COMPUTING FLUVIAGENY WITH ARCGIS

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Introduction

Fluviageny refers to the history of river segment lineages as they change through time. For example, when considering fish populations, the introduction of dams into a river network disrupts movement of fish across the dams, creating segments of rivers between dams in which a given fish population that was once ubiquitous throughout the river network begins to evolve independently within each portion of the river network between a set of dams. This concept is similar to and derives its name from phylogeny in biology, i.e., the Tree of Life.

This document describes a workflow that can be used with the accompanying ArcGIS toolbox to compute fluviageny in a river network using ArcGIS 10.1 or greater, with a Standard or Advanced license (does not work with Basic license).

About Fluviageny Codes

Numerical codes can be assigned to river segments to represent fluviageny. The convention we use here is as follows. Consider a river network with no dams. When the first dam is built, all river segments upstream of the dam are assigned a fluviageny code of 1. All river segments downstream of the dam are assigned a fluviageny code of 2. When the second dam is built, upstream river segments between the new dam and any upstream dams or river terminations have ".1" appended to their fluviageny code. Likewise, the uninterrupted portion of the river network downstream of the dam will have ".2" appended to its fluviageny code. 1.

To illustrate this, consider the river network in Figure 1. Flow direction, as indicated by black arrows is from the top of the figure to the bottom. A series of dams will be added to this network over time. Their names and the year they are built are shown in Table 1.

Table 1: Dams and Year Built

Dam Name	Year Built
a	1920
b	1930
c	1937
d	1938
e	1952

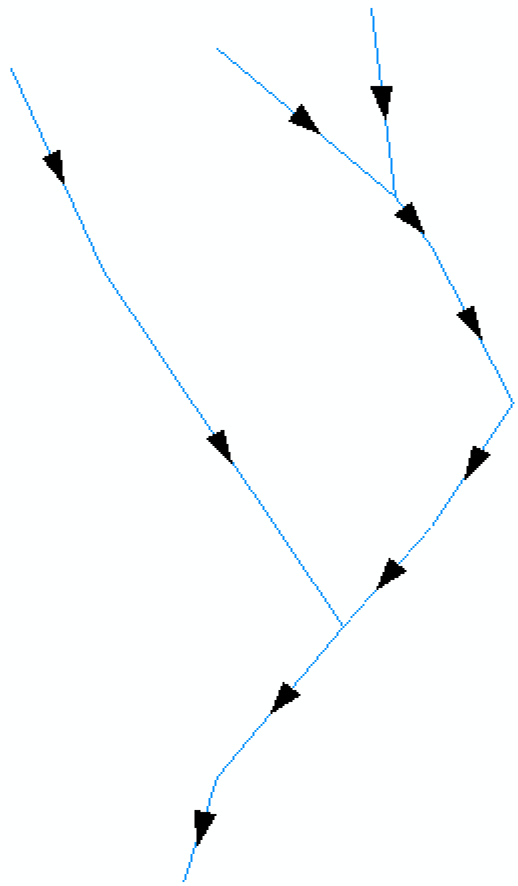


Figure 1: Original river network. Flow direction is indicated by the arrows.

Once the first dam is built, all rivers upstream of the dam are assigned a fluviageny code of 1, while the rest are assigned a code of 2, as shown in Figure 2.

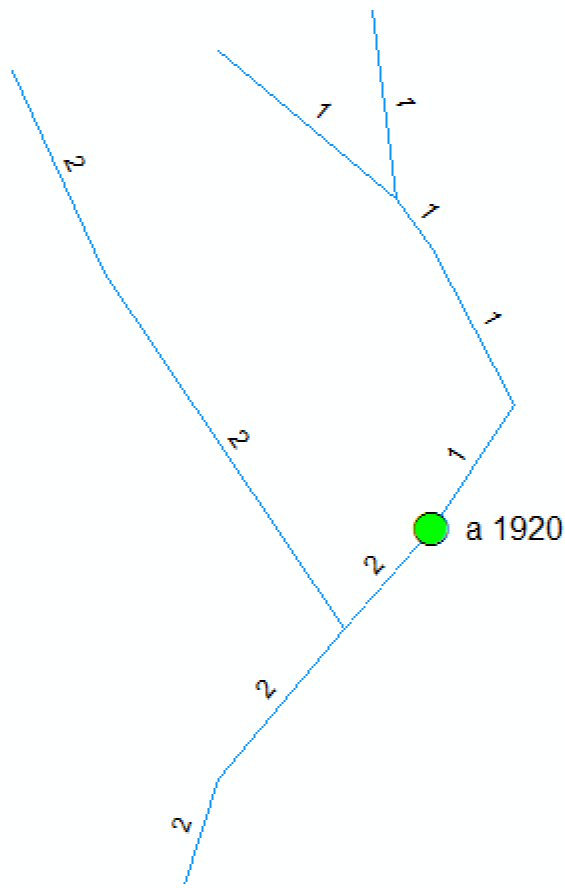


Figure 2: Fluviageny after Dam "a" is built. Dam “a” is labeled with the dam name and year it was built. Rivers are labeled with fluviageny code.

When dam “b” is built, river segments upstream of that dam have “.1” appended to their fluviageny code. The portion of the river network connected to the river segment downstream of dam “b” have “.2” appended to their code. Codes are not modified for portions of the river network that are not adjacent to the new dam. One way to think about it is like this: if a fish in a given river couldn’t swim to the new dam, then codes for that river don’t need to be updated when the dam is put into place. The result of adding dam “b” is shown in Figure 3.

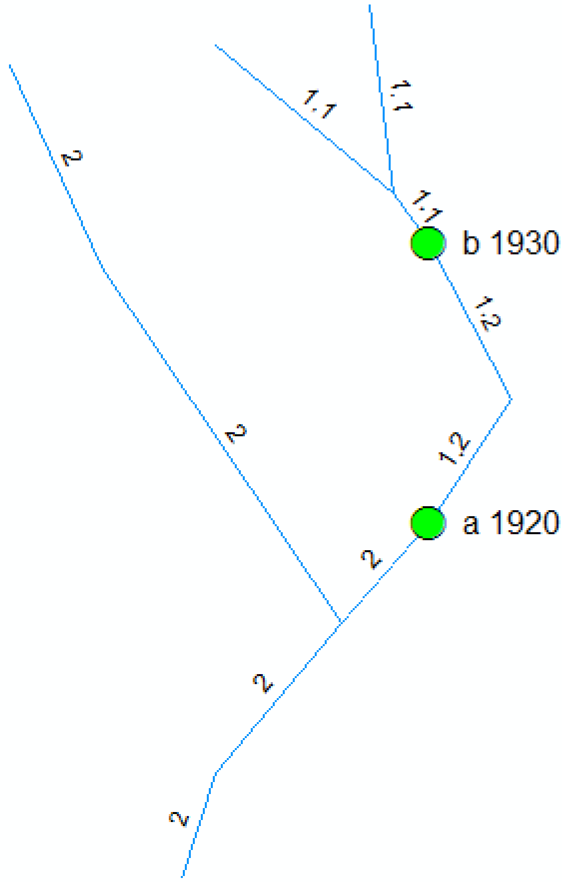


Figure 3: Fluviageny after dam "b" is built.

Fluviageny codes once all five dams are built are shown in Figure 4.

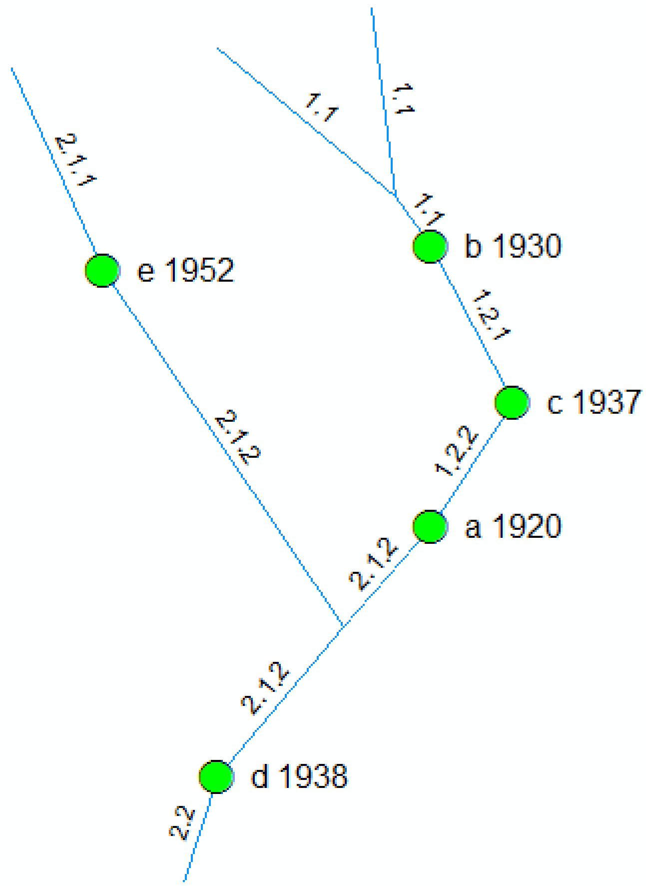


Figure 4: Fluviageny once all dams are in place.

The river segments are labeled with their fluviageny code.

GIS METHODOLOGY

The general procedure to compute fluviageny in GIS is described in this section. This section is written so that the approach could be applied to any GIS, provided its capabilities are sufficient. Note that this approach best applies to dendritic river networks in which flow is always in the same direction.

In a GIS, you have feature classes of a given geometry type, e.g., lines, points; and each feature class defines attributes that features within the feature class possess to describe it. For example, in a point feature class representing dam locations, each feature could be attributed with the name of the dam and the year it was built.

To compute fluviageny, we need a point feature class of dam locations, and a line feature class of river segments. The GIS needs to support the idea of river network tracing (either through attributes defining topology or geometric topology), such as finding out to which dam each river flows. This probably means snapping your dam locations so that they are spatially coincident with river features, and also splitting river features at dam locations so that dams are at the endpoints of rivers and not along the interior of a river. Your GIS may have additional requirements.

Each dam needs to be attributed with a unique identifier, the identifier of the next downstream dam, and a number indicating the order in which dams should be processed using the methodology we are about to describe, namely, from youngest to oldest. In summary, dam attributes include:

- Unique ID
- Downstream Dam ID
- Processing Order

Each river needs to be attributed with the identifier of the dam that it flows to. It also needs an attribute to store fluviageny code, which will be assigned in this methodology. In summary, river attributes include:

- Downstream Dam ID
- Fluviageny Code (to be populated by our methodology)

> **Note**
> If you are far enough downstream in the river network so that there is no downstream dam, then use a large value like 99999 for Downstream Dam ID.

The methodology is to loop through all dams, from youngest to oldest. As we process each dam, we compute the portion of the fluviageny code pertinent to that dam, and then remove that dam from the system. For each dam:

1. Get the dam's Downstream Dam ID. Now we know the current dam ID and the next downstream dam's ID.
2. Find rivers whose Downstream Dam ID matches the Downstream Dam ID of the current dam. This identifies the portion of the river network between the downstream end of the current dam and any other dams or river network terminations. Prepend ".2" to the fluviageny code for these rivers.
3. Find rivers whose Downstream Dam ID matches the ID of the current dam. This identifies the portion of the river network between the upstream end of the current dam and any other dams or river network terminations.
    a. Prepend ".1" to the fluviageny code for these rivers.
    b. For these upstream rivers, update the Downstream Dam ID to match the current dam's Downstream Dam ID. In other words, we're telling each river that it no longer flows to the current dam (which we are effectively removing from the system), and that it now flows to the next downstream dam.
4. Find dams whose Downstream Dam ID matches the ID of the current dam. This identifies dams that are upstream of the current dam. Update the Downstream Dam ID to match the current dam's Downstream Dam ID. In other words, we're telling each upstream dam that it is no longer upstream of the current dam (which we are effectively removing from the system), and that it is now upstream of the next downstream dam.

Once all dams have been processed, you'll find that the first character in all fluviageny codes is a period, e.g., "`.1.2.1.1`". This is because we prepend ".1" or ".2" each time we update fluviageny codes in our approach.

Thus, you'll need to remove the first character from the fluviageny code after all dams have been processed, to give a number without the leading period, e.g., "`1.2.1.1`".

ArcGIS Procedure of Application

An ArcGIS toolbox, Fluviageny.tbx, accompanies this document to facilitate computation of fluviageny codes in ArcGIS. This section presents discussion and exercise illustrating the procedure of application for assigning fluviageny codes in ArcGIS.

This toolbox uses geometric network tracing, and so an ArcGIS Standard or Advanced license is required. Apologies to Basic license holders!

> **A word for the geeky**
> Fluviageny.tbx uses standard tools included with ArcGIS, with no custom programming. This improves sustainability, since no programming skills are required to update the tools. However, this also limits the tool palette to those included with ArcGIS, along with the overhead of executing ArcGIS geoprocessing tools. If you are a programmer, you'll find that you can write a tool to calculate fluviageny that runs much faster than the tools in Fluviageny.tbx.

Requirements:

- ArcGIS for Desktop 10.1 or greater, with a Standard or Advanced license
- Arc Hydro Tools*, freely available from http://resources.arcgis.com/en/communities/hydro/
- Fluviageny.tbx
- fluviageny.gdb - Esri file geodatabase with sample data for use in this exercise

*The Arc Hydro Tools include tools for assigning unique identifiers and working with river networks. They make it easier to accomplish the workflow described in this document. This tools aren't absolutely required to complete the workflow, but without them, you'll have to program or create your own geoprocessing model for achieving some of the same functionality that the Arc Hydro Tools provide, namely, finding the next downstream dam from each dam.

From this point forward, we're going to be heavy into ArcGIS lingo. A nice thing about using so much out of the box functionality in this procedure of application is that many of the tools may already be familiar to you, and they are usually already well-documented. See your ArcGIS help if you need help with any ArcGIS terms or tools.

Acquire and Clean Up Your Data

You'll need a point feature class of dams, and a line feature class of rivers. You can get both of these from the National Hydrography Dataset (NHD). We recommend using NHDPlus, as the river connectivity is better, though resolution is a bit coarser than NHD. For this exercise, some simple example data is provided for you. Skip to the next section for hands-on training with the data, or read the remainder of this section to see what to do if you were to acquire your own data.

You're eventually going to build a geometric network out of these feature classes, so you'll need them in a feature dataset within a geodatabase. For your feature dataset coordinate system, you can use whatever system your data are already in.

To support network tracing, you'll need to make these edits to your dam and river feature classes in ArcMap:

- Delete river segments that aren't useful to your analysis, such as disconnected segments.
- Make sure all remaining rivers are connected. You can spot some gaps between river segments graphically, but it may be easier to find unintentionally disconnected segments after you've built your geometric network.
- Make sure all dams are snapped to the river network. See the **Snap** tool in ArcToolbox for help with this. You'll probably want to snap to endpoints of rivers.
- Make sure dams are located at river endpoints. Split river features in two if necessary. This helps with network tracing, and you can't assign a river segment a single fluviageny code if it spans a dam. See the **Split Line At Point** tool in ArcToolbox for help with this.

No Arc Hydro?
If you **are not** using the Arc Hydro Tools, then you will also need to create a point feature class to serve as sinks in your geometric network. These are the river outlets, where water leaves your entire basin. You'll use these sinks to set flow direction in your network. Save this feature class in the same feature dataset as your dams and rivers. Create a sink feature and the end point of your most downstream river.

ADD ATTRIBUTES

At this point in the exercise, you can open fluv.mxd and work with the example data.

Add the following attributes to your feature classes. Most of these are placeholders that you'll populate later in this exercise.

Table 2: Dam Attributes

Name	Type	Purpose
HydroID	Long	Unique ID of this dam
NextDownID	Long	HydroID of next downstream dam
NextDamID	Long	Initially, a copy of NextDownID. We'll update this in our procedure as we remove dams. We work on a copy of NextDownID because NextDownID can be tedious to populate, so once we've got it, we want to preserve it.
SortOrder	Short	Indicates processing order. Use data type of Long if you have more than 32,000 dams.

Table 3: River Attributes

Name	Type	Purpose
JunctionID	Long	HydroID of next downstream dam. We call this JunctionID because in ArcGIS network terminology, the dams are serving as network junctions.
DamID	Long	Initially, a copy of JunctionID. We'll update this in our procedure as we remove dams. We

		work on a copy of JunctionID because JunctionID can be tedious to populate, so once we've got it, we want to preserve it.
FluvCode	Text	Fluviageny code. Make sure the length of this field is longest to store your longest anticipated fluviageny code. For example, if your max code will be "1.2.1.1.1", then you'll need 10 characters (9 for the final code, plus one more for the leading period that the procedure creates and then removes). Note that field lengths longer than 255 can sometimes be hard to work with in ArcGIS.

No Arc Hydro?
If you created a sinks feature class, then add HydroID to it as well.

BUILD THE GEOMETRIC NETWORK

A geometric network enables tracing, such as finding features downstream of other features. Some of the options for building the network depend on whether or not you are using Arc Hydro. If you do not have the Arc Hydro Tools, then you must have a feature class to serve as network sinks. (Even if you do have Arc Hydro, you may like using a sink feature class better than setting flow direction with Arc Hydro anyway.) If you are using Arc Hydro and you don't have sinks, then pay no attention to any mention of sinks in the steps that follow.

To build the network:

1. In the Catalog window in ArcMap, right-click your feature dataset (fluviageny.gdb\Texas in the example data) and point to **New > Geometric Network**.
2. Click **Next** and select your Dam and River feature classes. Also select your sinks if you have those. Click **Next**.
3. If you have sinks, change the value in the **Sources & Sinks** column for the sinks to **Yes**. Click **Next**.
4. Click **Next**, and click **Finish**.
5. If you network features (dams, rivers, optionally sinks) aren't already in your map, then add them.

Once the network is built, you'll notice a new point feature class named [your_network]_Junctions. These features are called "generic junctions" and are created when two or more rivers meet and there isn't already a dam there. Geometric networks require point features to be at all network junctions, i.e., where lines meet. **If you are using Arc Hydro, then you'll need to add a HydroID field to the generic junction feature class.**

Now it's time to set flow direction.

To set flow direction in the network with Arc Hydro:

1. Make sure no river features are selected.
2. On the **Arc Hydro Tools** toolbar, click **Network Tools > Set Flow Direction**.
3. Click **Select All**. If your river layer does not show up in the panel on the left, then make sure your network is selected in the **Utility Network Analyst** toolbar.
4. Select the flow direction method and click **OK**. **WITH_DIGITIZED** is usually a good choice.

About Flow Direction Methods

Typically river features are created by drawing them from upstream to downstream. Thus, flow direction is in the same direction in which the features were digitized, hence, WITH_DIGITIZED. If your dataset was made in the opposite direction, then choose AGAINST_DIGITIZED. Some datasets also included an attribute indicating flow direction, in which case you'd choose FLOWDIR_ATTRIBUTE. If you dataset isn't like any of these cases, then you may have to use a sink feature class and the Utility Network Analyst to set flow direction instead of Arc Hydro.

If you don't have Arc Hydro, then to set flow direction using the Utility Network Analyst:

1. Show the **Utility Network Analyst** toolbar.
2. Start editing.
3. Update the **AncillaryRole** attribute for your sinks to be **Sink**. This is a numerical value of **2**.
4. On the **Utility Network Analyst** toolbar, click the **Set Flow Direction** button. If this button is not enabled, then make sure you have selected your network in the network drop down on the same toolbar.
5. On the **Utility Network Analyst** toolbar, click **Flow > Display Arrows**. If the arrows point in the wrong direction, then adjust the placement or assignment of your sinks accordingly. If you see circles instead of arrows, then ArcGIS could not determine flow direction. You'll need to update your sinks and/or edit the rivers in your network to remove complex features like loops.
6. Once flow direction looks good, save edits. It doesn't matter if you keep the edit session open from this point forward.

ASSIGN ATTRIBUTES

Now you'll assign attributes required for our methodology to work.

SORTORDER

Sort order determines the order in which dams are removed from the analysis. It is required in order for our geoprocessing model to iterate the dams in the right order. The youngest dam should have the lowest number, and the oldest dam should have the highest number, as in Table 4. The numbers don't have to start at 1 and be monotonically increasing, but they do have to be in the right order, and no numbers can be repeated.

If all of your dams were built in different years, then one way to calculate this is to subtract the year built from 9999. The numbers wouldn't start at 1, but they would be in the right order. For more complex cases, consider using something like Excel to compute a table with your sort order, join the table to your dam features, and copy the sort order to the dams.

Table 4: Example Dams and Sort Order

Dam Name	Year Built	SortOrder
a	1920	5
b	1930	4
c	1937	3
d	1938	2
e	1952	1

HydroID

HydroID is the unique ID for each of our dams.

To calculate HydroID using Arc Hydro:

1. On the Arc Hydro Tools toolbar, click **Attribute Tools > Assign HydroID**.
2. Select your Dam layer and click **OK**.

> **Arc Hydro Memory Errors**
> If you get a memory error, then restart ArcMap and try again. If you continue to get errors, try the approaches described here for users without Arc Hydro.

If you don't have Arc Hydro or can't get it to work, you can still compute HydroID. We just need a unique identifier for all features in the Dam layer. Note that you could also use ObjectID, but it's best practice to preserve unique IDs in another attribute, since ObjectIDs can change as you migrate geodatabases or feature classes.

To calculate HydroID without Arc Hydro:

1. Start Editing if you haven't already started an edit session.
2. Use the field calculator to calculate HydroID as ObjectID. In other words, copy ObjectID to HydroID.

NextDownID

NextDownID is a dam attribute that stores the HydroID of the next downstream dam.

To calculate NextDownID using Arc Hydro:

1. Make sure no features are selected.
2. On the Arc Hydro Tools toolbar, click **Attribute Tools > Find Next Downstream Junction**.
3. Select your Dam layer, and make sure HydroID is chosen as the field. If HydroID is not in the list of fields, then you need to add HydroID to all other junction feature classes participating in your network, including generic junctions and sinks.
4. Click **OK**.

Arc Hydro computes NextDownID using network tracing. For the most downstream dam(s), there is no next downstream dam, so NextDownID is assigned a value of -1. However, the negative number will mess up our fluviageny geoprocessing model later on, so we need to change it to a positive number.

5. Start editing if you don't already have an edit session open.
6. Select any dams with a NextDownID of -1.
7. Calculate NextDownID for those dams to be a large number that is not already an existing HydroID. 99999 is often a good choice.
8. Save edits.

If you don't have Arc Hydro or can't get it to work, you can still compute NextDownID. For speedy performance, program a tool that works with the logical network if you know how to do so. Though slower in execution, you can also create a geoprocessing model with little or no programming to compute NextDownID. It will involve iterating each dam, setting a flag at that dam and barriers at all other dams, tracing downstream, and reading the HydroID of the dam that stopped the trace. For a similar model, see the **Assign Next Downtream Junction for Edges** tool in the **Fluviageny.tbx** toolbox.

JUNCTIONID

JunctionID is a river attribute that stores the HydroID of the next downstream dam.

To compute JunctionID, the **Assign Next Downtream Junction for Edges** tool in the **Fluviageny.tbx** toolbox has been provided for you. This geoprocessing model iterates through dams, setting a flag at the current dam and barriers at all other dams. It traces upstream from the current dam to get all rivers that flow to that dam before any other dam. The JunctionID for each of those rivers is then computed to be the HydroID of the current dam.

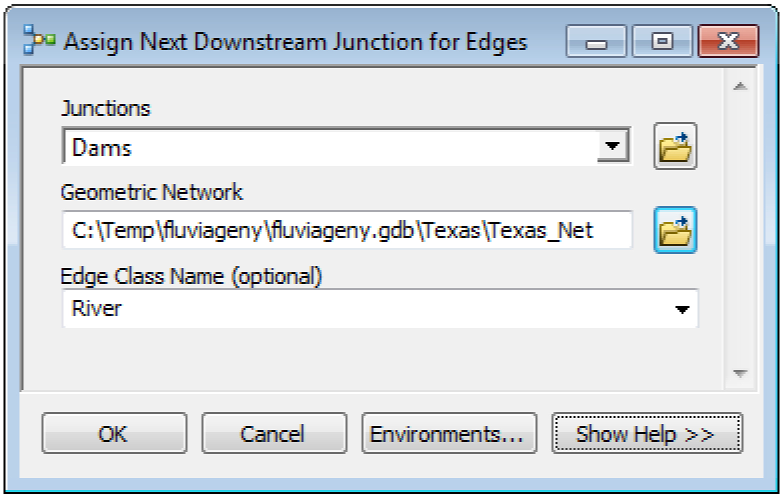
For rivers downstream of all dams, you'll have to compute their JunctionIDs after the tool finishes. For these rivers, you should use the same value as you did for NextDownID when there were no downstream dams, e.g., 99999.

Before you run the tool, **you need to change the name of your map layers to be different than their feature class names.** This is due to how the **Trace Geometric Network** tool works in ArcToolbox, which our geoprocessing model uses. That tool produces an output group layer with the feature classes from the geometric network. Thus, the layers will have the same name as your original dam and river feature classes (unless you changed the map layer names earlier). It will be hard to uniquely select those layers in our geoprocessing model since there will be two layers with the same name. Long story short: Now is the time to change your map layer names.

> **Arc Hydro Quirk with Layer Names**
> Ironically, sometimes Arc Hydro tools fail when your layer name IS NOT the same as the feature class name. You'll get a "layer/table not found" error. That's why we kept layer names the same as feature class names at the beginning of this exercise, and now that we're finished with Arc Hydro, we change the names to that the rest of our tools work.

To compute JunctionID:

1. Change your map layer names. For example, if your feature classes are named **Dam** and **River**, change their layer names in your map to **Dams** and **Rivers**.
2. In the Catalog window, double-click the **Assign Next Downtream Junction for Edges** tool in the **Fluviageny.tbx** toolbox.
3. Fill in the parameters and run the tool. Click **Show Help** at the bottom of the tool window to see help as you click on each input parameter. The tricky part is probably the third parameter. You have to provide the feature class name of your rivers, as it appears in your geodatabase. This should be different from the river map layer name, which you should have changed by now.

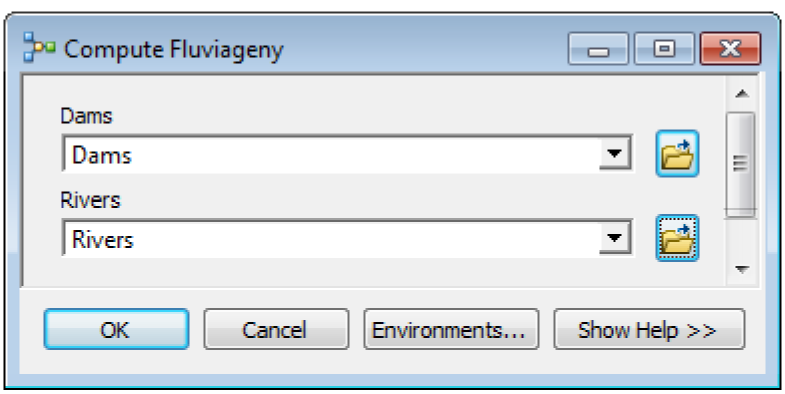


4. Start editing if you don't already have an edit session open.
5. Select any rivers with a NULL JunctionID.
6. Calculate JunctionID for those rivers to be the same as the NextDownID you used earlier when there were no downstream dams, e.g., 99999.
7. Save edits.

Compute Fluviageny

With the required attributes populated, you can now compute fluviageny codes.

1. In the Catalog window, double-click the **Compute Fluviageny** tool in the **Fluviageny.tbx** toolbox.
2. Fill in the parameters and run the tool. Click **Show Help** at the bottom of the tool window to see help as you click on each input parameter.



When the tool finishes, check the attributes of the Rivers layer, or label rivers by FluvCode to see the result, which should match codes in Figure 4 if you used the example data.

Next Steps

We've illustrated a GIS workflow for computing fluviageny codes. There are quite a few attributes involved, and a lot of pieces have to be in place involving network connectivity and attributes before fluviageny tools can be run. You are encouraged to modify the attributes that the geoprocessing model is looking for, or edit the model workflow itself as your needs dictate. The methods discussed in this document were purposefully implemented using out of the box tools, free tools, and a geoprocessing model with no programming required, to make it easier for end users to adapt this approach even without programming skills.