2018 Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative

Project Final Report

Developing stream network topologies for the Yukon and Kuskokwim rivers

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ABSTRACT

A central challenge to developing a comprehensive understanding of the river systems of the Arctic-Yukon-Kuskokwim (AYK) region, and the natural resources they support, is a robust analytical framework that accounts for and takes advantage of the spatial connectivity of rivers. The basis of such a framework is a topologically correct stream network, which explicitly defines the multi-dimensional spatial relationships of dendritic river networks, such as longitudinal connectivity, branching networks of streams, and abrupt changes at tributary confluences. In the last five years, a new class of powerful geostatistical models have been developed for river systems – spatial stream network models (SSNMs). Using the Alaska National Hydrography Dataset (NHD) and the Canadian National Hydrological Network (NHN) as our stream baseline data, we developed topological correct stream networks suitable for use in spatial stream network model (SSNMs) for the Yukon and Kuskokwim drainages. Two datasets were generated from for us in the SSN models: 1) the first dataset retains the original segmentation and attributes from the source data (NHD and NHN networks), 2) the second dataset consists of a simplified network that eliminates 1st and 2nd order streams and generates only one stream segment between confluences. The simplified stream network reduces network size and greatly increases processing time. The addition of these networks throughout the AYK region should pave the way for substantial advances in the research and management of this region's natural resources, including Chinook salmon. For example, the data products generated from these networks can be used to develop 'isoscapes' of strontium isotope ratios against which the strontium isotopes in Chinook salmon otoliths can be compared to assign individual adult salmon to their natal origins across the river basins. The Yukon and Kuskokwim stream networks that maintain the original segmentation and attributes will be available for public dissemination at the National Streams Internet (NSI) project (http://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html).

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I. INTRODUCTION

One of the largest impediments to modeling ecosystem processes in the Yukon and Kuskokwim rivers is the lack of a spatially-explicit stream network topology describing how water collects and drains through these vast and topographically complex river basins. Without such a spatial framework, a wide variety of scientific investigations are distinctly limited as they cannot capitalize on new spatially-explicit modeling approaches to characterize fluxes of water and the properties (e.g., temperature) and materials (e.g., sediments and contaminants) it transports downstream (Isaak et al. 2014). Management-relevant challenges such as a) understanding and projecting hydrologic and thermal responses to changing climate, b) quantifying sediment, nutrient, and contaminant loads throughout the river network, and c) applying geochemical tracers in fish otoliths to establish natal origins of fish, are all currently hampered by lack of a spatially-explicit stream network topology for these ecosystems.

River ecosystems exhibit high spatial structure and are shaped by their connectivity to both landscape and in-stream driven processes. Such structure can be characterized by flow-connected (transport downstream), flow-unconnected (upstream migrations of fish), and Euclidean (2-dimensional) spatial relationships (landscape features such as vegetation cover or geology). A robust understanding of river ecosystem functions and the natural resources they maintain requires accounting for these spatial dependencies unique to rivers. A new class of geostatistical models are now available, which account for the multi-dimensional spatial structure of rivers, including longitudinal connectivity, branching networks of streams, and abrupt changes at confluences (Garreta et al. 2010, Peterson and Ver Hoef 2010). These models are called spatial stream network models (SSNMs) and they are enabling a wide array of research on rivers previously unobtainable. For example, by using SSNMs to analyze a large regional temperature database, researchers have demonstrated how stream thermal regimes are shifting due to climate change (Isaak and Rieman 2013) and the importance of access to thermal refugia is for salmonid fishes (Isaak et al. 2015). The basis of these models is a stream network topology, which is developed within a Geographic Information System (GIS) to characterize the spatial relationships of rivers, including flow-connected, flow-unconnected, and Euclidean relationships. Once in place, the network topology can be used in conjunction with a Digital Elevation Model (DEM) for accumulating water, and its associated physical, chemical, and biological properties, as it flows downstream through the river basin. Additionally, it provides the framework to evaluate how different spatial relationships influence watershed features of interest, thereby improving model predictions and allowing unique insights into ecosystem processes. The result is an analytical framework, which is able to a) partition influence between landscape and in-stream driven processes, and b) make robust predictive models throughout river ecosystems of important phenomena for both fish populations and human communities

Stream network topologies, which are compatible with SSNMs, do not exist for most watersheds in Alaska, largely because of the substantial resources needed to perform these analyses at such a grand spatial scale. However, recent efforts by the Alaska chapter of The Nature Conservancy, funded by the Gordon and Betty Moore Foundation, have produced a spatially-explicit stream network topology for the Nushagak River. This work has opened up a wide array of new modeling approaches for understanding and managing this ecosystem. We have capitalized on this opportunity to develop new analytical approaches for studying the ecology of fish in the Nushagak River by using the stream network topology within the framework of SSNMs to predict strontium isotope ratios across the entire watershed, thereby substantially improving our capability for assigning migratory fish to their natal origins throughout the ecosystem (see below). Many other powerful and exciting applications are also now possible in the Nushagak River.

The primary goal of this project was to develop spatially-explicit stream network topologies for the Yukon and Kuskokwim rivers, thereby enabling the development and application of a broad array of future spatial modeling approaches for studying these river ecosystems.

II. OBJECTIVES

Objective 1: Produce a topologically correct stream network for the Yukon and Kuskokwim rivers, which is compatible with the STARS (Spatial Tools for Analysis of River Systems) (Isaak et al. 2014) and SSN (Spatial Stream Network) (Isaak et al. 2014) models.

The Yukon and Kuskokwim River stream networks have been cleaned (e.g., removed braided networks, removed complex confluences, and ensured correct directional stream flow) and topologically correct stream networks have been constructed for this drainage. The initial attributes and stream segmentation from the original databases (i.e., the Alaska National Hydrography Dataset (NHD) from the United States Geological Survey) have been maintained for use and dissemination into the National Streams Internet project (https://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html). In addition, we have created a singular stream databases for the Yukon and Kuskokwim Rivers for 3rd order (Yukon) and 2nd (Kuskokwim) and larger streams. These singular Kuskokwim and Yukon stream networks are being used for the SSNM modeling. Due to the large nature of the Kuskokwim and Yukon Rivers, the location of the field samples (all samples were collected on 3rd order or larger streams), and possible limitations of running such a large dataset through the STARS and SSNM models, we decided to simplify the singular Kuskokwim and Yukon databases by eliminating smaller order streams.

Objective 2: Synthesize the set of geospatial data products that will be used in the STARS and SSNMs as potential predictors in models, including permafrost extent, geologic heterogeneity, recent glaciation history, gridded precipitation and temperature estimates, vegetation cover, and DEMs for the Yukon and Kuskokwim rivers.

We compiled several datasets that are relevant to SSNM modeling (Table 1). They include, Digital Elevation Models (DEMs), glacial extent (https://crc806db.uni-koeln.de/layer/show/6) (Ehlers and Gibbard 2008), permafrost extent and probability (Jorgensen et al. 2008, Pastick et al. 2015), a previously published process-oriented strontium isoscape for Alaska and the Yukon River in Canada (Bataille et al. 2014), gridded precipitation and temperature (10 year annual mean) from Scenarios Network for Alaska+Arctic Planning (SNAP) (https://www.snap.uaf.edu), and geologic extent for the Yukon and Kuskokwim drainages, as delineated by the globally standardized Global Lithological Map (GLiM) (Hartmann and Moosdorf 2012).

Using the above data sources, several covariates have been developed for both Yukon and Kuskokwim rivers for use in an SSN. Covariates included elevation, mean precipitation, percent glaciated, predicted strontium isotope ratios weighted by precipitation and predicted strontium concentrations, percent geological type, and percent continuous and discontinuous permafrost. Several covariates were developed for geologic types. These included all geologic types that represented >1% of the total basin area. These were computed on the basis of the 'Litho' and 'xx' classes as described by the GLiM, which delineate different rock types and formations (e.g., metamorphic, siliciclastic sedimentary, or mafic plutonic). These classes represent the fine and broad scale geologic units, respectively, within the Kuskokwim and Yukon basins. All covariates computed in STARS and incorporated into SSN, explicitly describe the local conditions in the immediate basin area draining into each stream reach (i.e., Reach

Contributing Area [RCA]), and the watershed area located upstream of each stream reach including that of the said reach. For example, for a given geologic unit, we computed a covariate that describes the percent area of that unit within each RCA, and a covariate that describes the percent area of that unit upstream of each stream reach, which represents the percent watershed area that is composed of a given geologic type. For continuous variables, such as mean elevation, these were computed for each RCA as well. In order to accumulate these downstream, however, the continuous variables for each RCA were weighted (multiplied) by their RCAs (or precipitation amounts) and then the resulting product was accumulated downstream. To compute the mean elevation upstream of each reach, for example, these were then divided by the accumulated watershed area (or precipitation amount) upstream of each reach (Peterson and Ver Hoef 2014).

Objective 3: Make the geospatial data products produced during this project publically available via data clearinghouse sites, such as the National Stream Internet (NSI) project.
(http://www.fs.fed.us/rm/boise/AWAE/ projects/NationalStreamInternet.html)

The Yukon and Kuskokwim stream datasets have been sent to Dan Isaaks and Dave Nagel at the US Forest Service to be included in the National Stream Internet Project. Due to the large extent of the Yukon and the difficulties of running such a large dataset through the STARS and SSN models, the Yukon reconditioned stream networks were developed separately for the US and Canadian portions of the Yukon drainage. Original stream segmentation and attributes were kept for each Yukon dataset (US and Canada). These datasets can be downloaded separately. The Kuskokwim stream network is contained in one dataset.

III. METHODS

a. Data Sources

Stream Data - The Alaska NHD database was downloaded from the USGS site (https://www.usgs.gov/core-science-systems/ngp/national-hydrography) in July 2016. This download was used for reconditioning of stream in the US portion of Yukon and the Kuskokwim river drainages. A similar dataset was acquired from the Canadian GeoBase (http://www.geobase.ca/) – the NHN network for the Canadian portion of the Yukon.

Geospatial products – Several geospatial datasets were acquired to use as environmental predictors in an SSN model. Table 1 lists the data and its source.

Data	Source
Digital Elevation Model (DEM)	
Alaska	http://alaska.portal.gina.alaska.edu/catalogs/257-national-elevation-dataset-ned-dem
Canada	https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information
Geologic Data	

Global Lithological Map	https://www.geo.uni-hamburg.de/en/geologie/forschung/geochemie/glim.html
A Digital Atlas of Terranes for the Northern Cordillera	http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/GeoFiles/Pages/2011-11.aspx
Precipitation (10 year annual mean 2006-2015)	https://www.snap.uaf.edu/
Glacial History	https://crc806db.uni-koeln.de/layer/show/6
Strontium Isoscapes	Bataille et al 2014

Table 1. List of Geospatial products

The DEMS between Alaska and Canada were merged to create one dataset that covered the entire Yukon. The Alaska DEM was at a coarser spatial resolution of 61 m, thus the Canadian DEM with a resolution of 20 m was resampled to 61 m to match the resolution of Alaska DEM to maintain spatial integrity.

All other geospatial data products covered the entire study area.

b. Re-condition Stream Networks

Detailed description of methods is located in Appendix A. The document in Appendix A was developed for metadata of the database and will be included in the documentation of stream database for the National Stream Internet Project.

We followed (Nagel 2017) (https://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet/downloads/NationalStreamInternetProtocolandUserGuide.pdf) as a guideline for reconditioning the stream networks in Alaska, However the Alaska NHD dataset is not as fully developed as the NHD datasets in the conterminous United States, hence protocols for reconditioning the network were slightly different for initial clean-up steps. Minimal cleanup was needed for Canadian NHN network as braiding channels were already removed from the stream network.

The stream networks were processed at two different levels:

1) Original stream segmentation – All stream network segmentation was maintained from the original databases. The segmentation was maintained due to unique attributes that end users might want to use in future SSN model runs. Due to the large nature of these datasets, the Yukon was split into 2 stream datasets (US & Canadian portion of the Yukon – Figure1). The Kuskokwim is contained within one dataset. These datasets are included in the National Streams Internet Project.

2) Stream order – A second set of stream networks were developed based on stream size or order. We have created new stream networks based on stream order for the Yukon (3rd and above) and Kuskokwim (2nd order and above) Rivers. Due to the large nature of the Kuskokwim and Yukon databases, the location of the field samples (all samples were collected on larger streams), and possible limitations of running such a large dataset through the STARS and SSNM models, we decided to simplify the Kuskokwim database by

eliminating 1st order streams, and eliminating 1st and 2nd order streams for the Yukon database. In addition, we simplified the stream database by removing the original segmentation, thus creating one unique stream segment between confluences. All unique attributes available from the original databases were lost during this simplification procedure. These stream order-based stream networks were much more manageable to run through the STARs and SSN models.

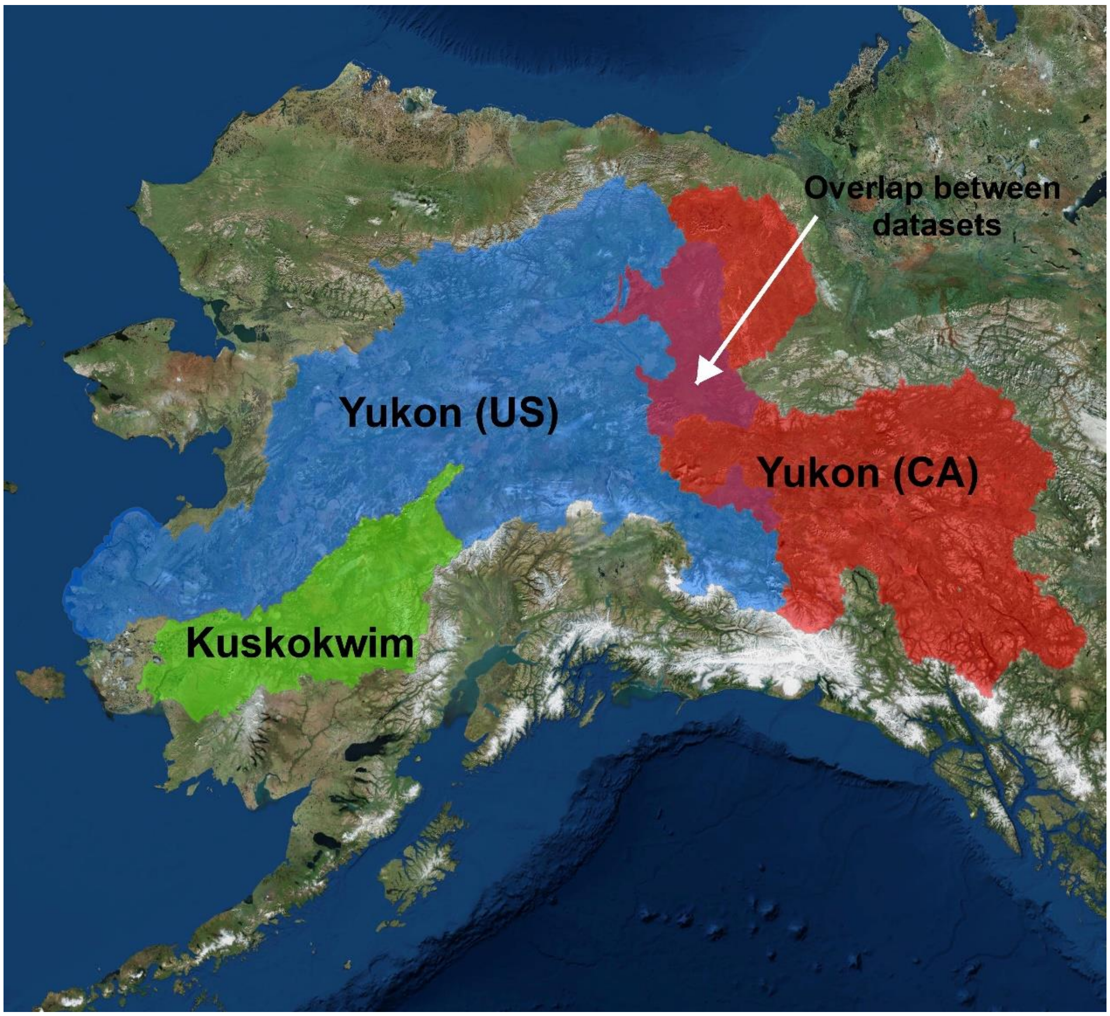

Figure 1. Extent of the 3 regions of stream network databases

IV. RESULTS

The reconditioning of Yukon and Kuskokwim stream networks were successfully completed. The stream order networks are shown in Figure 2. The stream networks were run several times through the STARs model to ensure its robustness in future runs. In addition, several environmental covariates were developed from the Geospatial products listed in Table1 for statistical analysis needed in the SSN models.

The covariates were resampled to a 61 m resolution of the DEM to normalize all the geospatial product data to one scale.

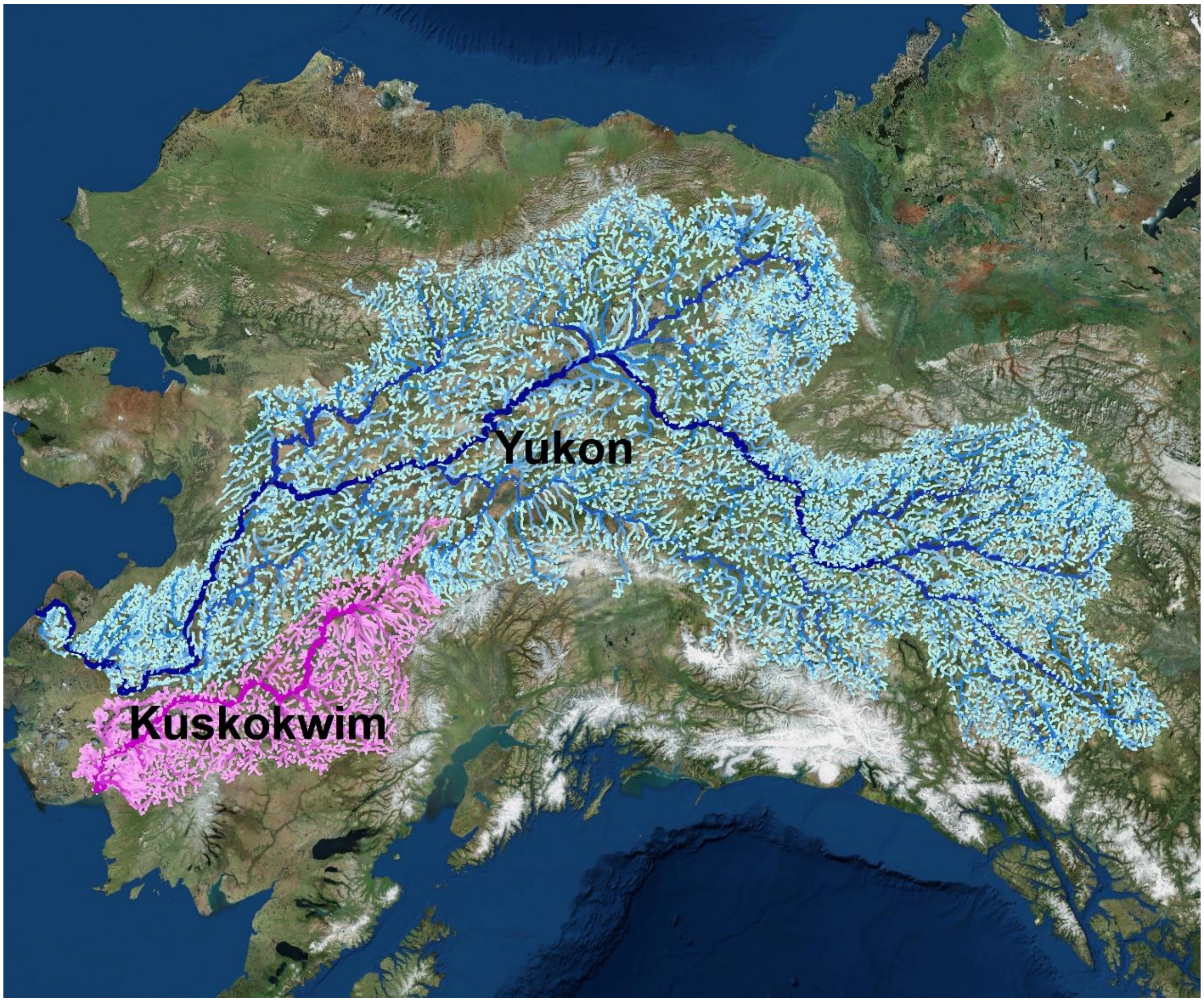

Figure 2. Stream order databases for Yukon and the Kuskokwim Rivers. The Yukon includes all 3rd order and larger streams, while the Kuskokwim includes all 2nd order streams and above.

V. DISCUSSION

The development of topological correct stream networks for the Yukon and Kuskokwim plays an integral role in the generating the strontium isoscapes, which we are using to determine the natal origins and movement patterns of Chinook salmon across the Yukon and Kuskokwim basins. Initial applications of the stream networks will include integration with our existing AYK SSI-funded project using strontium isotope ratios recorded in Chinook salmon otoliths to assign individual fish to their birth locations throughout the Yukon River (AYK#1515). From previous work, (Brennan and Schindler 2017) developed an analytical approach, which integrates i) isoscapes built via SSNMs, and ii) a continuous Bayesian assignment framework within the Nushagak River to map the production patterns of returning adult Chinook salmon. A similar approach is being used to model Chinook salmon production patterns across the Yukon and Kuskokwim Rivers. In addition, the stream networks will provide integral baseline data and overall framework for two other AYK funded projects ("Integrating genetics with otolith microchemistry to reconstruct production patterns of Chinook salmon throughout the Yukon River Basin", #1705, and "Building a strontium isotope baseline of the Kuskokwim River able to reconstruct the production patterns and life histories of Chinook salmon at fine spatial scales", #1704). Furthermore, in the Kuskokwim, we are using this newly developed stream network and associate covariates to model the controls on spatial variation in bioavailable mercury in slimy sculpin collected from across the Kuskokwim, and also to explore spatial controls on dissolved organic carbon and nutrient transport through this river. Thus, the clean stream networks developed herein, are already opening the doors to valuable spatially analyses and research that previously was not possible within these vast river networks.

The stream networks have wide-ranging implications for numerous other objectives and goals throughout the AYK region, including tracing pollutant transport, other chemical constituents in rivers, temperature patterns, and flow regimes. To this end, the topologically correct stream networks will be made publically available at the National Stream Internet (NSI) project http://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html) in order to facilitate interdisciplinary use of the resulting data products across the AYK region.

VI. REFERENCES

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VII. DELIVERABLES

The Yukon and Kuskokwim topologically correct stream networks are complete and will be publically available at the National Streams Internet (NSI) project (http://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html). The Yukon is separated into two datasets (US and Canadian portions), due to the large nature of these data products. The Kuskokwim is contained within one dataset. A meta data document is included with the stream datasets (Appendix A).

Four semi-annual reports were generated over the course of this project documenting the progress of our work over time.

1) SAPR #1609 SchindlerJul-Dec16
2) SAPR #1609 SchindlerJan-jun17
3) SAPR #1609 SchindlerJul-Dec17
4) SAPR #1609 SchindlerJan-jun18

Four oral presentations were delivered at the American Fisheries Society, Western Division 2018 Annual Meeting held in Anchorage in May 2018. The presentations are listed below.

Brennan, S., Schindler, D., French, D., Whited, D. (Spring 2018) *Invited talk*. "Strontium isoscapes as a tool to quantify production dynamics and life history variation of Yukon and Kuskokwim Chinook salmon", Session: Understanding the drivers of Chinook salmon decline in western Alaska & exploring new approaches to sustainable salmon management & stakeholder engagement. *American Fisheries Society, Western Division 2018 Annual Meeting, Anchorage, AK.*

Brennan, S. (Spring 2018) *Invited talk*. "Spatial Stream Network models and isoscapes", Session: Spatial-stream-network (SSN) models: Recent technical advances and a diversifying set of applications. *American Fisheries Society, Western Division 2018 Annual Meeting, Anchorage, AK.*

Brennan, S., Schindler, D. (Spring 2018) *Invited talk*. "Quantifying habitat use of anadromous fish using space-time isotope models", Session: Evolving methods for specifying anadromous waters in Alaska. *American Fisheries Society, Western Division 2018 Annual Meeting, Anchorage, AK.*

French, D., Brennan, S., Whited, D., Schindler, D. (Spring 2018) *Invited talk*. "Controls on the spatial variation of mercury in the Kuskokwim River", Session: Spatial-stream-network (SSN) models: Recent technical advances and a diversifying set of applications. *American Fisheries Society, Western Division 2018 Annual Meeting, Anchorage, AK.*

VIII. PROJECT DATA

The Yukon and Kuskokwim topologically correct stream networks are complete and will be publically available at the National Streams Internet (NSI) project (http://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html). The Yukon is separated into two datasets (US and Canadian portions), due to the large nature of these data products. The Kuskokwim is contained within one dataset. A meta data document is included with the stream datasets (Appendix A).

IX. ACKNOWLEDGEMENTS

The authors would like to thank Dan Isaak and Dave Nagel at US Forest Service, Rocky Mountain Research Station for their help and guidance in the cleanup and rec-conditioning of the stream networks.

Also for agreeing to post and host the finished stream networks. We also thank Erin Peterson at the Institute of Future Environments and the ARC Centre of Excellence for Mathematical and Statistical Frontiers, Queensland University of Technology with help troubleshooting the processing of the data.

X. PRESS RELEASE

One of the largest impediments to modeling ecosystem processes in the Yukon and Kuskokwim rivers is the lack of a spatially-explicit stream network topology describing how water collects and drains through these vast and topographically complex river basins. Without such a spatial framework, a wide variety of scientific investigations are distinctly limited as they cannot capitalize on new spatially-explicit modeling approaches to characterize fluxes of water and the properties (e.g., temperature) and materials (e.g., sediments and contaminants) it transports downstream. Stream network topologies, which are compatible with SSNMs, do not exist for most watersheds in Alaska, largely because of the substantial resources needed to perform these analyses at such a grand spatial scale.

Recent research funded by the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative and conducted by scientists at the University of Washington and the University of Montana have developed topological correct stream networks suitable for use in spatial stream network model (SSNMs) for the Yukon and Kuskokwim drainages.

The Yukon and Kuskokwim stream networks will be available for public dissemination at the National Streams Internet (NSI) project (http://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html). The NSI currently has a complete topologically correct stream network for the entire lower 48 states, which is explicitly designed in order to use with the Spatial Tools for Analysis of River Systems (STARS) and SSNMs. The addition of the Yukon and Kuskokwim stream networks will enable far-reaching interdisciplinary research and natural resource management throughout the AYK region. These statistical models can be used to better monitor and project stream thermal regimes, pollutant transport, and stream flows, which are all important aspects of Chinook salmon health and ecology and human communities.

The Yukon stream network is currently being used to model $^{87}Sr/^{86}Sr$ ratios across the entire Yukon River, to simultaneously delineate the natal origins and freshwater life history patterns of Yukon River Chinook salmon at unprecedented spatial and temporal scales. Such a model provides the framework to determine the relative production of different regions of the Yukon at fine spatial scales, as well as the variation in freshwater life history patterns of recruits annually.

XI. APPENDIX A

Reconditioning of the Yukon and Kuskokwim rivers for use in the STARs and SSN model.

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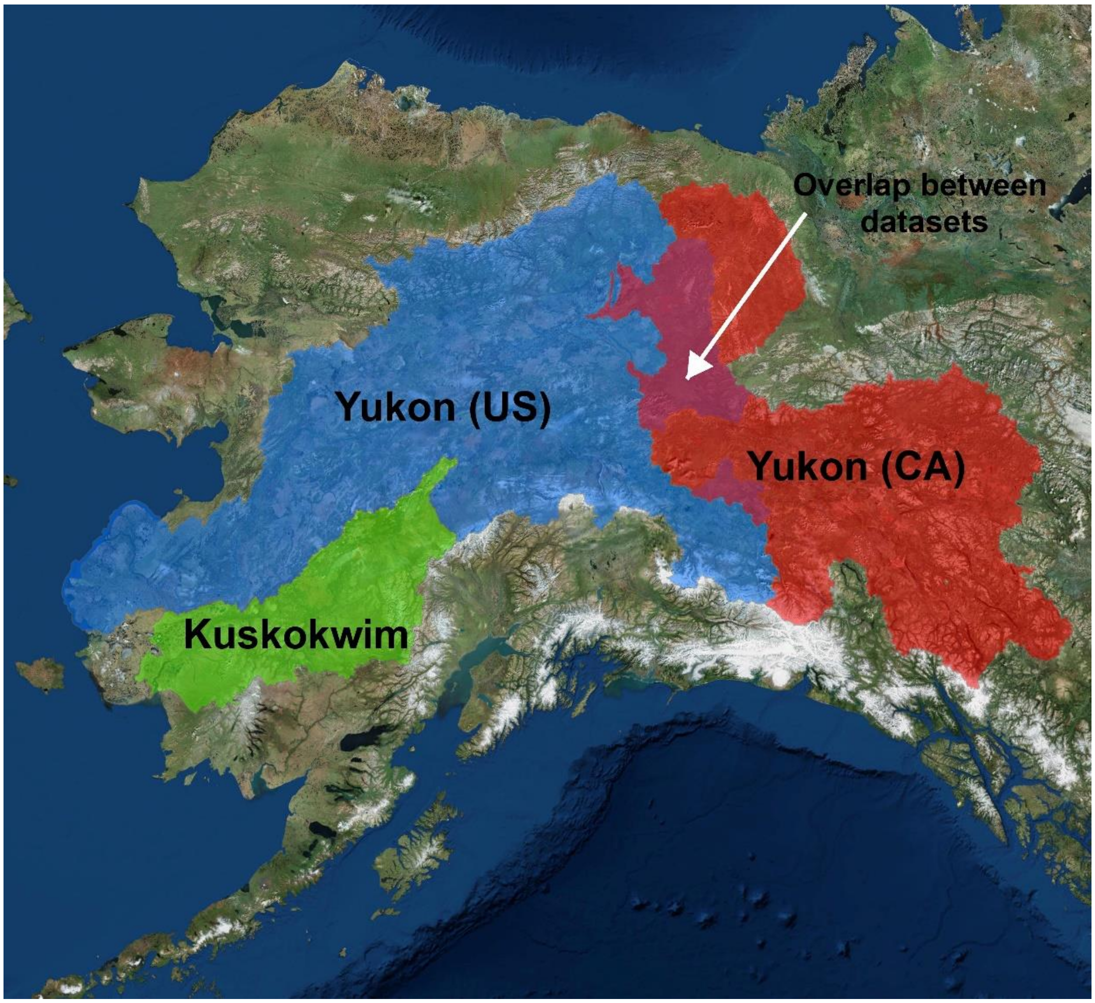

Stream Networks

The Alaska NHD database was downloaded from the USGS site (https://www.usgs.gov/core-science-systems/ngp/national-hydrography) in July 2016. This download was used for reconditioning of stream in the US portion of Yukon and the Kuskokwim river drainages. A similar dataset was acquired from the Canadian GeoBase(http://www.geobase.ca/) – the NHN network for the Canadian portion of the Yukon.

We used Nagel et al. 2017 (https://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet/downloads/NationalStreamInternetProtocolandUserGuide.pdf) as a guideline for reconditioning the stream networks in Alaska, However the Alaska NHD dataset is not as fully developed as the NHD datasets in the Lower 48, hence protocols for reconditioning the network were slightly different for initial clean-up steps.

Minimal cleanup was needed for Canadian NHN network as braiding channels were removed from the stream network. The following protocols follow Nagel et al 2017. If steps in stream reconditioning are identical, we refer directly to Nagel's guide. Part 1 describe the reconditioning of the Alaska NHD database, while Part 2 describes the reconditioning of the Canadian NHN database.

Due to the large extent of the Yukon and the difficulties of running such a large dataset through the STARS and SSN models, the Yukon reconditioned stream networks were developed separately for the US and Canadian portions of the Yukon drainage. Original stream segmentation and attributes were kept for each Yukon dataset (US and Canada). These datasets can be downloaded separately. The Kuskokwim stream network is contained in one dataset.

Part 1. Alaska NHD – Reconditioning.

1) Pre-Processing

The NHDFlowline.shp polyine, NHDFlowlineVAA attribute table, and the WBDHUC8.shp polygon were the 3 files used in the Alaska NHD database.

The Alaska NHDFlowline shapefile resides in the geographic, decimal degrees coordinate system. The data were reprojected to a rectangular coordinate system because distances measured using decimal degrees can change at different locations on the globe. Using a rectangular coordinate system satisfies the assumptions of the SSN package. The shapefile was reprojected to a national Albers coordinate system for Alaska. The following parameters were used:

Projected Coordinate System:	
	NAD_1983_Alb
es Projection:	Albers
False_Easting:	0.00000000
False_Northing:	0.00000000
Central_Meridian:	-154.00000000
Standard_Parallel_1:	55.50000000
Standard_Parallel_2:	65.50000000
Latitude_Of_Origin:	50.00000000
Linear Unit:	Meter
Geographic Coordinate System:	GCS_North_American_1983
Datum:	D_North_American_1983
Prime Meridian:	Greenwich
Angular Unit:	Degree

The Alaska NHD does not include as many attributes similar to lower 48. Key attributes in the Alaska NHD include (Table 1, https://www.usgs.gov/core-science-systems/ngp/national-hydrography/about-national-hydrography-products):

Permanent_:	Unique Identifier
FDATE:	Date of last feature modification
Resolution:	Code for source resolution: 1 –Local, 2 – High, 3 - Medium
GNIS_ID:	Unique Identifier assigned by GNIS
GNIS_NAME:	Proper name, specific term, or expression by which a particular geographic entity is known.
LENGTHKM:	Length of linear feature (KM)
REACHCODE:	Unique Identifier composed of two parts. The first eight digits is the subbasin code as defined by FIPS 103. The next 6 digits are randomly assigned.
FLOWDIR:	Direction of flow relative to coordinate order
WBAREA_PER:	Permanent Identifier of the waterbody through which the Flowline (Artificial Paths) flows
FTYPE:	Unique Identifier of a feature type
FCODE	Five digit integer value compromised of the feature type and combinations of characteristics and values
STREAMLEVEL:	Drain level of the downstream mainstream drain.

Table 1. Attributes used in the Alaska NHD database.

The NHDFlowlineVAA attribute was joined to NHDFlowline.shp polyine to specifically access the StreamLevel attribute. The StreamLevel attribute identifies the mainstem from tributaries at particular junctions in the stream network. This was useful for cleaning up braided networks. However in some areas, the StreamLevel attribute did not have any values to aid in the cleanup.

The NHD database was sub-setted into discrete basins Hydrologic Unit Code 8 basins. This created manageable datasets to edit for reconditioning the network (Figure 1).

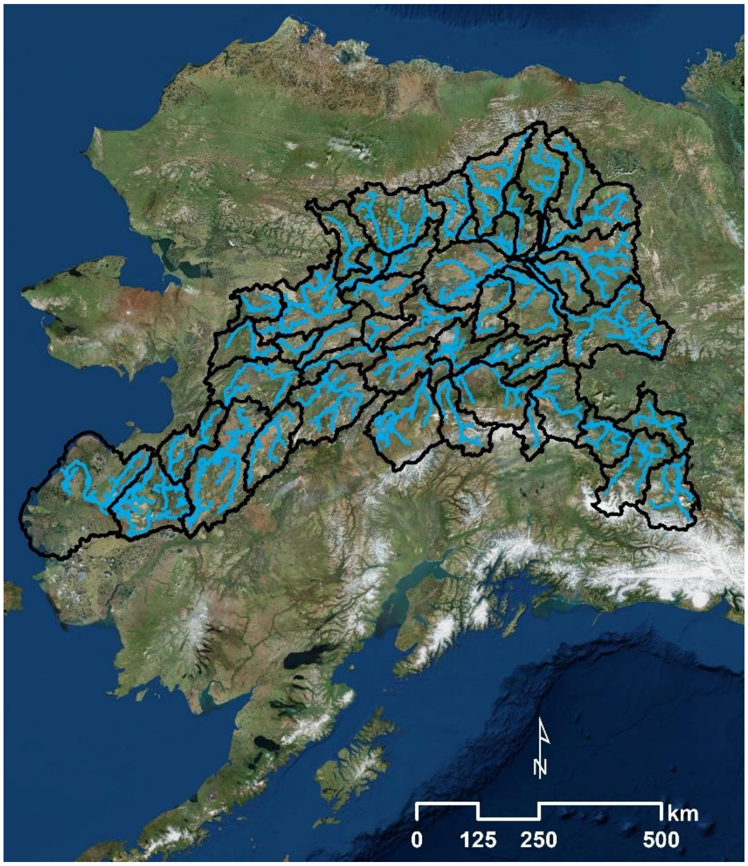

Figure 1. HUC 8 Basins for the US portion of the Yukon.

2) **Removing Uninitialized Flow – Refer to Nagel et al. 2017**

3) Isolated Networks

Isolated networks are disconnected from the main drainage structure. These networks were deleted from the database to eliminate unconnected drainages. The original purpose for development of the database was to model SSN for the entire Yukon and Kuskokwim drainages, thus these drainages were not needed and removed from the database.

4) Removing Braids and Diverging Flow

Braided and diverging stream segments are not permitted in the spatial stream network data model used by the SSN package. To remove braiding, the network was displayed with the StreamLevel attribute and polylines showing flow direction to aid in cleaning up the network. Braided networks were removed from the network by manually deleting them.

5) Building the Landscape Network –refer to Nagel et al. 2017

6) Identifying and Editing Topological Restrictions – refer to Nagel et al. 2017

**Complex confluences*

Complex confluences were moved according to Nagel et al. 2017, however additional attributes were not created to highlight these segments. The new segments created from moving the complex confluences retain the original attributes.

7) Identifying Downstream Divergences - Refer to Nagel et al. 2017

8) Outlets and Sinks - Refer to Nagel et al. 2017

9) Merging HUC8 basins into the US portion of the Yukon.

Each HUC8 basin was run through the above 8 steps for reconditioning the stream network and checking for topological errors. After successfully creating a LSN object with no topological errors. The HUC8s were merged into one dataset cover the US portion of the Yukon or the Kuskokwim drainage. See figure 1 for extent of US portion of the Yukon.

Steps 5 through 8 were repeated to check for new possible topological errors after merging the HUC8 networks together. Topological errors were corrected and a final networks were developed for the US portion of the Yukon and the Kuskokwim. A stream order attribute (STRAHLER) was added to the stream network in the final versions.

Part 2. Canadian NHN – Reconditioning.

1) Pre-Processing

The Canadian NHN database was used to develop a reconditioned stream network for the Canadian portion of the Yukon. The NHN_HN_PrimaryDirectedNLFlow_1.shp and the NHN_WORKUNIT_LIMIT_2.shp files were the 2 features used from Canadian NHN database. The primary directed flow represented a stream network where braiding channels were removed and a single channel represents flow through the drainage basin.

The Canadian NHN network was projected to the CSRS Yukon Albers 1983 projection. The following parameters were used:

Projected Coordinate System:	NAD_1983_CSRS_Yukon_Albers
Projection:	Albers
False_Easting:	500000.00000000
False_Northing:	500000.00000000
Central_Meridian:	-132.50000000
Standard_Parallel_1:	61.66666667
Standard_Parallel_2:	68.00000000
Latitude_Of_Origin:	59.00000000
Linear Unit:	Meter

Geographic Coordinate System:	GCS_North_American_1983_CSRS
Datum:	D_North_American_1983_CSRS
Prime Meridian:	Greenwich
Angular Unit:	Degree

The Canadian NHN includes similar attributes to the Alaska NHD but with different names. Key attributes in the Canadian NHN include (Table 2 http://ftp.maps.canada.ca/pub/nrcan_rncan/vector/geobase_nhn_rhn/doc/GeoBase_nhn_en_Catalogue_1_2.pdf):

NID:	Unique Identifier
validityDate:	The date of data creation or revision. A known value in the format YYYY/MM
acquisitionTechnique:	The source of data used to populate the NHN
datasetName:	Unique Identifier assigned by GNIS
planimetricAccuracy:	Planimetric data accuracy expressed as the Circular Map Accuracy Standard (CMAS).
Provider:	The affiliation of the organization that generated (created or revised) the object
networkFlowType:	Mode of creation of the Network Linear Flow (-1 – Unknown, 0- None, 1 – single water course, 2 – passing through a water area, 3 – isolated networks)
flowDirection:	Indicates if the event follows the same direction as the digitizing of the Network Linear Element
Isolated:	Any Waterbody or Single Line Watercourse that has no connection with any other Waterbody or Single line Watercourse

Table 2. Attributes used in the Alaska NHD database.

The NHN Network was then sub-setted into discrete NHN WORKUNITs. The NHN WORKUNITs are at a similar scale to the HUC8s that was used in US portion of the Yukon. This created manageable datasets to edit for reconditioning the network (Figure 2).

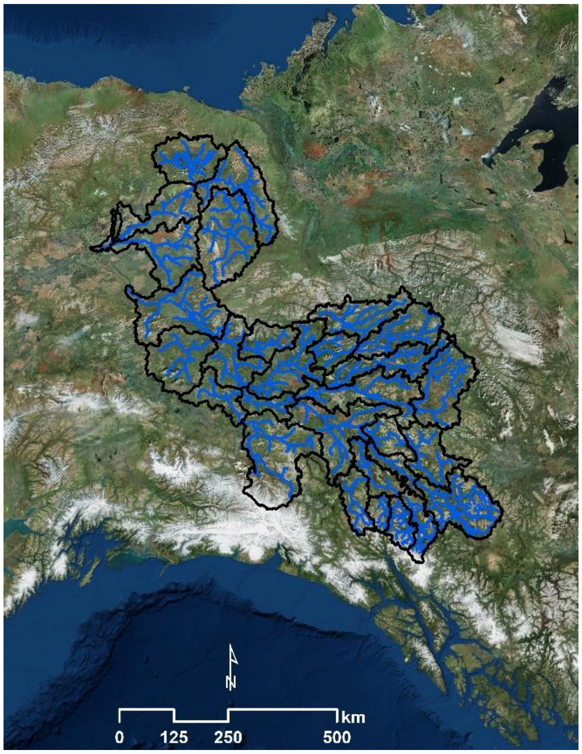

Figure 2. NHN WORKUNIT Basins for the Canadian portion of the Yukon.

2 and 3) Removing Uninitialized Flow & Isolated Networks

The Canadian NHN databases did not include an attribute for uninitialized flow, so this step was skipped. Isolated networks were deleted from the database to eliminate unconnected drainages. The original purpose for development of the database was to model SSN for the entire Yukon and Kuskokwim drainages, thus these drainages were not needed and removed from the database

4) Removing Braids and Diverging Flow

Due to relatively clean network of using the NHN_HN_PrimaryDirectedNLFlow_1.shp, minimal cleanup was need for removing braids and diverging flow. This was checked during the STARS Check Network Topology tool. If braiding or divergent flows were found there manually deleted.

Steps 5 through 9 were identical from the reconditioning step of the Alaska NHD as described above.

References

Nagel D,, E. Peterson, D. Isaak, J. Ver Hoef, and D. Horan. 2017. National Stream Internet Protocol and User Guide. U.S. Forest Service Report v3-22-17. 46p