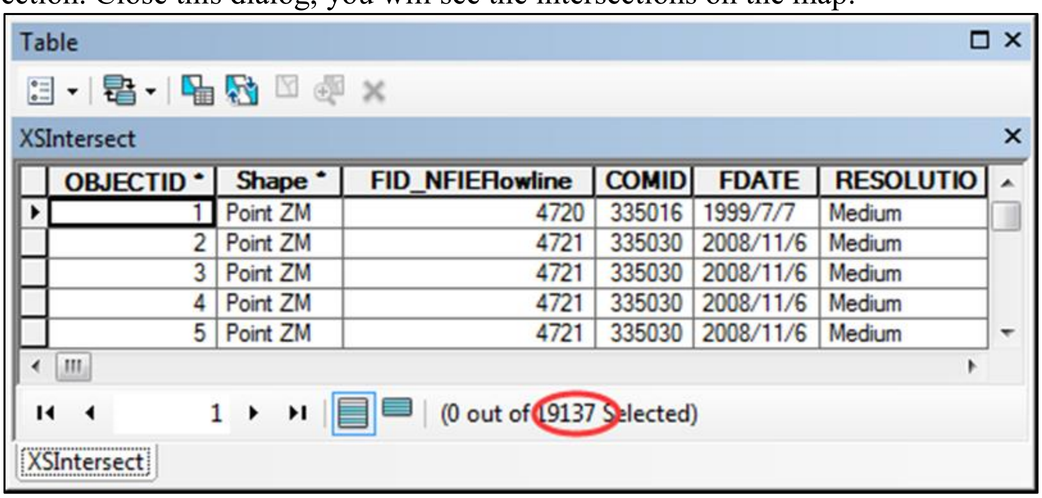


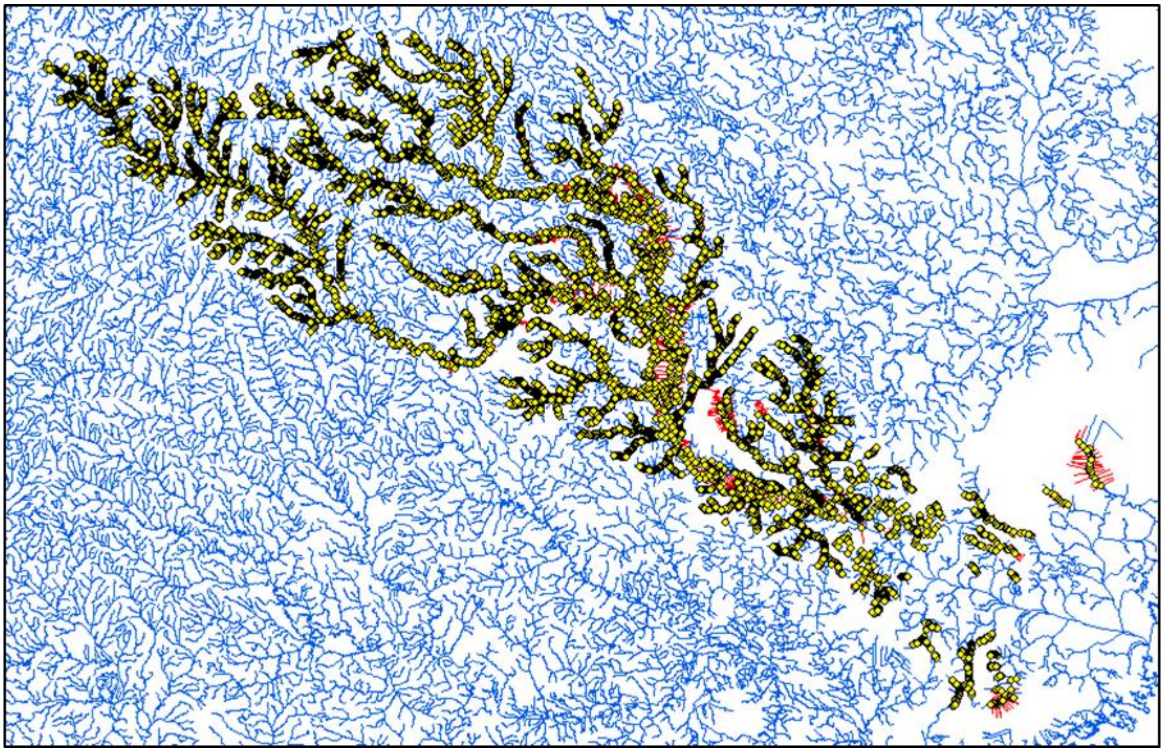


This tool does not only output the intersect feature class, it will also report the XSID and the extra intersection numbers for those cross sections that have more than one intersections with the flowline.

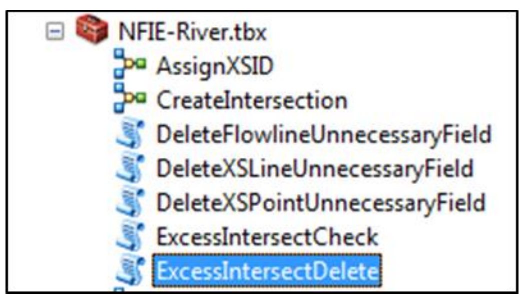


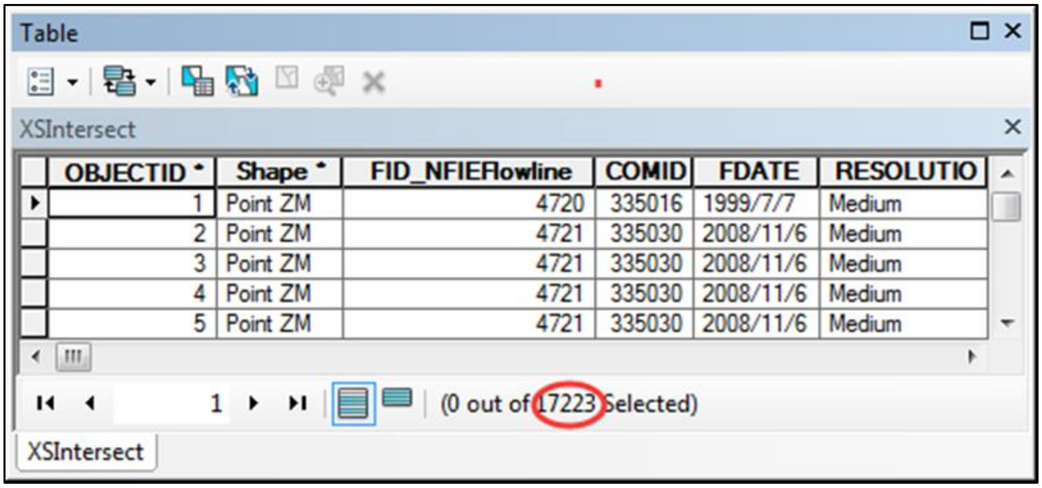
After you run this tool successfully, you will see the dialog with excess intersection information. For example, for cross section '9070', we got one extra intersection. Close this dialog, you will see the intersections on the map.



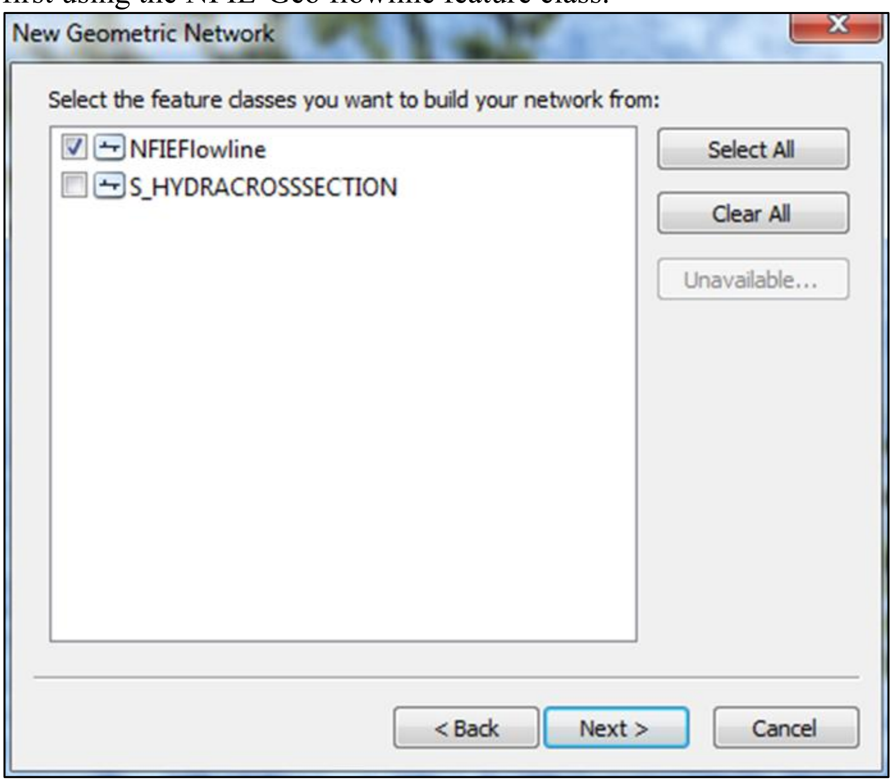


4. Run the ExcessIntersectDelete script to delete the extra intersections from the XSIntersect feature class. For each cross section, which intersections will be treated as excess ones to be deleted is decided by the program randomly.

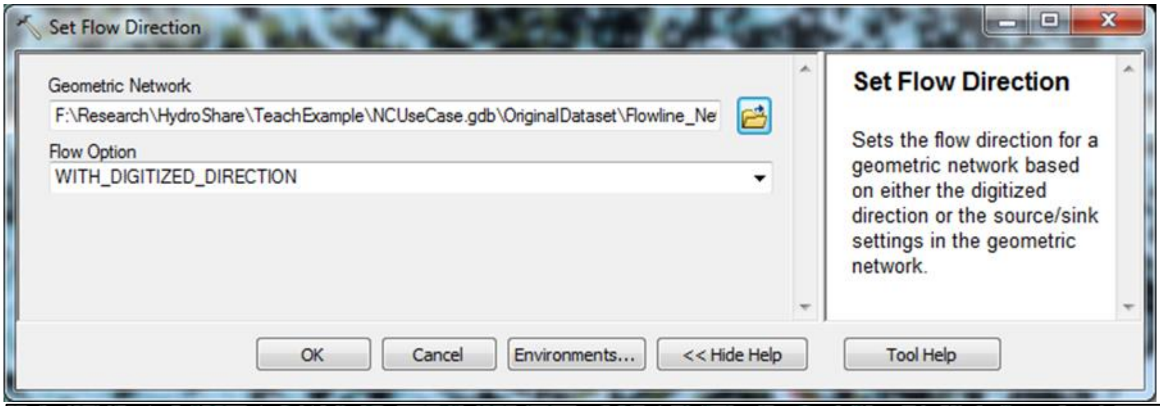


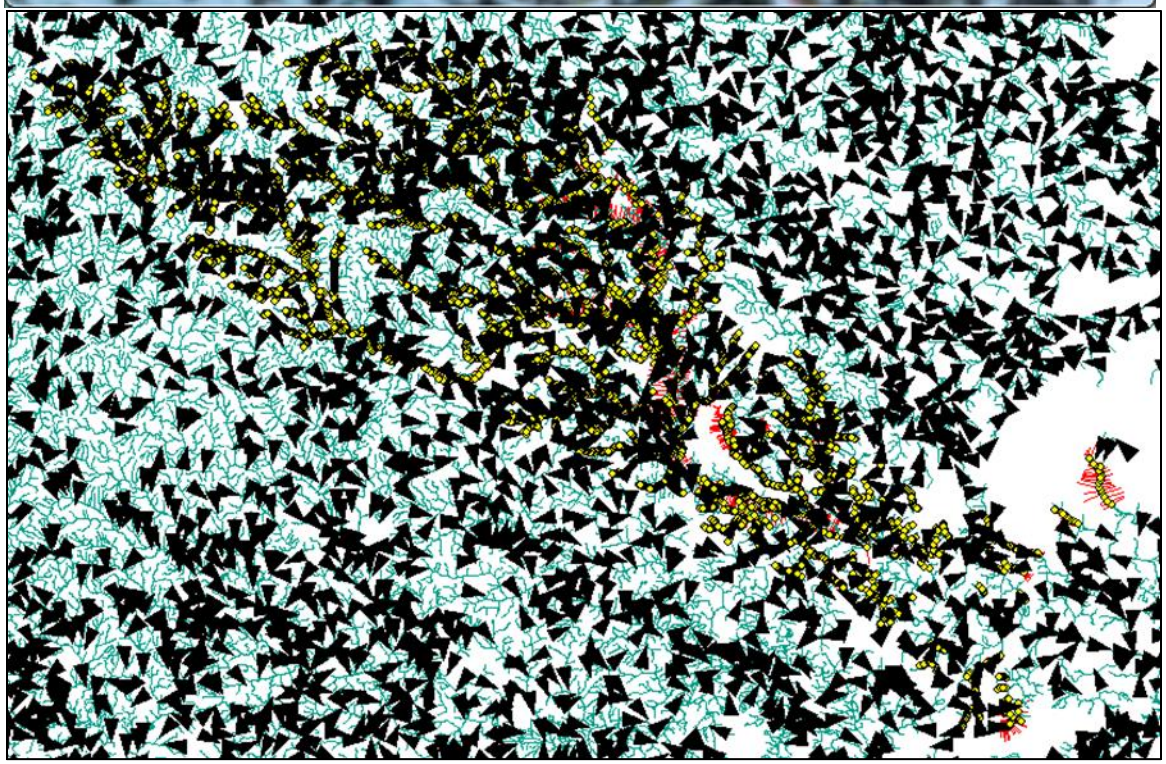


5. Now the flowlines intersected with the cross sections and the flowlines between cross sections must be identified from the NFIE-Geo flowline feature class. In order to do that, a geometric network must be built up at first using the NFIE-Geo flowline feature class.

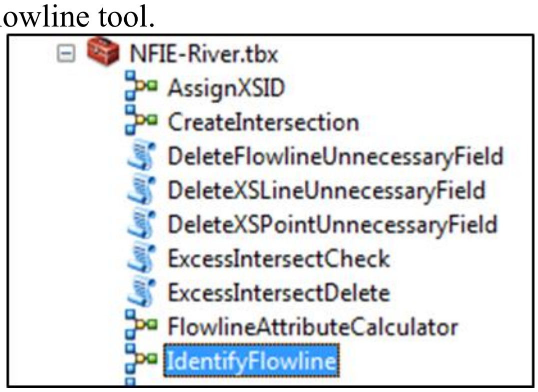


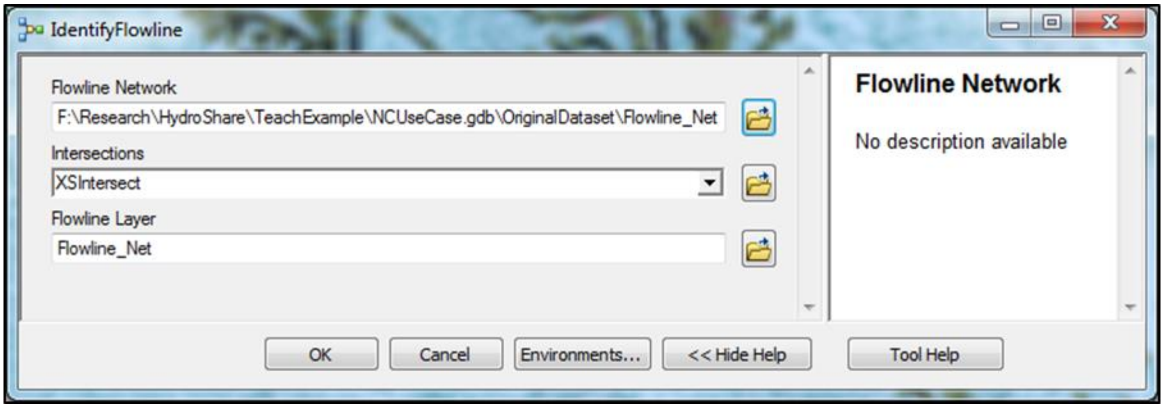
Search for the Set Flow Direction tool, and use it to set the flow direction for this network with the With_DIGITIZED_DIRECTION option.



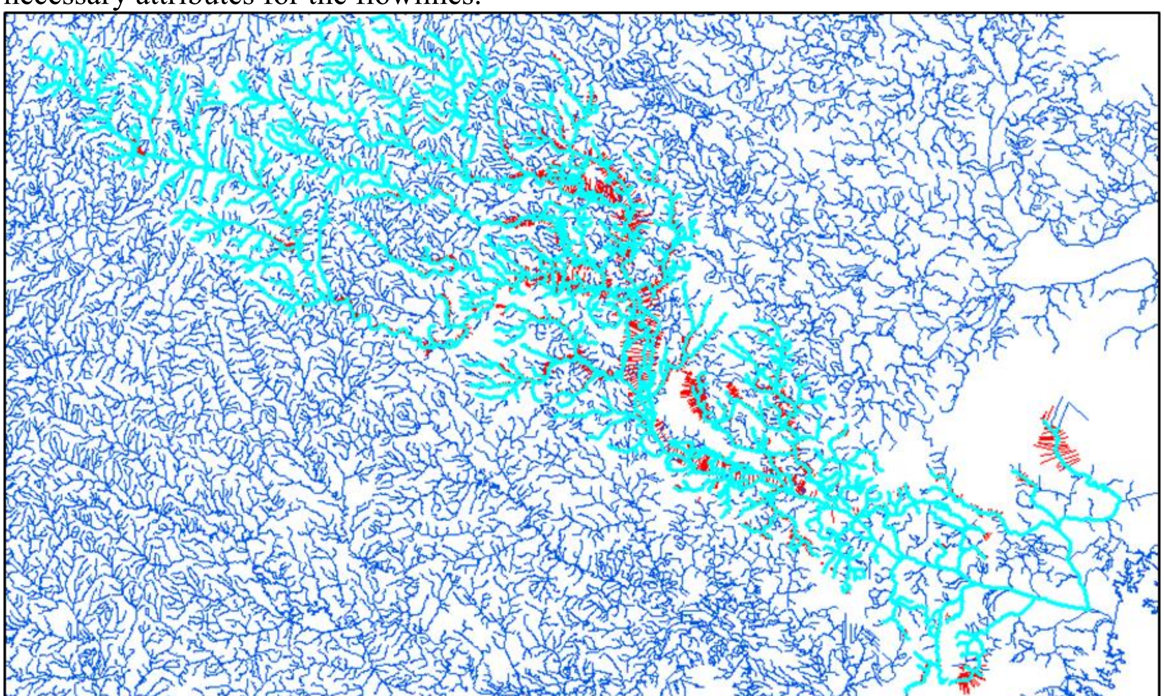


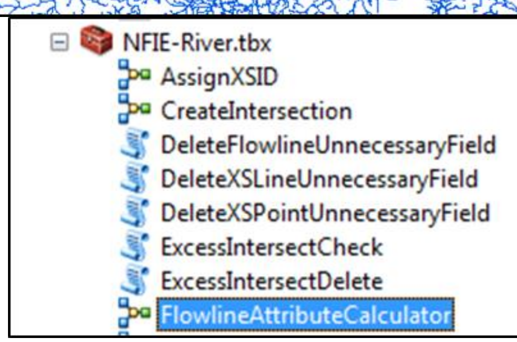
Run the IdentifyFlowline tool.

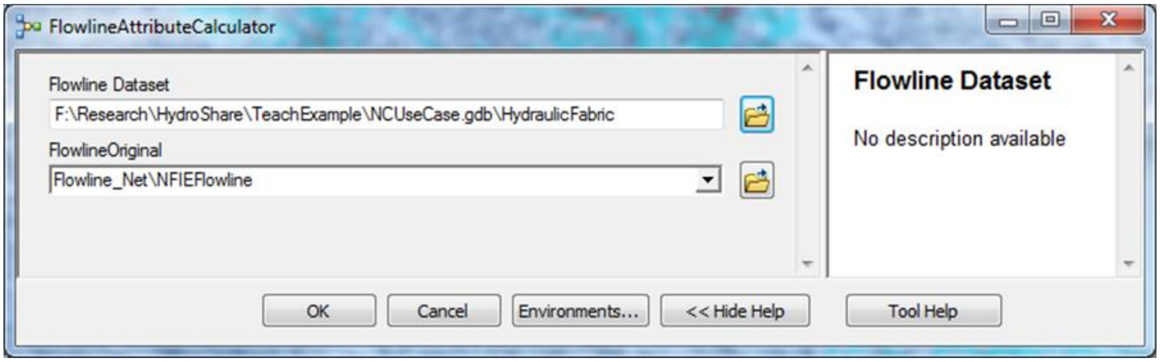




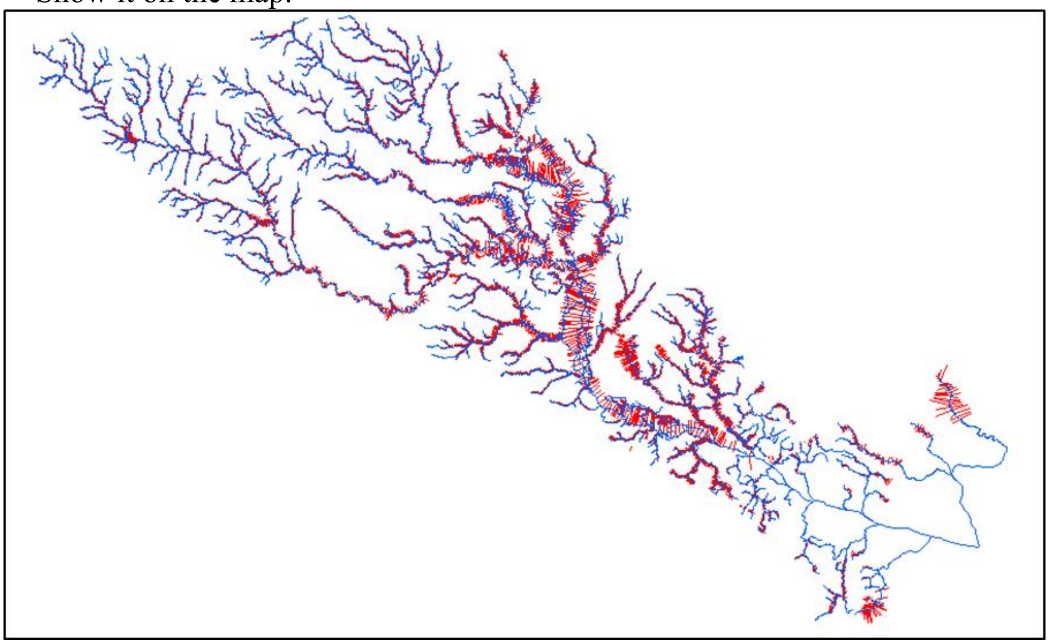
So flowlines in the study region will be selected from the NFIE-Geo flowline feature class. Run the FlowlineAttributeCalculator tool to import selected flowlines into HydraulicFabric dataset as a new feature class named Flowline, and delete all the necessary attributes for the flowlines.



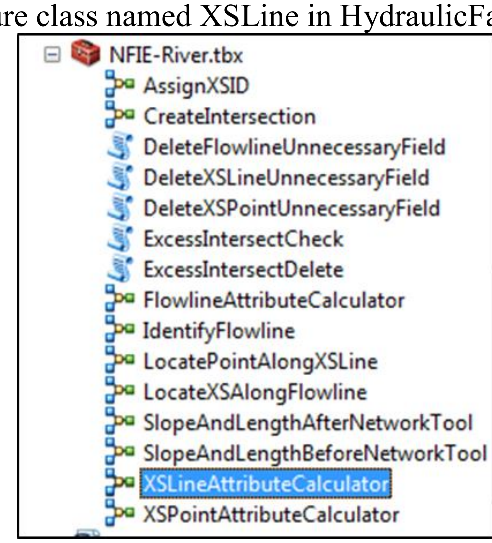


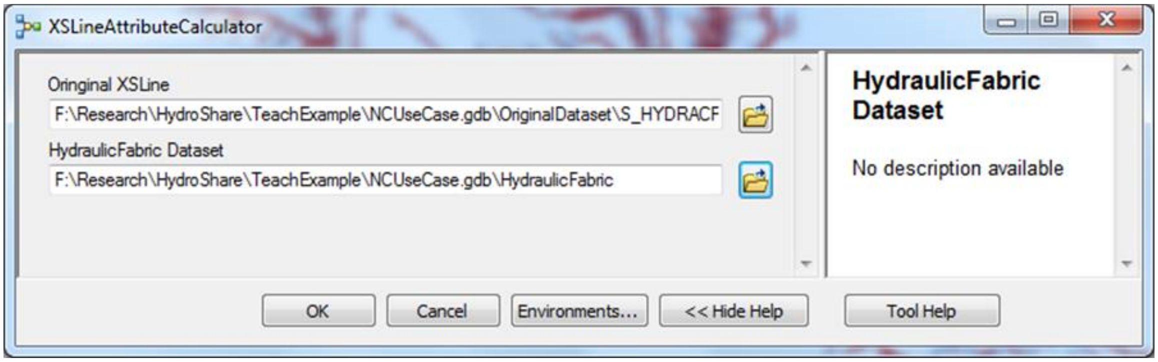


Show it on the map.

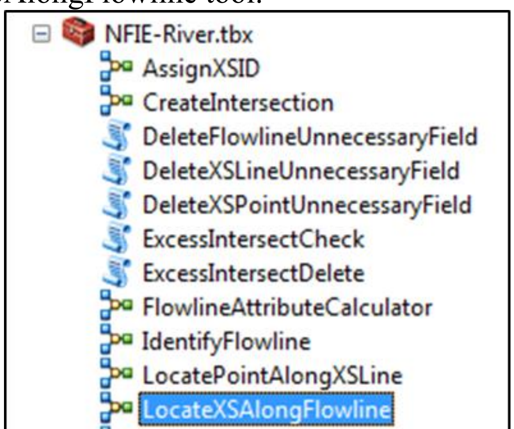


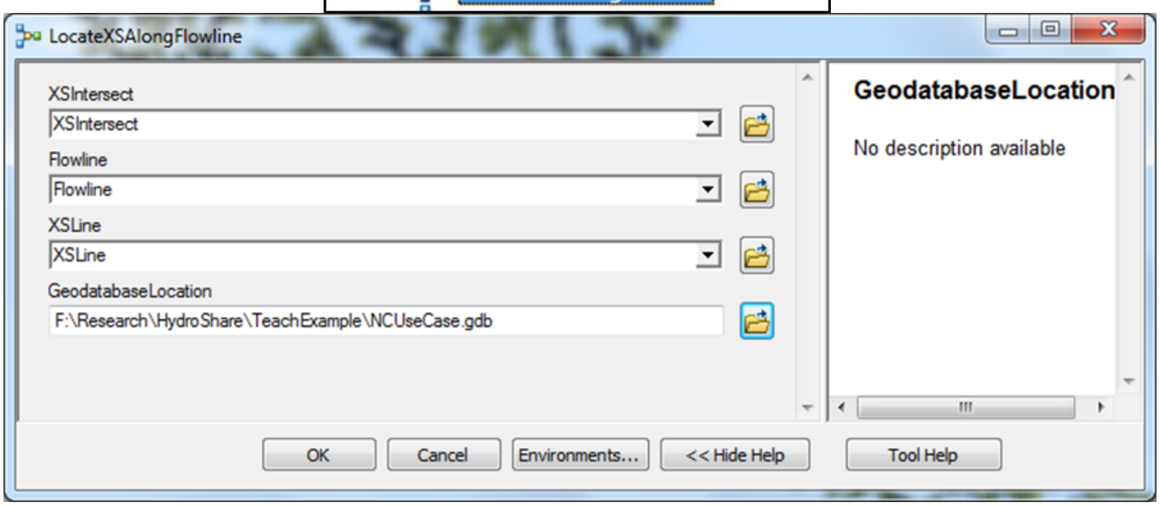
6. Similarly, run the XSLineAttributeCalculator tool to create a new cross section feature class named XSLine in HydraulicFabric dataset.



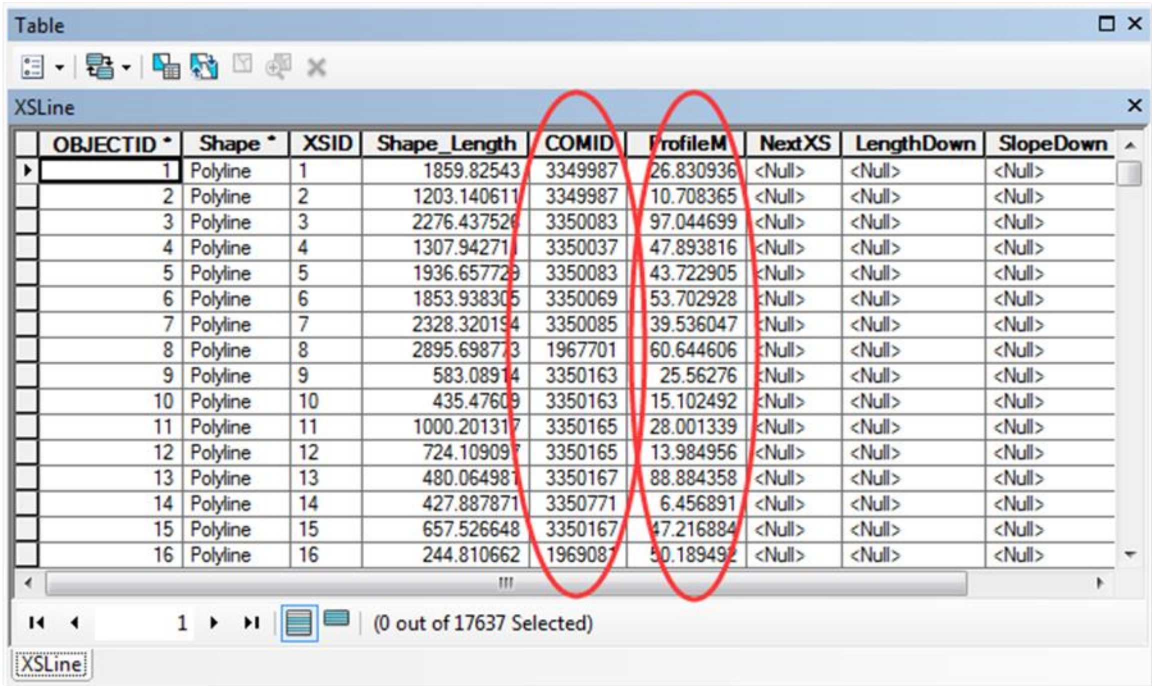


7. At last, after you get all the feature classes ready, run the LocateXSAlongFlowline tool.





After the process is completed, open up the XSLine attribute table, and you will find out the COMID and ProfileM fields are populated for all the cross section lines intersected with the flowline. The COMID is the identifier of the reach that the cross section is located on, and the ProfileM is the percentage measure of the cross section intersection location to the downstream end of that reach.



OBJECTID *	Shape *	XSID	Shape_Length	COMID	ProfileM	NextXS	LengthDown	SlopeDown
1	Polyline	1	1859.82543	3349987	26.830936	<Null>	<Null>	<Null>
2	Polyline	2	1203.140611	3349987	10.708365	<Null>	<Null>	<Null>
3	Polyline	3	2276.437526	3350083	97.044699	<Null>	<Null>	<Null>
4	Polyline	4	1307.942711	3350037	47.893816	<Null>	<Null>	<Null>
5	Polyline	5	1936.657729	3350083	43.722905	<Null>	<Null>	<Null>
6	Polyline	6	1853.938305	3350069	53.702928	<Null>	<Null>	<Null>
7	Polyline	7	2328.320194	3350085	39.536047	<Null>	<Null>	<Null>
8	Polyline	8	2895.698773	1967701	60.644606	<Null>	<Null>	<Null>
9	Polyline	9	583.089144	3350163	25.56276	<Null>	<Null>	<Null>
10	Polyline	10	435.476009	3350163	15.102492	<Null>	<Null>	<Null>
11	Polyline	11	1000.201317	3350165	28.001339	<Null>	<Null>	<Null>
12	Polyline	12	724.109097	3350165	13.984956	<Null>	<Null>	<Null>
13	Polyline	13	480.064981	3350167	88.884358	<Null>	<Null>	<Null>
14	Polyline	14	427.887871	3350771	6.456891	<Null>	<Null>	<Null>
15	Polyline	15	657.526648	3350167	47.216884	<Null>	<Null>	<Null>
16	Polyline	16	244.810662	1969081	50.189492	<Null>	<Null>	<Null>

Figure 5 Cross Section Locations on NHD Flowlines

Conclusion

In this paper, the Hydraulic Fabric data framework is proposed where we can put cross section geographic information, cross section geometric information, and cross section discharge-elevation relationship into an integrated system. Then the workflow of linear referencing cross sections on NHD flowlines is described and tested using a dataset from North Carolina. The success of this case study verifies the feasibility of the workflow, which is the first attempt of building a national scale cross section dataset. In the past, water data framework is mainly designed for describing “blue lines”, which are the flowlines following the flow direction of the river. NHDPlus dataset, or NFIE-Geo dataset specifically in NFIE project, is such a hydrologic fabric weaved for the whole country. However, no geospatial information framework exists for cross sections, which is the basic unit to organize river channel geospatial information perpendicular to flow direction. Using the data model and workflow introduced in this paper, all the cross section data from various sources can be linked to the “blue line” in a consistent way.

Reference

Maidment D. R. 2015. A Conceptual Framework for the National Flood Interoperability Experiment. Austin: The University of Texas at Austin. <https://www.cuahsi.org/Files/Pages/documents/13623/nfieconceptualframework_revised_feb_9.pdf>