

Using RivEX and National Hydro Network Data to Classify Water Quality Stations by Strahler Stream Order

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http://www.env.gov.nl.ca/env/Env/water_resources.asp

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Overview

The Water Resources Management Division (WRMD) of the Department of Environment and Conservation, Government of Newfoundland and Labrador required a simple and standardized means to classify streams and associated water quality monitoring stations. The goal was to identify those stations which best represented pristine conditions to provide baseline data for a national water quality monitoring program. Using Geographic Information Systems (GIS) and National Hydro Network (NHN) data, streams were classified by Strahler stream order thereby allowing stations on or close to headwaters to be systematically and easily identified.

The Environment

The Water Resources Management Division (WRMD) of the Department of Environment and Conservation is the lead provincial agency for water resources management in Newfoundland and Labrador. The Division uses GIS to better deliver on its mandates including coordinating the chemical water quality monitoring of over 500 public drinking water supplies; environmental assessments; land use planning; flood forecasting; flood response; dam safety; water allocation; and the permitting of development activities within watersheds. WRMD maintains an enterprise level geodatabase which includes spatial layers related to most of the programs it administrates and participates in. One of these layers is a file indicating the location of water quality stations which was used in conjunction with the NHN data to classify stations by stream order. More information on WRMD is available at: http://www.env.gov.nl.ca/env/Env/water_resources.asp

The analysis of streams and water quality stations was conducted using GIS. The Government of Newfoundland and Labrador has a site license for the ESRI™ suite of products and as such ArcGIS 9.2 Desktop was used. ArcGIS Desktop software products allow users to author, analyze, map, manage, share, and publish geographic information. For additional information on ESRI™ and the ArcGIS suite of products see the company's web page at the following link: <http://www.esri.com/>

The National Hydro Network (NHN) was the data source utilized to derive stream order. The NHN describes and models features of the inland surface-water system of Canada. The NHN is a vector, topographic data product primarily designed to allow hydrographic network analysis. It is intended for water flow analysis, water and watershed management, environmental and hydrographical applications, as well as for a multitude of cartographic applications. For more information on this product refer to the following link: <http://www.geobase.ca/geobase/en/data/nhn/index.html>

RivEX is a third party software extension to ArcGIS which serves as a river network tool. RivEX can perform a number of network analyses and attribute functions and was used in this project to calculate stream order. Additional information on RivEX can be found at this link: <http://www.RivEX.co.uk/index.htm>

The Challenge

The project was completed by the Hydrologic Modelling Section (HMS) of WRMD. HMS develops, evaluates and implements computer-based techniques and methodologies required for water resource management and provide general technical support for WRMD. This includes the incorporation of GIS and remote sensing into the Division's activities. This specific analysis was conducted in conjunction with the Canada-Newfoundland Water Quality Monitoring Agreement (WQMA) program. The WQMA program is a partnership between Environment Canada and the Department of Environment and Conservation to monitor ambient water quality in selected waterbodies in the province. The WQMA provides for the regular monitoring of an index network of stations, as well as an annual recurrent study concentrating on water quality, sediment and biota in a selected watershed. For more information on WQMA see:

<http://www.env.gov.nl.ca/env/Env/waterres/WQMA/WQMA.asp>

The WQMA section of WRMD is currently participating in the Canadian Aquatic Biomonitoring Network (CABIN) program. CABIN is a national, collaborative program and network for collecting, assessing and distributing information on the biological condition and biodiversity of aquatic ecosystems in Canada. The key to assessing the condition of our waterways through CABIN is the use of the Reference Condition Approach. Reference sites are established based on minimal impacts by human use, and present users with a baseline for assessing potentially impaired sites. The reference sites represent as many different geographic regions and stream sizes as possible and are used to establish the type of community of organisms expected to occur in the range of natural habitat types present in regions covered by the CABIN network. Once the reference condition has been established, sites suspected of being impaired are sampled. Differences between the organisms found at the reference sites and the test-site indicate the extent, if any, of impairment at the site. For more information on CABIN see:

<http://cabin.cciw.ca/Application/welcome.asp?Lang=en-ca>

In this context, the need was to assess potential suitable locations for sampling for CABIN. Due to limited resources, in order to make participation in the program feasible WRMD had a need to co-locate CABIN reference sites with existing WQMA sampling stations. The goal was therefore to assess these existing stations for suitability – that is to select those with the most pristine conditions. The desire was to assess the stations in a consistent and standardized manner. The process was impacted by the fact that there were several new staff in the program who had limited background knowledge of many stations.

WRMD decided an appropriate and feasible means of classifying streams and water quality stations would be via their associated Strahler Stream Order. Strahler Stream Order is a simple hydrology algorithm to define stream size based on a hierarchy of tributaries. Stream order allows us to rank the size and potential power of streams. Orders range from small streams with no branches (1st Order) up to streams the size of the Mississippi River, which is a 10th Order. When two first-order streams come together, they form a second-order stream. When two second-order streams come together, they form a third-order stream. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. It is not until a second-

order stream combines with another second-order stream that it becomes a third-order stream. Illustration of this concept is shown in Figure 1.



Figure 1: Strahler Stream Ordering

WRMD decided a simple means of assisting in identifying the most pristine WQMA stations would be to select those located at the headwaters of river systems – i.e. lower order streams. This is based on the assumption that most headwaters are generally less susceptible to anthropogenic impacts than higher order streams.

The Solution

Analysis for this project was conducted in the ArcGIS Desktop environment. The functionality required is contained in the RivEX software extension (RivEX 4.6 was the version used for this project). RivEX tools are contained within a supplied map document (.mxd) that once opened exposes the tools via a custom toolbar. For information on system requirements, purchasing and installation of RivEX, see the online manual at the following link: <http://www.rivex.co.uk/>

The RivEX toolbar is greyed out until an appropriate polyline dataset is added to the project. The NHN feature class used is the Network Linear Flow (NLF) layer. Unactivated RivEX tool and ArcMap's "Add Data window" are shown in Figure 2.

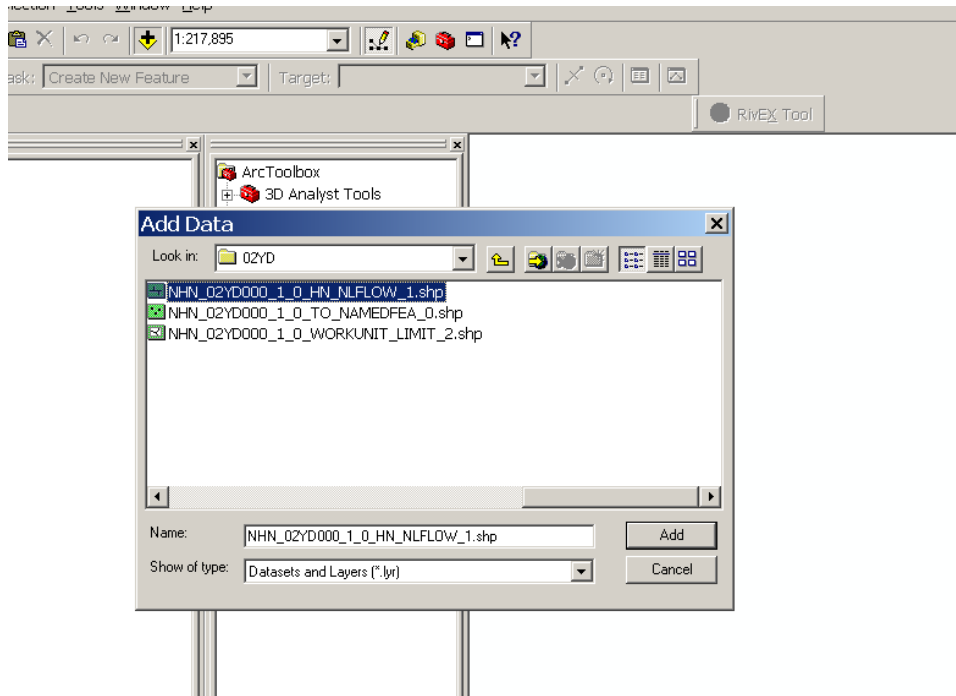


Figure 2: Unactivated RivEX tool and ArcMap's "Add Data" window

The RivEX Tool becomes activated when data is added to the project. See Figure 3.

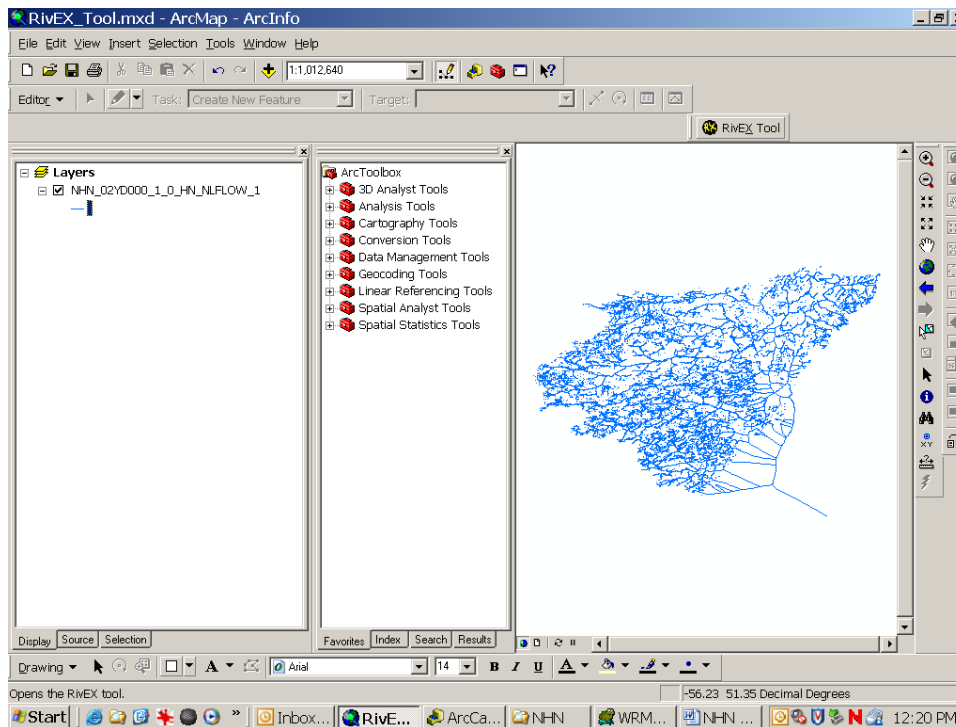


Figure 3: RivEX tool activated in ArcMap

To calculate a network attribute such as stream order, you must have a unique ID number for each polyline and populated *From-* and *To-* node fields in the attribute table of your river network. These must be built before attempting to attribute your network. To generate nodes:

- Hit the RivEX Tool to launch the River Network tool. See Figure 4.
- Using the “Polyline layer” dropdown list, select the desired layer (i.e. flow layer), being the Network Linear Flow (NLF) feature class in NHN data.
- Under the “Polyline ID” dropdown list, select the appropriate polyline ID field. In the case of NHN data this would be the FID.
- To create the From and To Nodes, select the ***?*** option from the “From node” and “To Node” dropdown lists.
- Hit the Build button to complete the process.

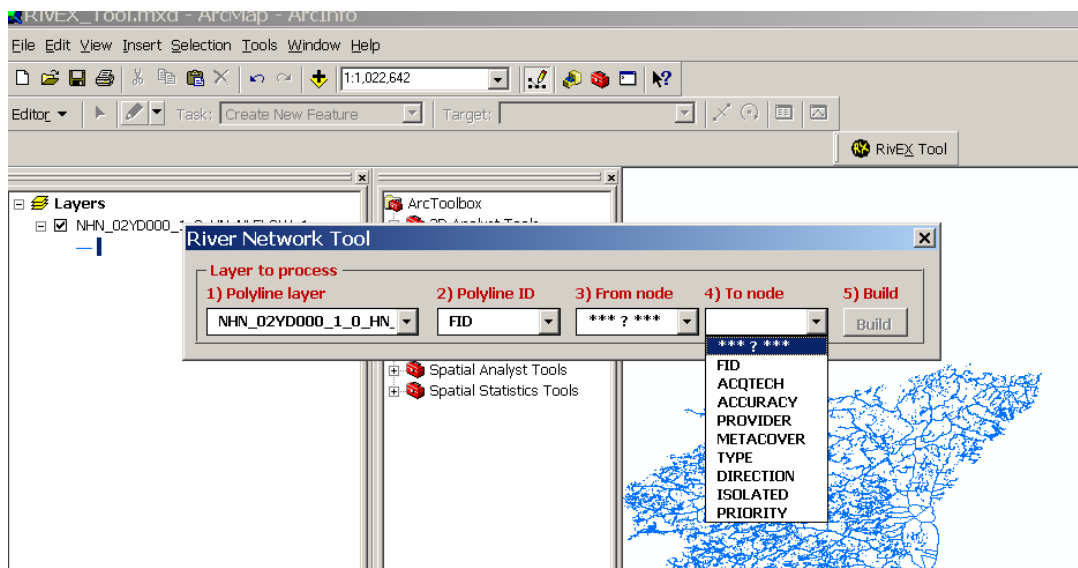


Figure 4: RivEX's "River Network Tool"

RivEX will only allow the process of generating nodes at this point and accordingly will supply a message indicating this. Say OK to this message and a screen will appear that initiates the node creation process. See Figure 5. To complete the node creation process:

- Check the “Update attribute table” box from the “Generate node data” panel located under the Nodes tab.
- Hit the “Go” button.

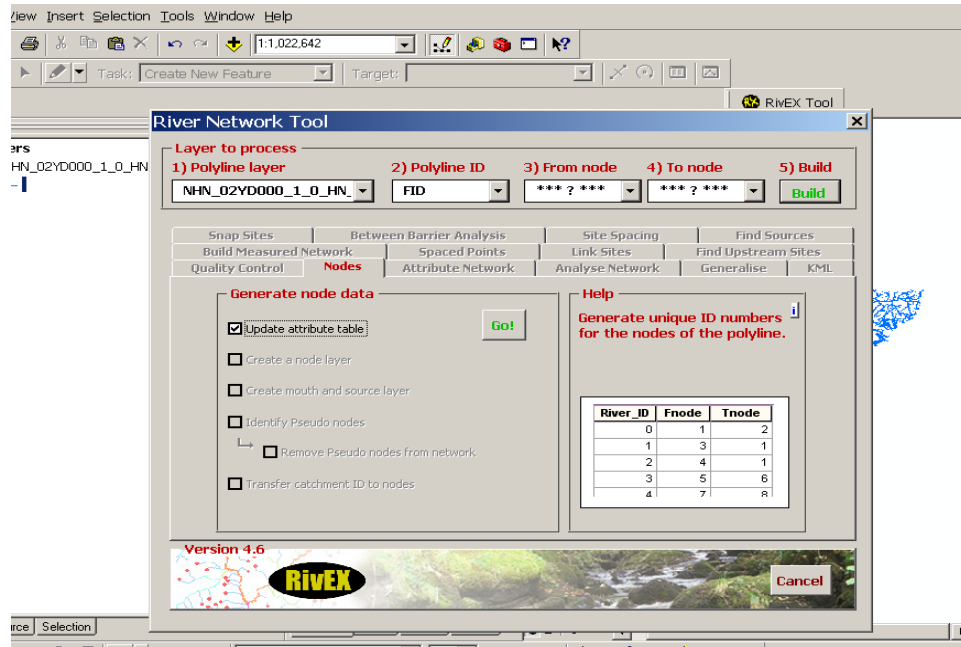


Figure 5: Generating Node Data

RivEX will process the flowline data to determine To and From nodes for each segment or feature. It will then ask the user to rebuild the data dictionaries with this node information. See Figure 6. To complete this process:

- Hit the “OK” button to clear the message
- Leave the default values supplied in the dropdown lists
- Hit the “Build” button.

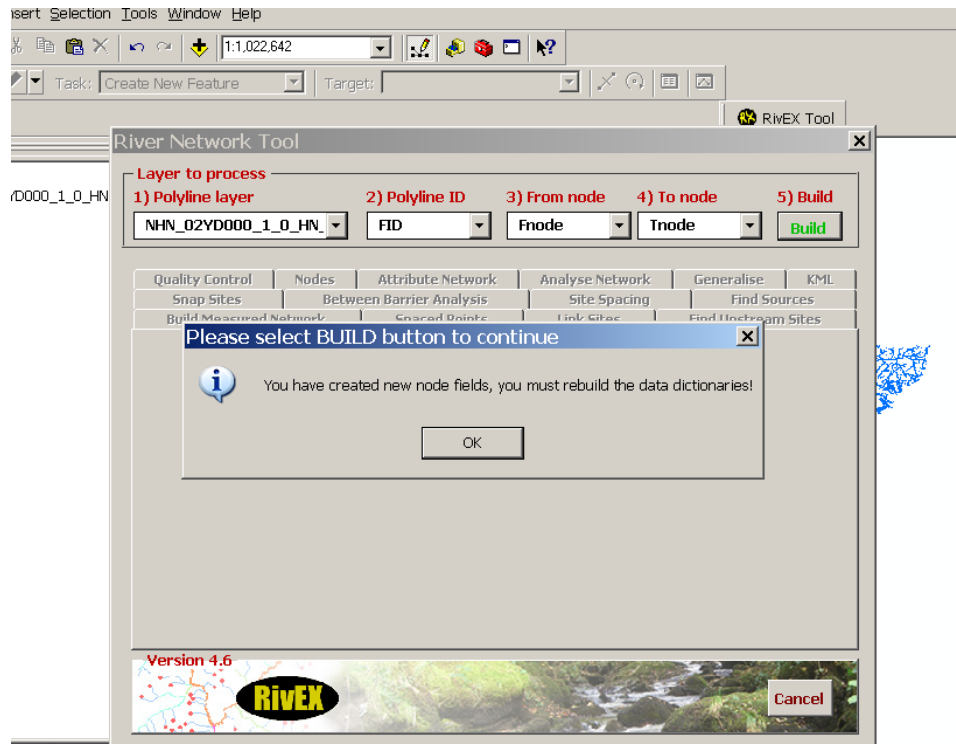


Figure 6: Assigning To and From nodes to flowline features

Once this process is complete there are numerous options available for performing quality control, analyzing and attributing the river network data. For the purposes of this document we will only be focusing on the process of determining Strahler Stream Order for the network but documentation on other functionalities is available within RivEX via help screens on each tab or via the website at: <http://www.RivEX.co.uk/>

The functionality to determine Strahler Stream Order is under the RivEX's Attribute Network tab. See Figure 7. As previously mentioned, there are other attributes that can be generated but which are outside the scope of this project. To create the Strahler Stream Order attribute:

- Check the “Strahler” box from the “Calculate new values and add to polyline” panel located under the Attribute Network tab.
- Hit the “Go” button.

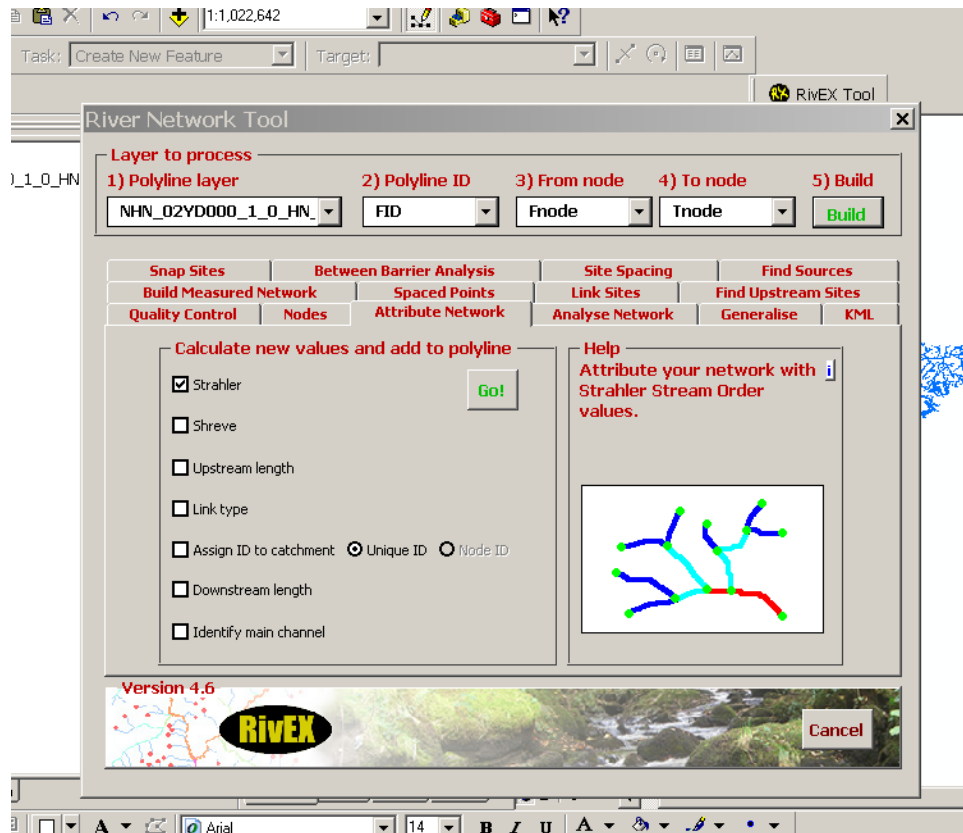


Figure 7: Determining Strahler Stream Order

After processing is complete you may get a message indicating a number of polylines have zero stream order values. This is due to polylines pointing from a mouth to source direction. To deal with these you must:

- Flip the polyline (reverse the polyline digitizing direction).
- Rebuild *from-* and *to-* node fields
- Re-run the stream ordering

In NHN data, the presence of zero stream order values seems to occur in areas with braided flow network patterns. One method which often overcomes this problem is to perform the stream order attributing only on Network Linear Flow (NLF) features with "Level Priority" = 1. The "Level Priority" attribute is used to classify the route or path followed by the Network Linear Flow feature within the NHN hydrographic network. The domain of values for this attribute includes the following values : "UNKNOWN" (-1) ; "PRIMARY" (1) ; "SECONDARY" (2). The "PRIMARY" value identifies the main route whereas the "SECONDARY" value identifies an alternate or secondary route followed by the Network Linear Flow feature. In many applications or analyses, such as in this case, the use of only the primary flow route is sufficient for the users needs. Users should however review the results of the analysis carefully, particularly when using NHN data of the [Completeness Level 1](#) (NHN-CL1). In the NHN-CL1

automatic production process, the "PRIMARY" value is allocated based on the shortest path principle instead of the size and importance of the watercourse. Thus, in NHN-CL1 data, it is possible to have a narrow and shallow section of a watercourse be identified as "PRIMARY ", whereas a wider and deeper but longer alternate section be identified as "SECONDARY ".

Another more reliable method to overcome this problem is to perform the stream order attributing only on NLF features with "Flow Direction" = 1. The "Flow Direction" attribute is used to indicate the water flow direction compared to the feature digitizing direction. The attribute value "SAME DIRECTION" (1) means the flow direction and the digitizing direction are the same, which should avoid having zero stream order values in the process. Again, users should carefully review results when screening NLF features by the "Flow Direction" attribute as it may exclude some water bodies of interest.

Once the process of calculating stream order is complete (see Figure 8), determining the order of water quality stations is relatively simple. For the purposes of this project zooming to individual stations and manually assigning the value of the stream the station is located on was used. This method was chosen as this was the first use of this process and dataset by the organization and it allowed the opportunity to check the validity of the stream ordering for the area of interest.

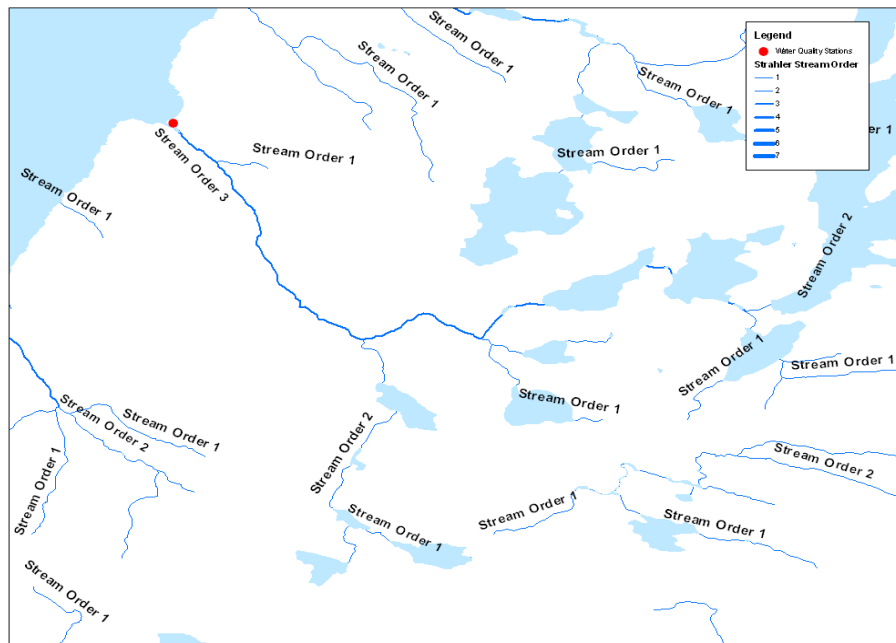


Figure 8: Data resulting from the Strahler Stream Order computation

For users having a large number of stations etc. to classify and who are confident in the accuracy and reliability of the stream ordering, a Spatial Join could be used instead. This process would automatically assign the attributes of the closest stream to each station. See Figure 9. To perform a Spatial Join:

- In ArcMap, right click on Water Quality Stations (i.e. point file) in the table of contents and select Join and Relates – Join... option. See Figure 9.

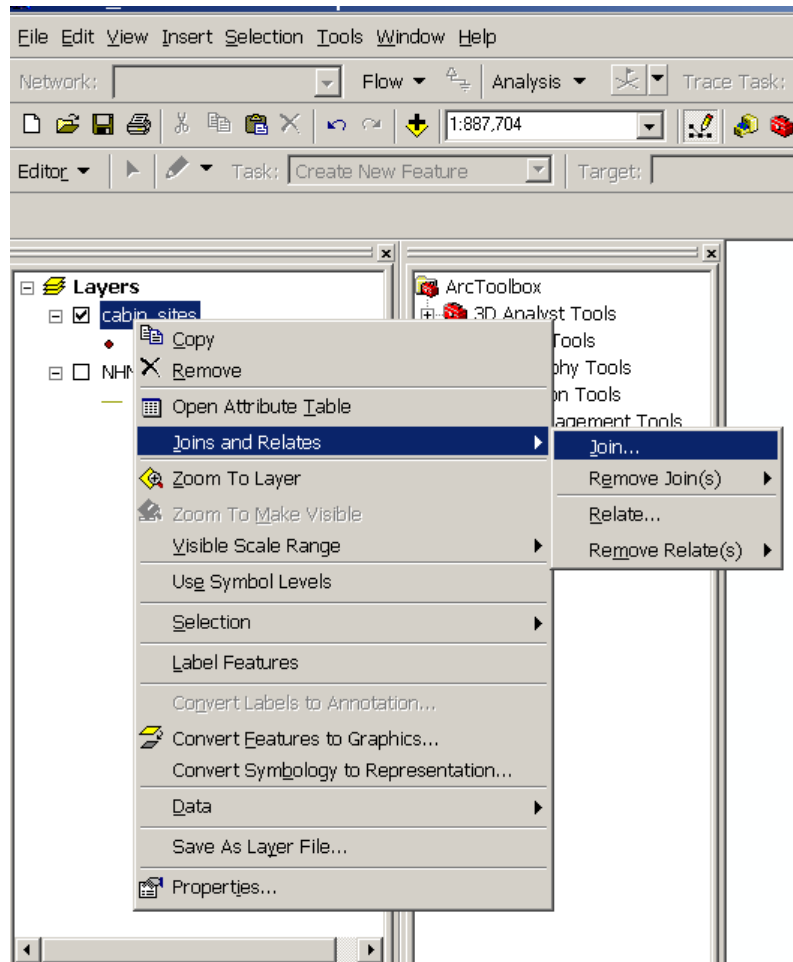


Figure 9: Initiating a Spatial Join in ArcMap

- In the dropdown list shown at Figure 10 under “What do you want to join to this layer?” select the “Join data from another layer based on spatial location”
- In the dropdown list of “1. Choose the layer to join to this layer, or load spatial data from disk:”, select the correct NHN file with Stream Order attributes.
- At “2. You are joining: Lines to Points:”, select the “Each point will be given all the attributes of the line that is closest to it, and ...” radio button.
- In the text box located under “3. The result of the join will be saved into a new layer. Specify output...:”, specify a Shapefile name and location to save results in.
- Hit the “OK” button.

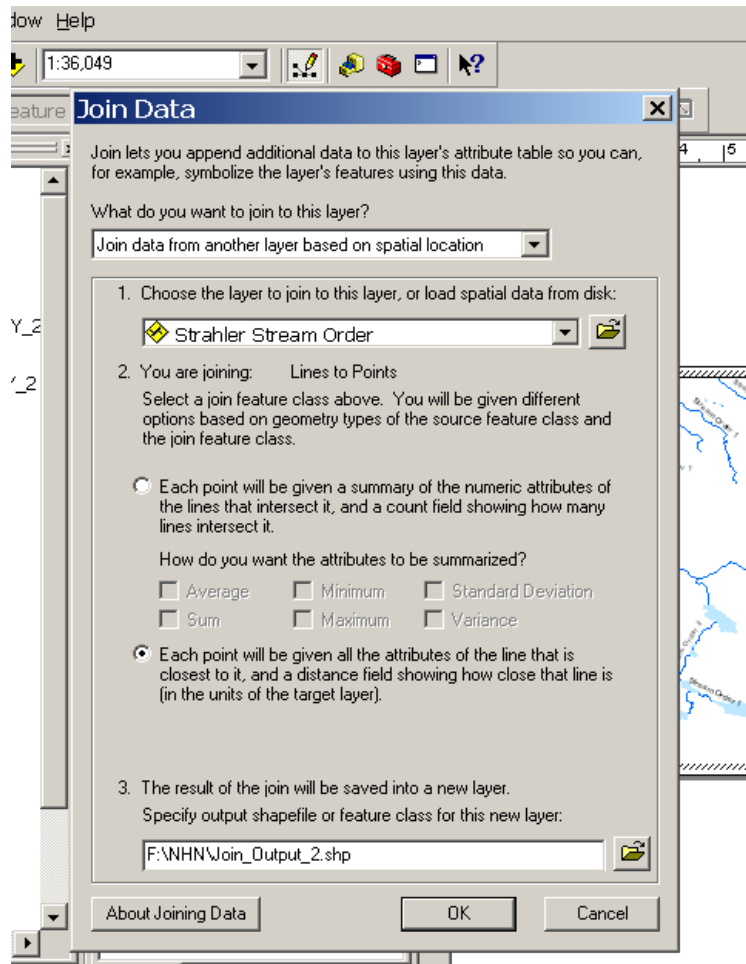


Figure 10: Launching a Spatial Join in ArcMap

As is the case in any automated analysis or calculation, it is important to check the results for accuracy.

The Outcome

This project was successful in that it provided a simple and consistent means of determining suitable sampling locations to serve as baseline reference sites for the CABIN program. It allowed WRMD to systematically identify the existing water quality stations that are closest to the headwaters of watersheds and presumably display the most pristine conditions. In this context, the dataset of NHN Network Linear Flow features with stream order attached can be used to locate suitable sites for the next set of CABIN sampling sites – sites suspected of having impaired water quality. Water quality stations with higher stream orders can be targeted with the assumption that they are more likely to be impacted by urban developments or other anthropogenic factors. As well, stream order can be used as a secondary predictive mechanism of the characteristics of waterbodies. General longitudinal models for rivers, such as the River Continuum Concept, propose that the physical structure and associated biological components of

rivers change as a river travels from its headwaters to its outlet. These models suggest particular types of biotic communities and stream structures are expected to be found at specific reaches or stream orders. More information on this topic is available from:

<http://www.d.umn.edu/~seawww/depth/rivers/02.html>

There are several aspects of this process which leave some room for improvement. Some staff were surprised at the high stream orders of some of the water quality stations that are perceived to be close to headwaters or pristine. It is important to keep in mind that while lower stream orders are generally associated with unimpaired conditions and higher order watersheds are more open to potential contamination, this is certainly not always the case in reality. As well, the need to co-locate CABIN sites with existing water quality monitoring stations limited site selection in this case. In circumstances where resources are not an issue, this methodology could be even more effective as a selection tool for pristine headwaters.

A potential drawback of this methodology lies in the possible errors and limitations that can exist in the NHN network flows. The NHN data is, among other things, a representation of the flow of water through the environment, but like any mapping data can contain errors and limitations. As previously mentioned, this may be more prevalent in NHN Completeness Level 1 data. In the course of this project an error in flow direction resulted in incorrect stream ordering. This error was only determined via manually reviewing the results of the stream order calculation. The problem was resolved by flipping the direction of the flowline in question and re-running the stream order process. Examples such as this highlight the need to review any analysis conducted using the flowlines.

The dataset of NHN Network Linear Flows with stream order attribute has a number of other potential uses. Additional datasets, such as stream flow stations or drinking water intakes, from other WRMD programs can be classified by stream order. One future planned implementation of the stream order flow dataset is to use this data in determining variable width buffers within the watersheds of Protected Water Supplies. Higher order waterbodies would be given larger buffers (e.g. 50 metres) than small order streams (e.g. 30 metres). Several years ago WRMD had used a similar variable width buffer based on stream order in conjunction with other datasets (e.g. slope, proximity to intake) to assist in developing a Watershed Management Plan for a sensitive Public Water Supply. While that project was successful, the need to manually create a digital layer of stream order proved to be quite time consuming and made it difficult to apply the methodology to develop similar Watershed Management Plans. The availability of a digital stream order dataset makes this initiative, and other related projects, a more feasible option for future watershed management activities.

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