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Delineation of Watersheds in the Mackenzie Mountains

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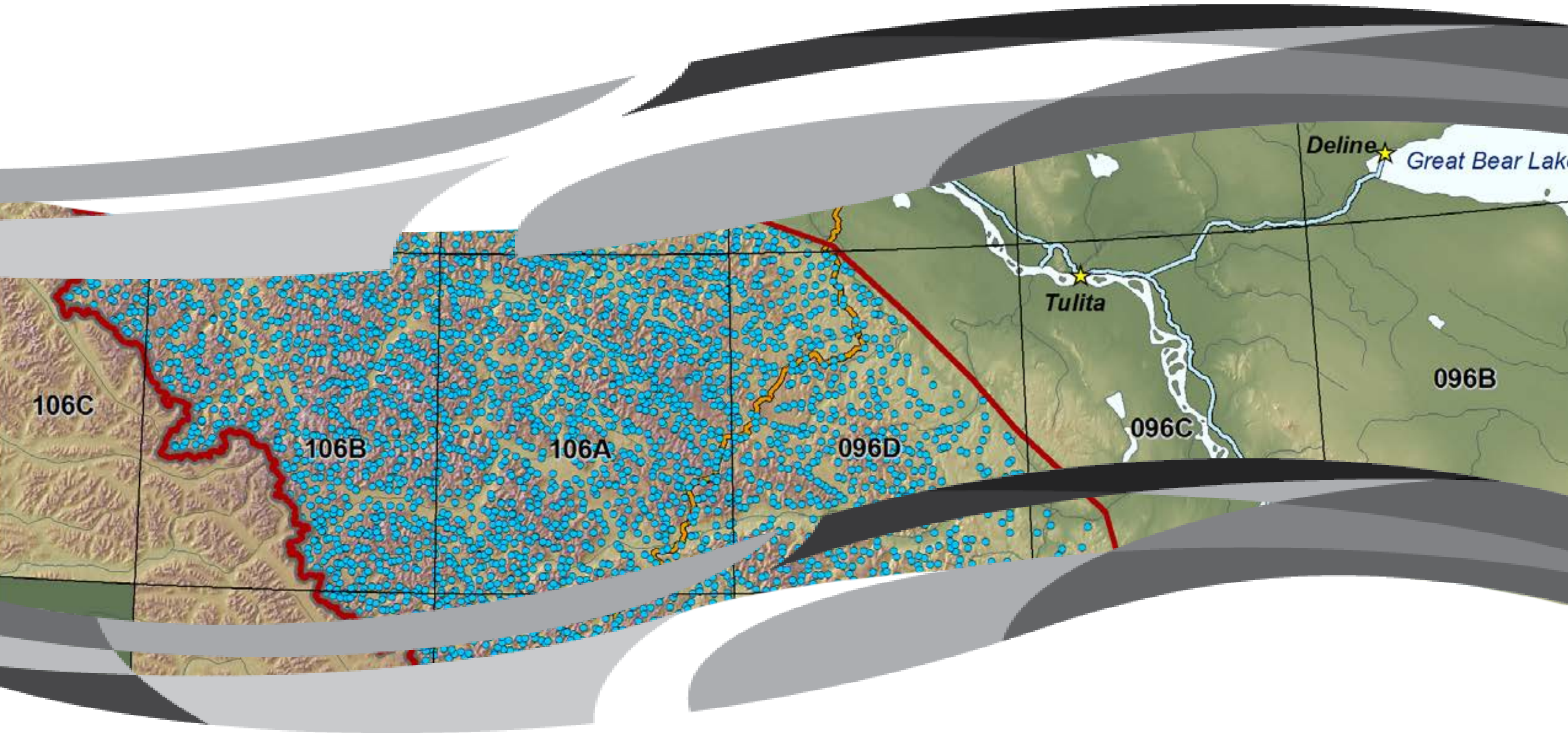

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NORTHWEST TERRITORIES
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Government of
Northwest Territories

NWT Open Report 2015-007

Explanatory Notes for Delineation of Watersheds in the Mackenzie Mountains

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INTRODUCTION

The Northwest Territories Geological Survey has been systematically completing a regional stream sediment sampling program across the Mackenzie Mountains, in partnership with the Geological Survey of Canada. To synthesize and interpret the results of the geochemical analyses, a set of detailed watersheds based on stream segment order was required. However, the best publicly available watersheds for the study area are those provided from GeoGratis in the Atlas of Canada, National Frameworks Data, Hydrology dataset at approximately a 1:1,000,000 scale. The detailed dataset required for the sampling program did not exist.

This publication contains a nested series of watersheds created for third through to sixth order of stream segments. The watersheds were derived for the stream sediment sampling study area (Figures 1 and 2) using Canadian Digital Elevation Data (CDED) at ~15m resolution, along with stream network and waterbody data from the National Hydro Network (NHN).

Figure 1. Location of the study area (red outline) in the Northwest Territories.

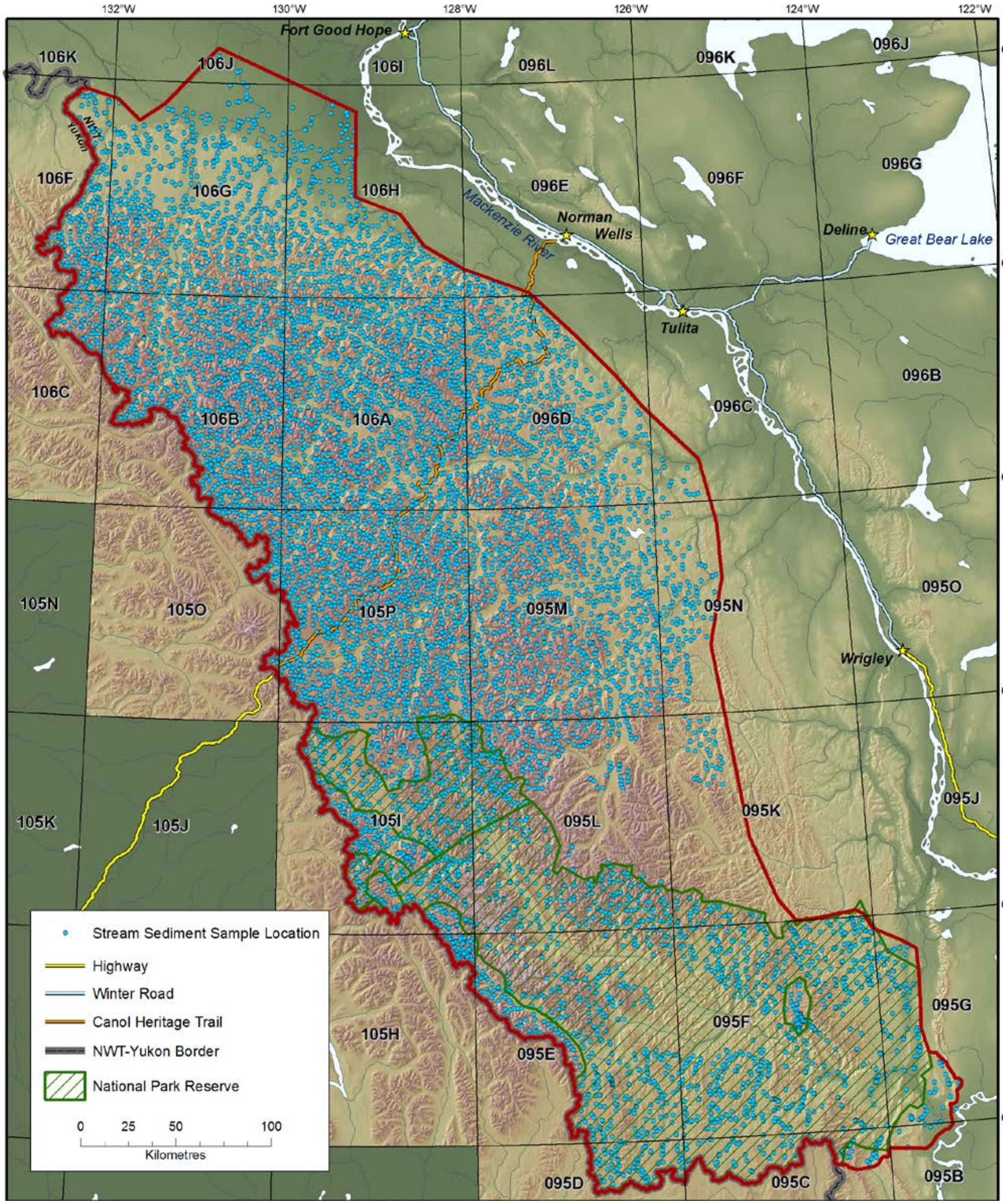

Figure 2. Physiographic relief map showing the locations of all stream sediment samples (blue dots) collected in the study area (red outline).

ABOUT THE DATASET

The dataset was managed using ESRI® ArcGIS™ 10.2 software with ArcHydro Tools and Spatial Analyst extensions. It was created utilizing an ArcGIS™ geoprocessing model (courtesy of R. Fraser, Canada Centre for Remote Sensing) with parameter modifications as best suited for delineating watersheds in the mountains.

All data are projected in Universal Transverse Mercator (UTM) zone 9, North American Datum 1983 (NAD 83).

FILE STRUCTURE

\ - Contains the Explanatory Notes (PDF), a PDF file depicting the ArcGIS™ geoprocessing model, the ArcMap™ 10.2 MXD project file, and readme file (TXT).

\Layer_Files

- Contains ArcMap layer files (LYR) that store symbology for each layer.

\Shapefiles_Tif

- Contains directories of the shapefiles converted from each feature class in the file geodatabase. Each shapefile is associated with a projection information file (*.prj) and metadata file (*.xml).

  \BaseData

  DEM_MackenzieMtns – Tif image of the mosaicked DEM, from CDED, used as the DEM data input in the geoprocessing model
  NHN _NetworkFlow_Primary – National Hydro Network main route network linear flow, used as the watercourse data input in the geoprocessing model
  NHN _Waterbodies – National Hydro Network lakes, used as the waterbody data input in the geoprocessing model
  NHN _Watercourses – National Hydro Network streams
  NTS_Grid_50k – 1:50,000 scale NTS grid
  Study_Area – Extent of the project area

  \Watersheds

  Watersheds_3rd_Order – Watershed boundary for third order streams
  Watersheds_4th_Order – Watershed boundary for fourth order streams
  Watersheds_5th_Order – Watershed boundary for fifth order streams
  Watersheds_6th_Order – Watershed boundary for sixth order streams

\Watersheds_MackenzieMtns.gdb

- ArcMap™ 10.2 file geodatabase. The file structure of this geodatabase is visible within ArcCatalog. See the *Shapefiles_Tif* directory, above, for a brief description of each feature class.

METHODOLOGY

Data Inputs

All input datasets are at a 1:50,000 scale and were downloaded from GeoBase (2012), now available from GeoGratis at www.geogratis.ca. To run the geoprocessing model, a digital elevation model (DEM) and hydrology data (streams and lakes) are required as inputs.

The DEM was generated using CDED rasters that were at approximately 15m resolution. The image tiles were downloaded by 1:50,000 scale National Topographic System sheet, then assembled into a mosaic, and the resulting image reprojected to UTM zone 9.

For the hydrology, NHN data were downloaded based on the Water Survey of Canada sub-sub-drainage areas (NHN Work Unit). The Waterbody shapefiles from each NHN Work Unit were merged and reprojected to UTM zone 9. The Network Linear Flow shapefiles were used for the watercourses; these were merged from each NHN Work Unit and reprojected to UTM zone 9.

Given the mountainous and un-vegetated nature of much of the study area, a number of stream features common to this terrain had to be treated in a special manner. The braided streams and alluvial fans needed to be represented as a single watercourse line, in order to correctly produce the stream order raster. To do this, only the primary (main route) features from the merged Network Linear Flow shapefile were selected and used as the input watercourse data in the geoprocessing model.

Geoprocessing Steps

- DEM Reconditioning imposes or ‘burns in’ linear features into the DEM. It is based on the AGREE method developed by Ferdi Hellweger (1997) at the University of Texas, Austin. A sharp drop value of 1000m was chosen; this produces a DEM where the elevation under stream features was decreased by 1000m.

- The Fill Sinks tool is then used to create a DEM free of sinks. The presence of sinks, a common error in elevation data where neighbouring cells all have higher elevation values, may result in an inaccurately determined flow direction.

- A Flow Direction grid is generated, at approximately 15m resolution, from the depressionless (‘sink-free’) DEM. Each cell value in the grid represents the direction of steepest descent.

- Flow Accumulation calculates the total number of all cells flowing into a downslope cell.

- Stream Definition produces a stream raster from the flow accumulation grid, using a user-defined threshold of what flow accumulation value constitutes a stream. A threshold value of 300 was chosen empirically as the most representative of the NHN vector data. A value of 200 created a stream raster with an excessive number of false stream segments, whereas a higher value of 400 resulted in some missing stream segments.

- The DEM-generated stream raster still contained numerous false first order stream segments that are not in the NHN data. To remove most of these, a Raster Calculator was performed to compare the stream raster to a raster mask of input NHN water features. Only stream raster segments that overlapped the NHN raster mask by at least 30% were kept. However, consequences of this process are gaps in the stream network from removed stream segments that did not quite overlap by ≥30%. The 30% overlap value was selected to optimize the removal of as many ‘false’ first order stream segments as possible without also removing a large number of ‘real’ stream segments.

- To fill in these missing stream segments, a stream definition raster with a flow accumulation threshold value of 600 is added back into the 30% agreement raster. The flow accumulation value of 600 was selected as it was sufficient to fill in the stream gaps without also adding back in false stream segments. The final raster produced is a relatively clean stream network raster that was used to delineate the watersheds. The stream threshold values and overlap percentage were chosen through repeated trials to derive a DEM-based stream network raster most coincident with the NHN streams.

- Stream Segmentation creates a raster with uniquely identified stream segments.

- Stream Order classified the stream segments based on the number of tributaries and their order that fed into the stream segment. The process is based on the Strahler (1957) method of stream classification.

- Using the Con tool, stream rasters were created in increasing stream order that would be used to derive the nested series of watersheds (3rd order and higher, up to 6th order and higher). Pour points are needed to identify the locations to derive the contributing watershed. Each stream raster was used as the pour point raster in the Watershed tool, whereby a watershed is generated for each stream segment.

- The watershed rasters were then converted to polygon vector data. A topology was run with 20m tolerance to ensure the four watershed layers were coincident. This was followed by extensive quality control measures.

QUALITY CONTROL

The modeling efforts on the watershed boundary polygons required significant manual quality control. The standard approaches employed by the U.S. Geological Survey and U.S. Department of Agriculture (USGS and USDA, 2013) were used as a guideline in making these manual changes.

The accuracy and correctness of the watershed boundaries is limited by the quality and robustness of the input data. No smoothing of boundary lines or clipping to territorial borders was performed. If a degree of precision greater than the approximate 1:50 000 scale of the input data is required, additional data, such as airphoto studies, may be required to confirm the accuracy of the boundaries.

Note: All 3rd and 4th order watershed boundaries presented in this publication have undergone significant quality control measures. These quality control steps were also performed on the 5th and 6th watersheds boundaries, however due to their large areal coverage, the accuracy beyond the extent of the study area cannot be guaranteed.

Data errors

Inaccuracies and errors in the input datasets and minor discrepancies between the stream network raster and vector data resulted in locally incorrect stream order classifications and subsequent watershed delineations. This required carefully checking the stream vector data for the correct stream order and then merging or splitting out watershed polygons as necessary. Where a stream segment resulting in an increase in the stream order appeared in the raster data but not the vector data, satellite imagery were visually inspected to check if the stream segment actually existed. In instances where the resolution of the satellite image was too coarse to determine the presence of a stream, the vector stream network data were preferentially selected in favour of the model-generated raster stream network data.

In relatively flat-lying regions, where errors and inaccuracies in the DEM were a significant portion of the elevation changes, such as the plain adjacent to the Mackenzie River, the geoprocessing model had substantial difficulty discerning stream segments and subsequent stream order. Much care was necessary in doing quality control in these areas.

Braided streams and alluvial fans

The methodology for the automated process requires a network of single line streams. Braided streams and alluvial fans with interlaced ephemeral channels do not always conform to this model and posed a challenge. Consequently, post-model drainage basin boundaries had to be manually adjusted to encompass the extent of alluvial fans and the width of braided streams. Alluvial fans were treated as multiple outputs, similar to coastline features such as deltas, and the watershed boundary adjusted based on the USGS standards (USGS and USDA, 2013). With braided streams, enclosing the width of the stream and ensuring the watershed did not mistakenly flow upstream, were part of the manual adjustment process. The DEM and Flow Direction rasters were used as a guide in doing these corrections.

Remnant watersheds

Remnant watersheds are residual watershed areas that occur around the main stem of streams, after delineating adjacent watershed boundaries. As per the USGS standards (USGS and USDA, 2013), these remnant watersheds were merged along the main stream stem until intersecting with a higher stream order watershed.

QUALITY ASSURANCE

To test the validity of the geoprocessing model, DEM and hydrology data were downloaded for a mountainous region of Idaho, which had topography similar to that seen in the study area. The model was run using these data as inputs, and the output drainage basins compared to the products available from the National Watershed Boundary Dataset (WBD). The DEM, hydrology, and watershed boundary datasets are all available from the Geospatial Data Gateway of the USDA, Natural Resources Conservation Service. The watersheds in the WBD are not delineated by stream order; however the post-model watersheds were comparable and closely aligned with the WBD watersheds.

The model-derived watersheds were also compared to the NHN Work Unit boundaries, which are at a 1:1,000,000 scale and approximately equivalent to a 7th or 8th stream order watershed. The two datasets aligned very well with only a few discrepancies. These discrepancies were checked with the stream network, DEM, and flow direction data to inspect if any further manual adjustments to the model-derived watersheds were needed.

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