Remote sensing of vegetation land covers as a template for monitoring and assessment of aquatic resources in Gates of the Arctic National Park

Prepared for

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Under

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Project Study Area

Gates of the Arctic National Park and Preserve (GAAR), located in the central Brooks Range of Alaska, was established in 1980 as a protectorate of large undeveloped ecosystems. GAAR, well known for its extensive wilderness and diverse ecotypes, encompasses approximately 8.2 million acres of public lands with 7.2 million acres designated as wilderness area. The Park adjoins with the 5.6 million acre Noatak National Preserve on the Western border making the area one of the world's most extensive and un-visited protected areas.

Due to this large expanse of terrain, the National Park Service is continually seeking methods by which ecosystems (both aquatic and terrestrial) may be observed and monitored rapidly and at reduced cost while maintaining accuracy standards. It is within that framework that this project was initiated.

1.0 Project Objectives

<u>Primary Objective:</u>
The National Park Service and various state and federal organizations have collected a variety of spatial and synoptic data for Gates of the Arctic National Park and Preserve. It was proposed to use these previously collected remotely sensed images and existing spatial data layers for GAAR region to develop and assess techniques of cataloguing aquatic ecosystems and classification of catchments. The study will analyze results and determine if existing NPS GIS coverages are adequate for such an analysis.

2.0 Project Funding Participants

This project is funded under the Rocky Mountains Cooperative Ecosystem Studies Unit RM-CESU Cooperative Agreement Number: CA-1200-99-007. The project participants include Dr. Chris Luecke Utah State University; Diane Sanzone, National Park Service; and Christopher McGinty, RS/GIS Laboratory at Utah State University. The Appendix of this report contains contact information and additional participant contact information.

3.0 Data Collection and Pre-Processing

The concept behind this project was to utilize currently available GIS and remotely sensed data. Many national parks are known to have large data holdings available to scientists and researchers. At the time this project was started, much of the data was unavailable or difficult to obtain due to the lack of digital access or data restrictions thus creating a data-poor environment for analysis. However, as the completion date of this project has neared, additional data layers have become available via various sources and incorporated into this analysis. Listed below are the available data and the steps taken to process said data for analysis.

3.1 Digital Elevation Models & DEM Products

While data-rich in many respects, large areas of Alaska, such as Gates of the Arctic National Park, are often without continuous datasets. One of several data sources that were found to occur continuously across the study area are Digital Elevation Models (DEMs). These datasets, while seemingly only to represent elevation, have allowed for the extraction of a number of variables that will enhance the ability to catalogue aquatic systems.

The DEMs utilized for this analysis were downloaded as a subset of the National Elevation Dataset (NED) from the United States Geological Survey Seamless Data Distribution System (http://seamless.usgs.gov). The spatial resolution of NED DEM data for the state of Alaska is $60m^2$.

The data were acquired in tiles as ESRI ArcInfo Grid format and imported using ArcGIS 9.1. The raw grids were mosaiced together using Erdas Imagine 9.1, however this process could have been completed within the ArcGIS environment. The resulting Imagine (.img) file was exported via the Direct Write command to the ESRI GRID format. The mosaic was projected to meet the standards of the project (Alaska Albers, NAD83) see Appendix for detailed projection parameters.

Prior to analysis, pre-processing steps must be taken in order to perform hydrologic and watershed modeling upon DEMs. To aid in processing efficiency and storage, the GAAR DEM was converted from a floating point to integer format. This step reduced the DEM file size by 50 percent, 202.28 and 101.14 megabytes respectively (See Figure 1).

Analysis was initially completed using command line ArcInfo and ArcInfo Grid methods. These methods were automated using the ArcHydro toolset for ArcGIS developed by research scientists at the University of Texas at Austin (http://www.crwr.utexas.edu/giswr/hydro/ArcHOSS/index.cfm). The toolset allows for the rapid processing and delineation of aquatic features such as streams and catchments.

DEM conditioning must be preformed on DEMs that are to be used in hydrologic modeling. While several steps could be taken, due to the nature of the grid resolution, it was deemed that the FILL command would perform sufficient conditioning. The FILL command "fills" pits and holes within the elevation data that result from interpolation, rounding of elevation values, and the resolution of the data (Tarboton and Rodriguez-Iturbe 1991). This process creates a hydrologically continuous surface upon which water can "flow" within the GIS landscape. Without this process stream networks defined with the GIS would stop or break at the points where errors within the DEMs occur.

From the filled DEM, the flow direction grid can be derived. Within the flow direction grid, each pixel or cell is assigned the value that water will most likely flow. The direction is assumed to be in the direction of the neighboring cell with the largest downhill elevation change from the cell of interest. For example, if water is poured onto the blank center cell in Figure 2, and the steepest downhill gradient exists between the center cell and the cell directly above it (north), then the value of the center cell will be 64. Figure 2 depicts the possible values assigned to each of the compass directions.

The flow accumulation grid is calculated from the flow direction grid. The flow accumulation process determines for each cell within the DEM, how many other cells are flowing into it. Values within this grid can range from 0 contributing cells (hilltop cells) to millions of cells (large river basins). This information is valuable for several reasons. First, it can be used to define stream networks within an area where a cartographic description of stream networks has not yet been well defined. Second, the flow accumulation grid can be used to give us a continuous map of drainage areas for all stream locations across the entire park boundary by using the knowledge of the spatial size of the cells and the value of each flow accumulation cell.

Stream definitions are created from the flow direction grid. While stream data layers may exist having been digitized via satellite or aerial imagery, this method allows for the extraction of potential streams sites directly from the DEM. Stream definitions are grid cells that are considered to drain a certain defined amount of area. It is thought, based upon streams delineated on 1:24,000 USGS quadrangle maps, that these areas will also potentially have flowing surface water at some point during the warm season. While highly dependent upon climate, latitude, elevation, geology, and landcover it is thought, as a rough estimate, that cells receiving contribution from approximately one square kilometer (~1 Km^2) will contain flowing water. It should be mentioned, however, that there are multiple methods for determining the number of contributing cells needed to contain water and set the threshold value, and the method used here is not optimized. Due to the size of the study area, this analysis will assumes, at the spatial resolution of $60m^2$, a cell that receives drainage area corresponding to 300 grid cells, will most likely contain flowing water at some point. In addition to creating a stream definition that will possibly contain flowing water, the stream definitions will be utilized to delineate catchments, see figure x. For display purposes, the potential water courses have been aggregated into larger stream segments, see figure x.

Catchments can range in size based upon the methods and analysis type. Due to the size of the GAAR study area, it would be difficult to use exceedingly small catchments for analysis. Using the stream definition of approximately 300 grid cells (~1 Km^2), there would be several thousand catchments across the GAAR study area. While this would be adequate for a fine scale analysis, it is not practical for this study. A stream definition of 250 Km^2 was created to generate catchments that would be of practical size for classification analysis within this project, see Figure 3.

Following catchment delineation, slope and aspect grids were created to support analysis. The grids were created using ArcGIS 9.1 slope and aspect functions, and incorporated an area of interest mask layer for grid cell coincidence, see figures 4 and 5.

Given the limited amount of geospatial information available for the GAAR region, digital elevation models were the primary source of data used to derive the above grids. Despite the limitations, the above grids represent a set of variables that are proving to be important for modeling biological assemblages for bio-assessment and monitoring within the lower 48 states. They are assumed to represent surrogates for the environmental setting at the stream in a rough sense. For example, drainage area gives an indication of the size of the river and therefore indicates a variety of environmental settings based on the ideas of the River Continuum Concept (RCC; Vannote *et al.* 1980).

3.2 Digital Imagery: Landsat 7 ETM+ and Landcover

Analysis originally called for the creation of a landcover classification layer to help identify differences in catchments. Landcover is often descriptive of soil-types and management, or natural, events occurring within a specified area. Landcover classifications are typically based upon a number of different methods including manual aerial photo interpretation, unsupervised classifications, and supervised classifications. In this case two methods were available: the first was to acquire digital imagery for the GAAR area and complete a semi-supervised classification; the second would utilize a former supervised classification created by the National Park Service GIS Team at the Alaska Regional Office in Anchorage. Both methods were considered until benefits of data and accuracy of one method exceeded those of the other.

The semi-supervised classification was attempted using Landsat ETM+ 30-meter multispectral data. This data was collected from the Alaska View website which is part of the America View program (http://glovis.gina.alaska.edu). The data collected represented one year, 1999, but were spread across three dates in June, July, and August. Images were of fair quality; however, significant seasonal differences were apparent across the study area. These issues proved significantly challenging due to the factors of latitude (sun angle), cloud cover, shortness of the snow-free season, and sensor path and acquisition schedule. The project also coincided with the Landsat 7 ETM+ scan line corrector (SLC) failure which also limited the collection of newer Landsat digital imagery.

Following collection, the data were imported from .hdf files into Erdas Imagine 9.0 for processing. Each image was projected into an Albers Conical Equal Area Projection to match the DEM data, see appendix for detailed projection information.

Each image was independently standardized using the COST without Tau (Dark Object Subtraction) method (Chavez 1996). Image standardization is critical to account for differences in pixel values due to sun illumination geometry, atmospheric effects, and instrument calibration. COST without Tau was utilized based upon tests by the Remote Sensing / Geographic Information Systems Laboratory at Utah State University showing that for ETM scenes, in more northerly latitudes where solar zenith angles are a higher, the standardization method with Tau present is significantly overestimated.

The six images that covered the GAAR study area were mosaiced together and subset to the study area boundary. Using Erdas Imagine 9.0, landcover signature sets were derived from known landcover such as water, bare rock, dwarf shrub, low shrub, and tall and low willow. It quickly became obvious that these were only a small number of the classes that would be required to generate a complete landcover map. Additional problems became apparent with respect to north aspect slopes and shadow areas. These areas appeared, spectrally, identical to deep/dark water areas and thus significantly reduced accuracy.

The landcover map created by the NPS GIS Team was completed in 1990 and was comprised of Landsat TM (Landsat 5) data with a spatial resolution of $30m^2$. Available metadata did not describe methods of data creation or a subsequent accuracy assessment. Although the dataset is more than 15 years old it was the best option based upon the previous test, the dataset mapped multiple landcover types, see figure 9.

3.3 Geology

Geology is often a strong indicator of surface processes (Personal Communication, Green 2006). A surficial geology layer was created for GAAR by the National Park Service regional office in Anchorage between 1975 and 1987. The geological types were collected using helicopter-supported field mapping of the central Brooks Range and foothills. Sampling and mapping was completed by the NPS and United States Geological Survey (See Figure 6). The data was downloaded from http://www.nps.gov as an Arc Interchange File (.e00) and imported using ArcGIS 9.1. The data were reprojected to match the study projection and converted to GRID format for analysis.

3.4 Additional Data

As has been recognized in many analyses, anthropogenic boundaries can induce limiting factors on biophysical studies by applying false areas of influence. These bounding areas should be recognized as not merely the edge of a study site, but the continuum of the region as a whole. As such the Gates of the Arctic National Park boundary was not used as study area per se, but was allowed to extend beyond the region so that complete catchments could be included in the analysis, see figure 3. These catchments were identified starting at 0 and ranging to 106. Some catchments extended beyond the 15 kilometer geology and landcover buffer employed by the NPS GIS Team, those areas were analyzed based on a whole, but excluded the areas of no-data where landcover or geology data were not available.

4.0 Analysis Methods and Processing

Due to the nature of the project, data types were limited to free, readily available, and previously collected information. These limits placed restrictions on the analysis, however, they provided a well defined framework for what could be delineated and determined from the available data and analysis techniques.

4.1 Methodology

The primary goal was to generate a method by which catchments, over a large area, could be delineated and clustered based on similar biophysical and remotely sensed variables. The methodology was outlined in such a way as to promote a transparent, repeatable, and efficient analysis system.

- Data Collection & Pre-processing
  - Digital Elevation Models
    - Download
    - Import
    - Mosaic
    - Process
    - Subset
  - Landcover
    - Download
    - Import
    - Project
- Data Processing
  - Process DEM for anomalies
  - Generate slope from DEM
  - Generate aspect from DEM
  - Delineate catchments and stream definitions from DEM using ArcGIS ArcHydro Toolset. This process can be completed at multiple scales depending upon desired catchment size.

    - Perform zonal statistics (tabulate areas) based upon available Grids and catchment zones
    - Analysis
- Repeat or Report
    - Complete analysis
    - Re-run analysis if needed
    - Verify via accuracy assessment (if applicable)
    - Generate report of catchment similarity

4.2 Data Extraction and Display

Project analysis was based upon catchments, or zones, as shown in figure 3. Each catchment was given a unique identifier starting at 0 ranging up to 106. Using these catchments, each grid layer was processed for mean (elevation, slope, aspect), maximum (flow accumulation) and percent area type (geology, and landcover) values. These values were extracted using the Tabulate Areas and Zonal Statistics functions of ArcGIS 9.1 and the Zone Sample function in the StateModZone (Garrard 2002) ArcView 3.3 extension with minor Microsoft Excel computations for percent landcover and geology. See appendix for complete catchment assessment tables.

Each analysis variable was joined, using the catchment identifier, to the study catchment shapefile. These joins resulted in maps of each variable.

4.2.1 Figure 10

Figure 10 identifies mean catchment elevation. The mean elevation for each catchment was calculated using the Zonal Statistics utility in ArcGIS 9.1. The mean elevations were related to each catchment and displayed using a classified display method with breaks at 150 meter intervals, see figure 10. Catchment elevation gives a indication of the temperature regime at the each stream location. In addition, it may indicate whether or not the stream area thaws during the year (specific to Alaska), how late it thaws and how early the location around the stream freezes. The mean elevation of the catchment provides a significant amount of information with respect to the terrain within the catchment.

4.2.2 Figure 11

Figure 11 identifies mean catchment slope. Because slope estimates of stream channels are problematic and have been shown to be both inaccurate and imprecise. Calculated here is the mean slope for the entire catchment (all pixel slope values within the upstream catchment). This value is thought to indicate the general energy available within the catchment and also the sediment-production potential of the catchment. The mean slope for each catchment was calculated using the Zonal Statistics utility in ArcGIS 9.1. The mean slopes were related to each catchment and displayed using a classified display method with natural breaks, see figure 11.

4.2.3 Figure 12

Figure 12 identifies mean catchment aspect. Although aspect has not been found to be significantly critical in large watershed analysis, it may be critical due to the location of GAAR. Aspects in all regions produces different microclimates, however those microclimates may be exaggerated in northern

Alaska due to seasonal sun-angle orientation. Mean aspect values were calculated using the Zonal Statistics utility in ArcGIS 9.1. The mean slope values were then related to each catchment and displayed in compass bearings, 0°, 90°, 180°, 270° equating to North, East, South, and West respectively, see figure 12.

4.2.4 Figure 13

Figure 13 identifies the maximum flow accumulation, or drainage area, for each catchment. As discussed above, drainage area provides a simple indication of the size of the water course within a catchment and therefore could indicate the tropic setting, hydrologic stressors, potential nutrients, and temperature stability. Flow accumulation was crated using the ArcGIS ArcHydro toolset and is displayed as the maximum number of square meters drained per catchment in figure 13.

4.2.5 Figure 14

Figure 14 identifies the major landcover by percent area. This value was calculated by summing the total number pixels for each landcover for all catchments and then divided by the total area of each catchment. The major landcover was identified and mapped. This variable, why useful to managers for numerous reasons, was not directly used in catchment analysis. Rather, all landcover values were input as measures in the clustering methods used. This was done to avoid biasing a catchment towards any one single landcover when, in fact, there may be multiple landcover types that occur across a single catchment.

4.2.6 Figure 15

Figure 15 identifies the major geologic type by percent area. This value was calculated by summing the total number pixels for each geology type for all catchments and then divided by the total area of each catchment. The major geologic type was identified and mapped for each catchment. This variable, why useful to managers for numerous reasons, was not directly used in catchment analysis. Rather, all geology values were input as measures in the clustering methods used. This was done to avoid biasing a catchment towards any one single geologic type when, in fact, there may be multiple geology types that occur across a single catchment. It should be noted that perhaps a better measure of catchment geology, with respect to clustering, would have been to buffer the stream network and calculate values within that buffer and not across the entire catchment. As seen in figure 15, due to the course nature of geology type mapping, a majority of the catchments were identified as being predominately bedrock. Figure 8 shows that valley bottoms have been mapped in greater detail, resulting in more diverse geological types.

4.3 Cluster Analysis

While a number of analysis methods were available, it was thought that a clustering analysis would be the best statistical test to group catchments based upon available data. After evaluating multiple clustering methods, Ward's method was the chosen analysis method. Ward's seeks to join clusters in which the within-cluster sum of squares (i.e. within-group variance) is minimized. This leads to the tendency for the method to produce equal-sized clusters that are convex and compact (Lattin et al. 2003).

Variables were input into a text file and imported into the R statistical packaged via the read.table call. The data were standardized using the Euclidean distance measure and a cluster dendrogram (figure 16) was created using the hclust call. Multiple means exist to determine the proper number of clusters, however many of these methods require first-hand knowledge of the study area in question. Due to the lack of first-hand knowledge, two cluster maps were created using five and ten clusters, see figures 17 and 18 respectively. It should be noted that to accurately complete this analysis, further analysis of the clusters should be completed.

5.0 Discussion

The *theory* behind a cluster-based analysis utilizing previously collected remotely sensed images and existing spatial data layers for the GAAR region to develop and assess techniques for the classification of catchments appears to be sound. It may not, however, support a fine scale cataloguing of aquatic ecosystems due to scale issues and the general data reliability (i.e. landcover classifications.)

In answering the question as to whether or not the <u>freely available GIS and remotely sensed data would be useful in providing a reasonable assessment of the general characteristics of catchments</u>, the conclusion is a guarded "yes". Visually, to the eye, the analysis appears to extract differences. Statistically speaking, those differences appear in clusters, but should be evaluated based upon further, and varied, statistical assessments.

The topic of spatial-autocorrelation has not been discussed here, but should be mentioned and kept in mind when observing these clusters.

Further analysis should be completed.

Appendix of Figures

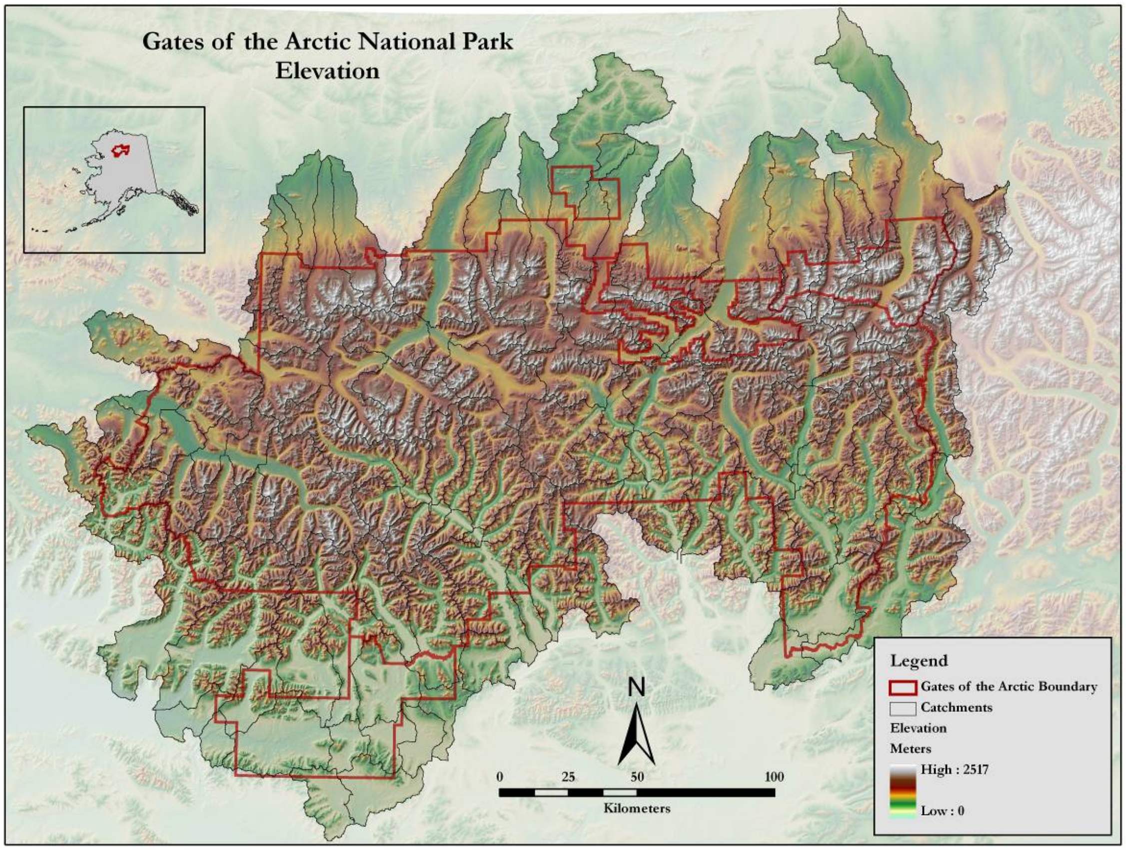

Figure 1: GAAR Digital Elevation Model (Meters)

32	64	128
16		1
8	4	2

Figure 2: Flow Direction

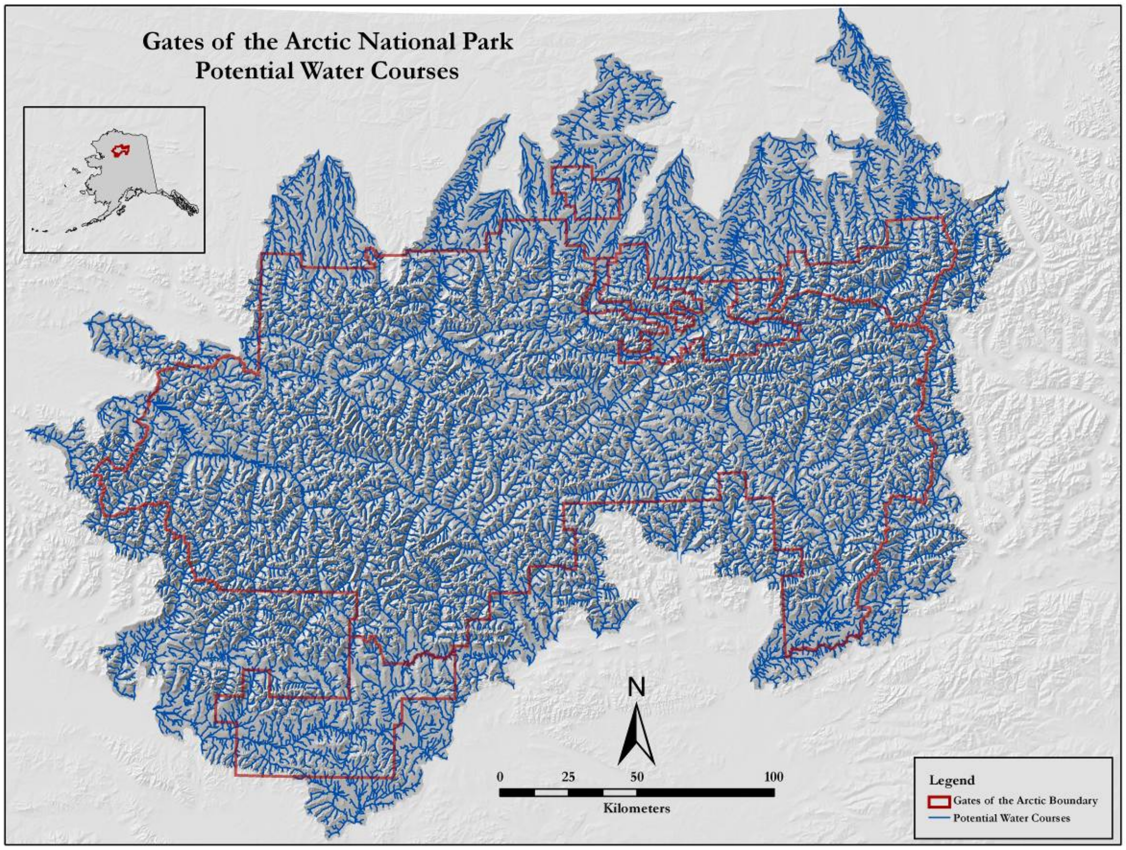

Figure 3: Potential Water Courses

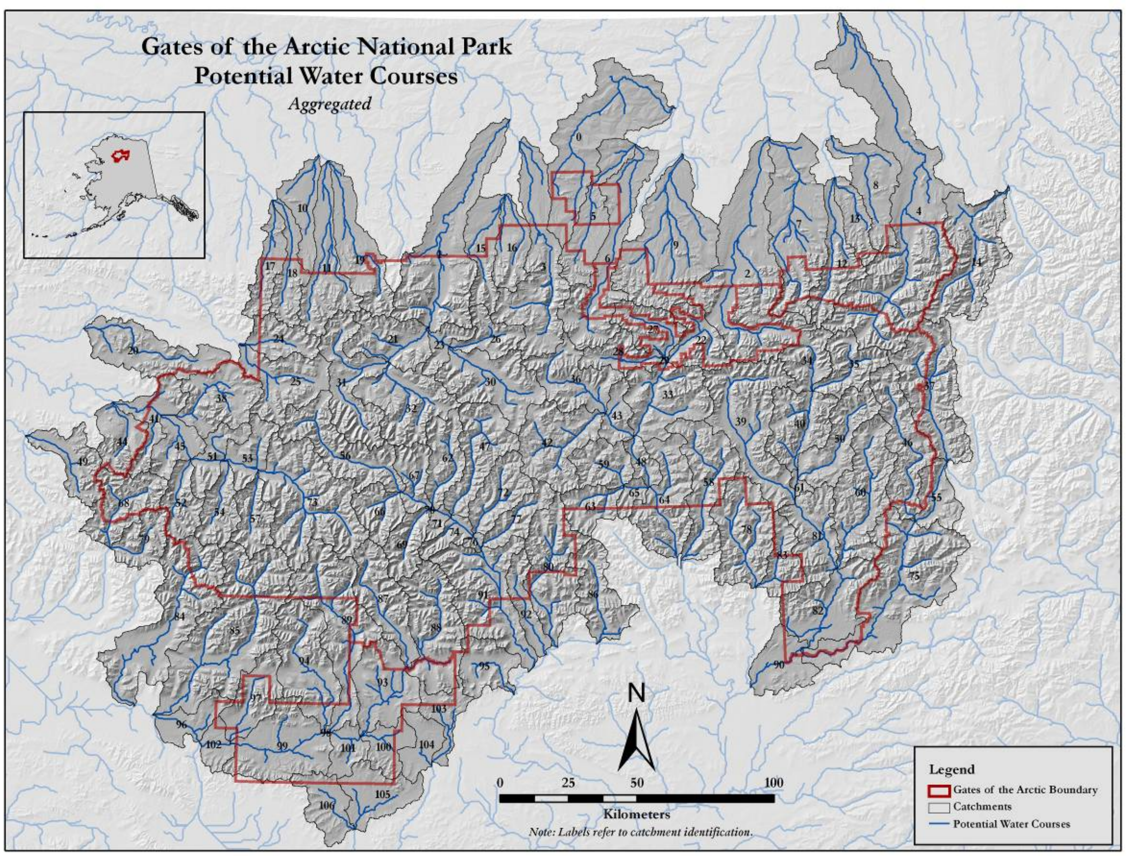

Figure 4: Potential Water Courses, Aggregated

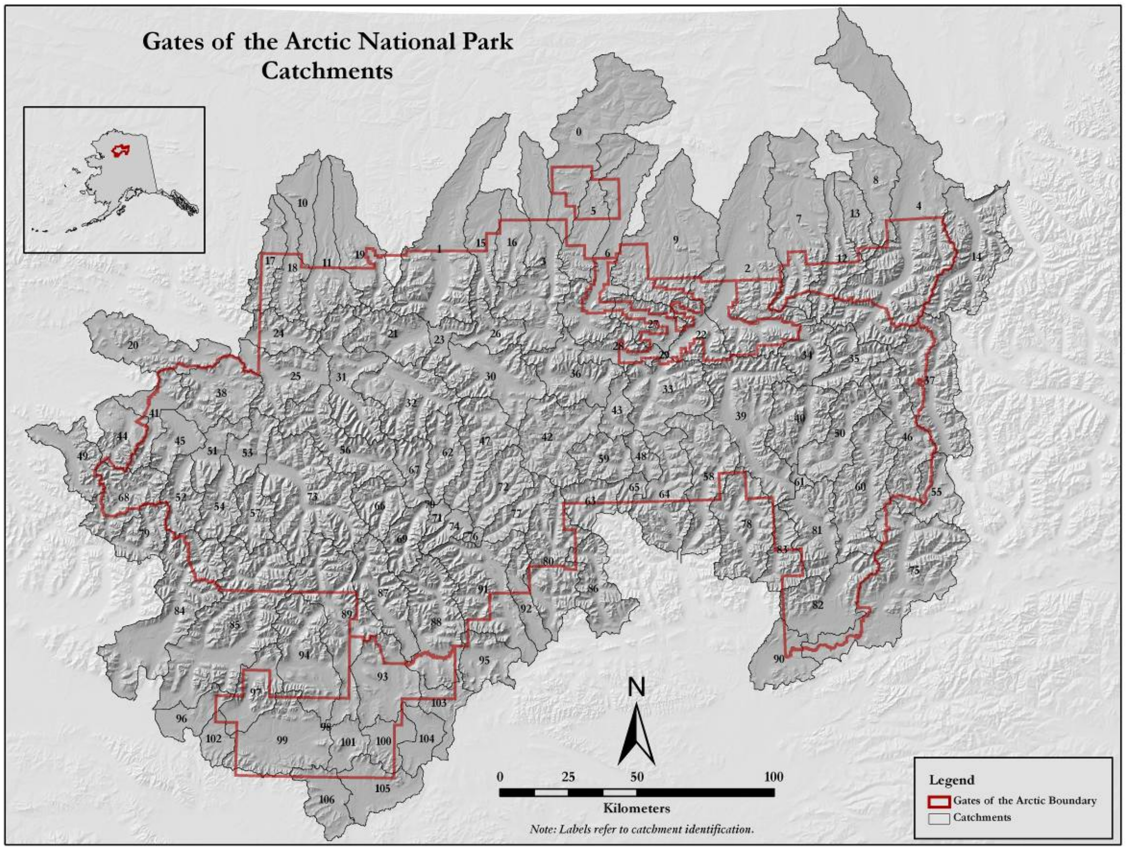

Figure 5: Delineated Catchments

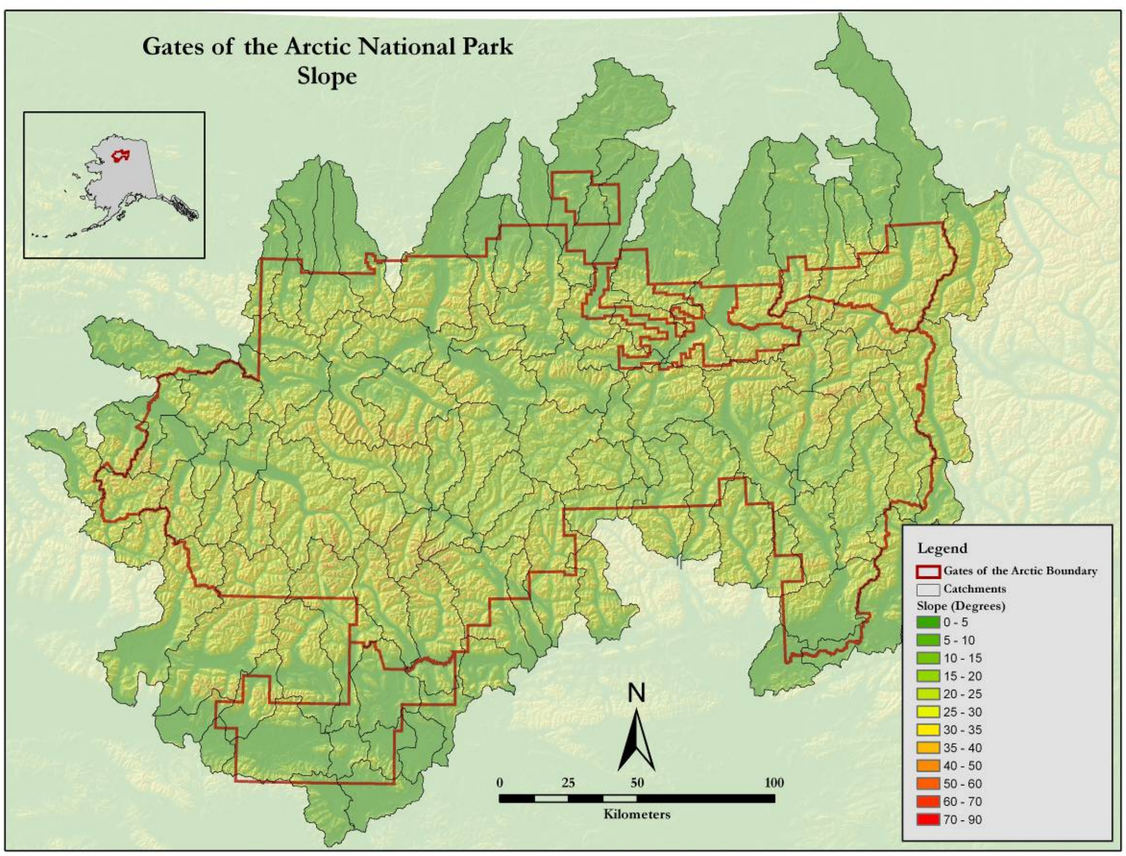

Figure 6: GAAR Slope (Degrees)

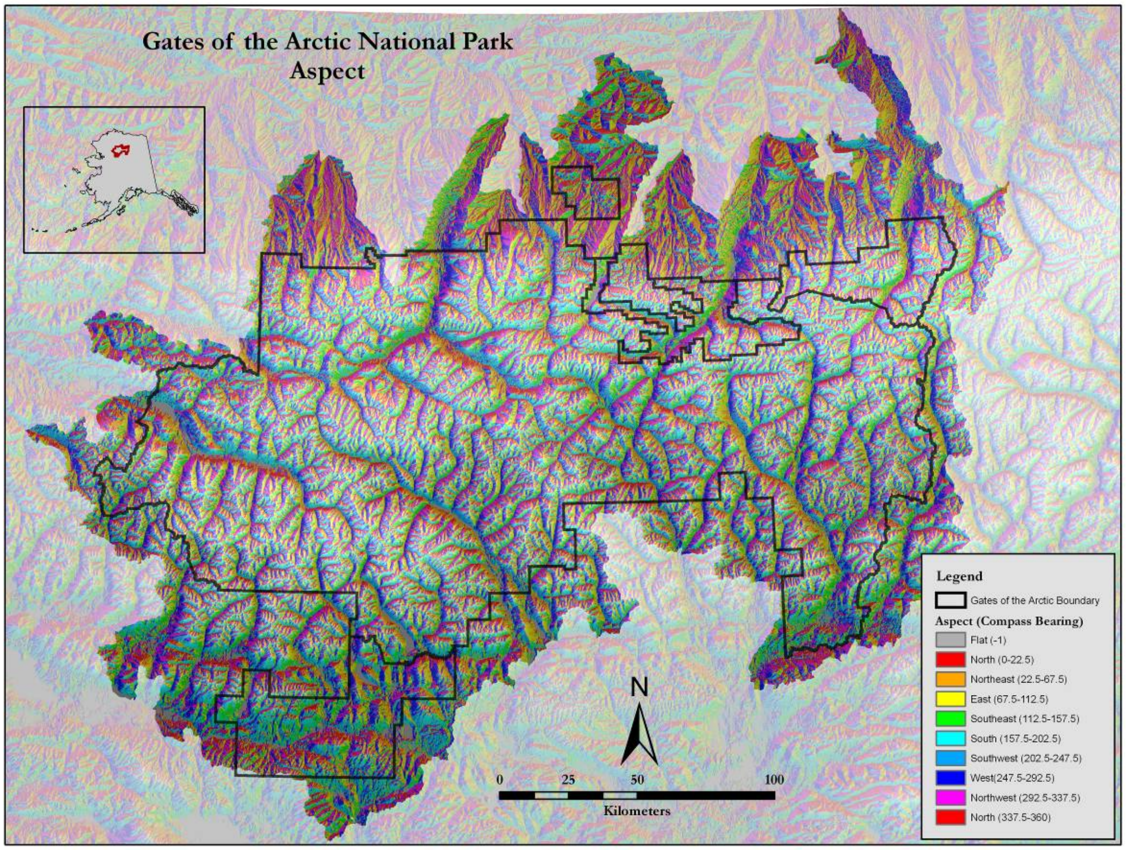

Figure 7: GAAR Aspect (Compass Bearings)

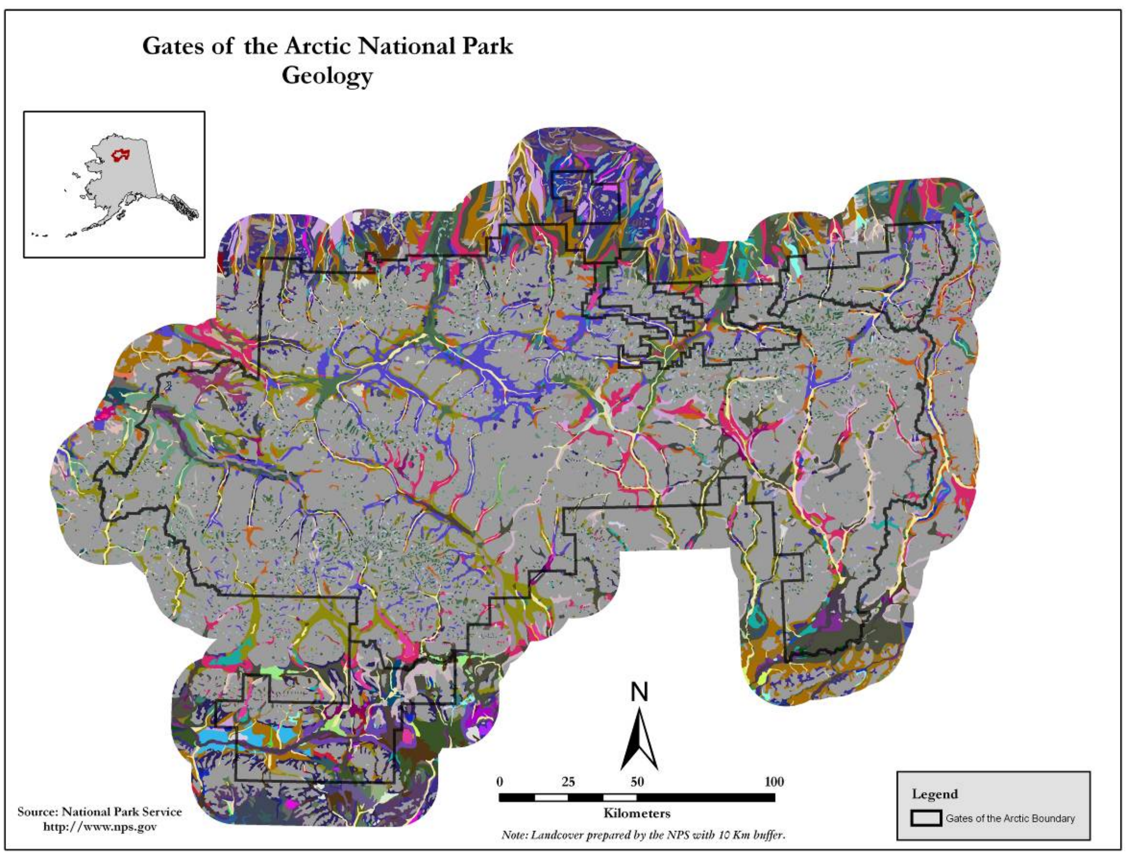

Figure 8: GAAR Geology (Majority geology type is bedrock)

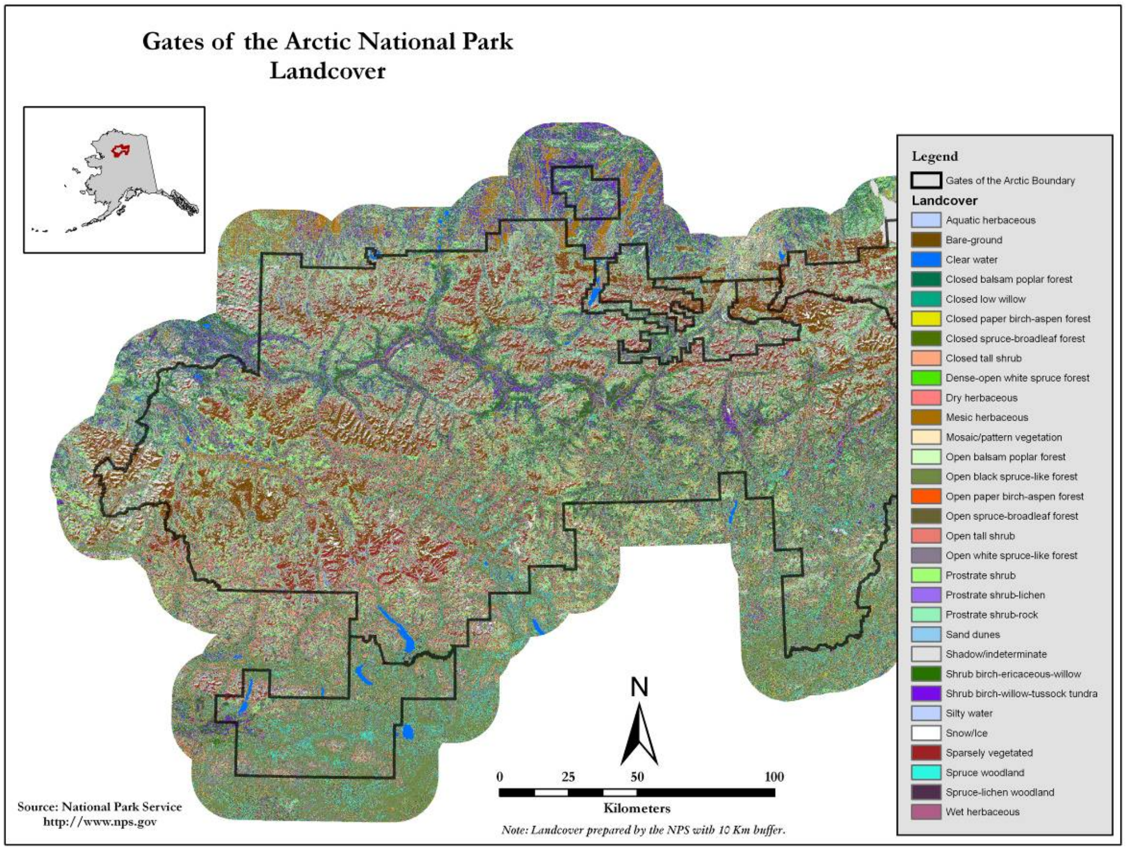

Figure 9: GAAR Landcover, National Park Service

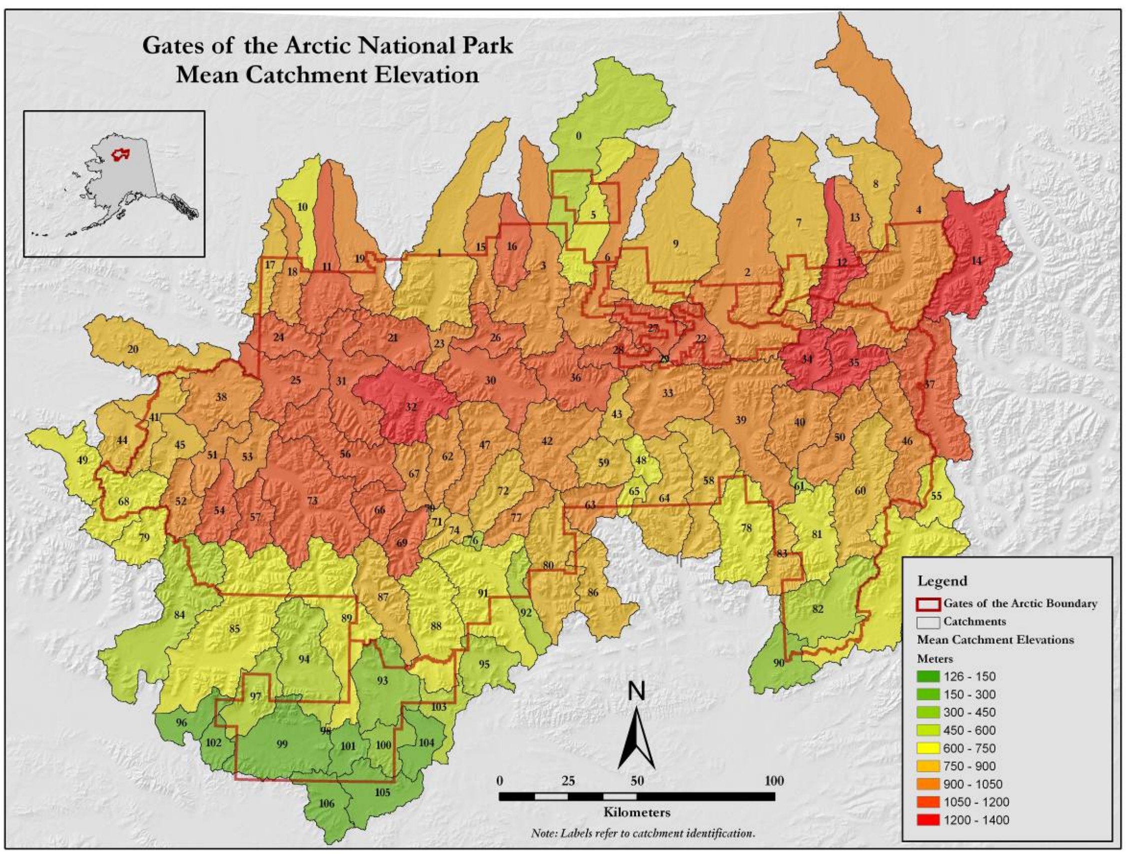

Figure 10: GAAR Mean Catchment Elevation (meters)

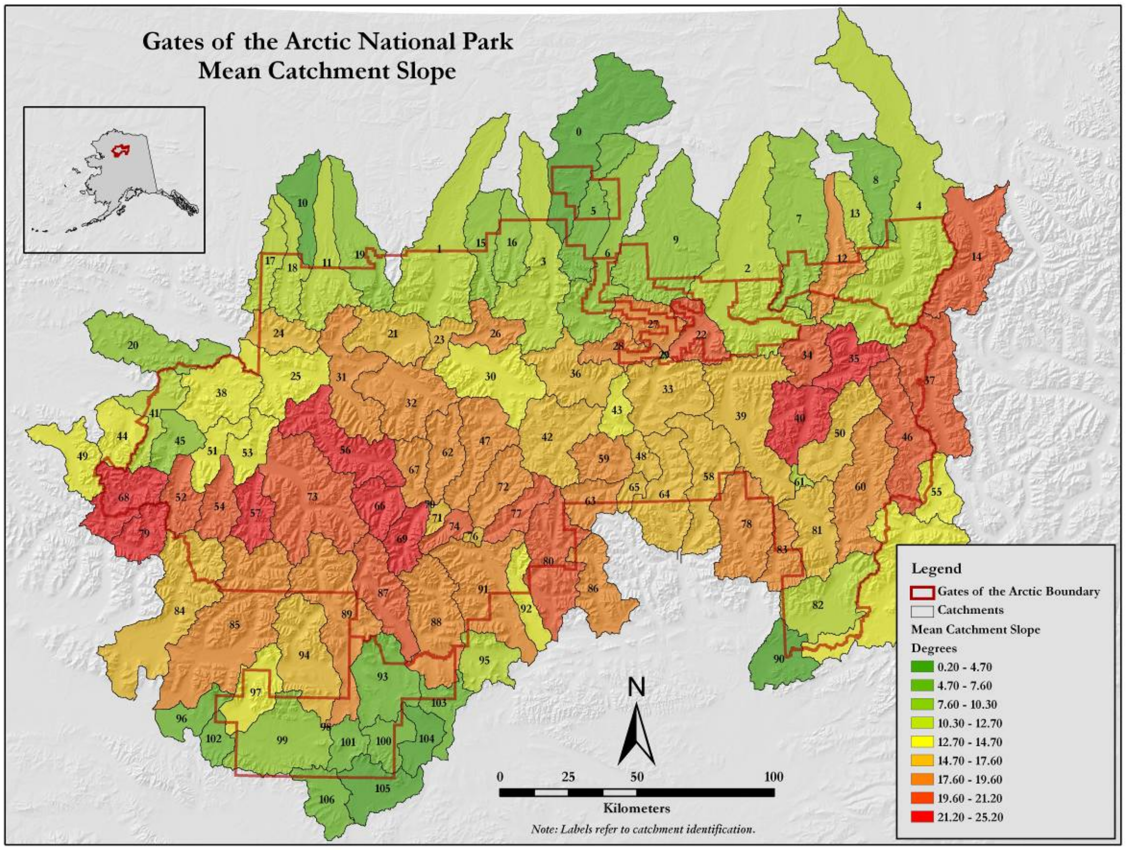

Figure 11: GAAR Mean Catchment Slope (degrees)

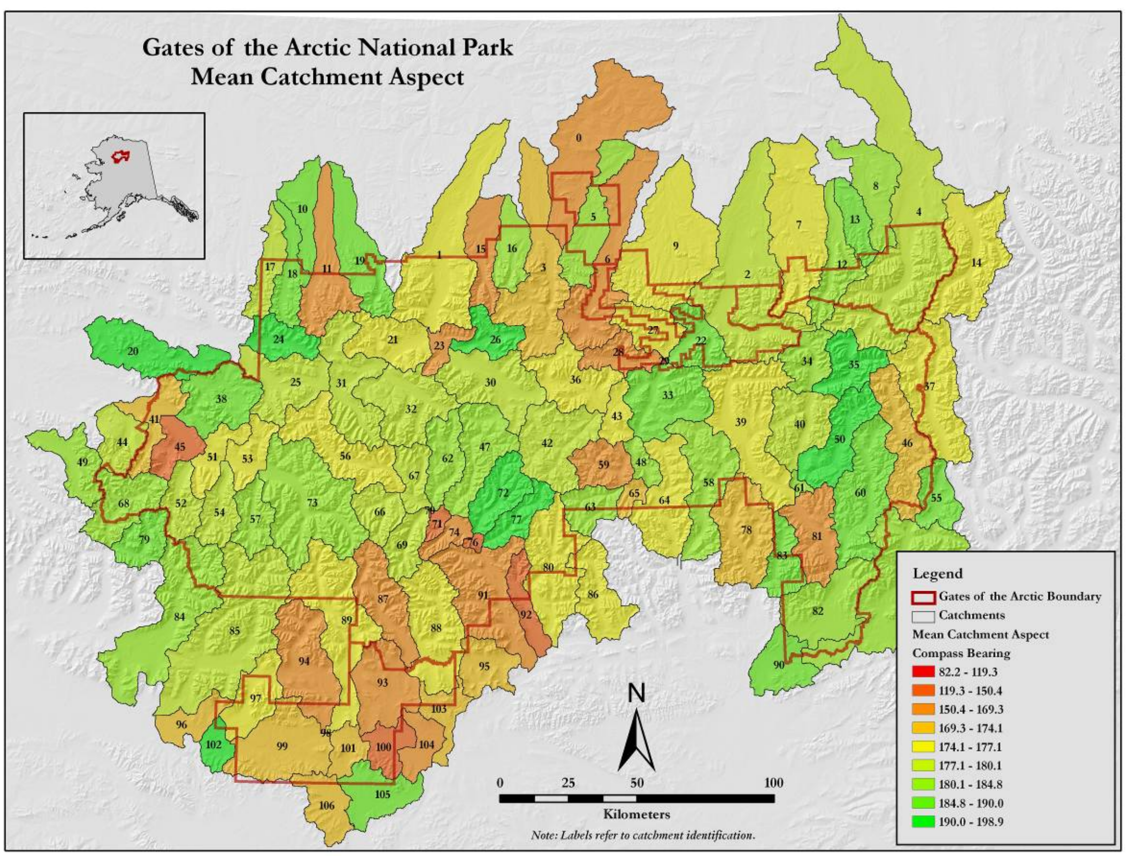

Figure 12: GAAR Mean Catchment Aspect (Compass Bearing)

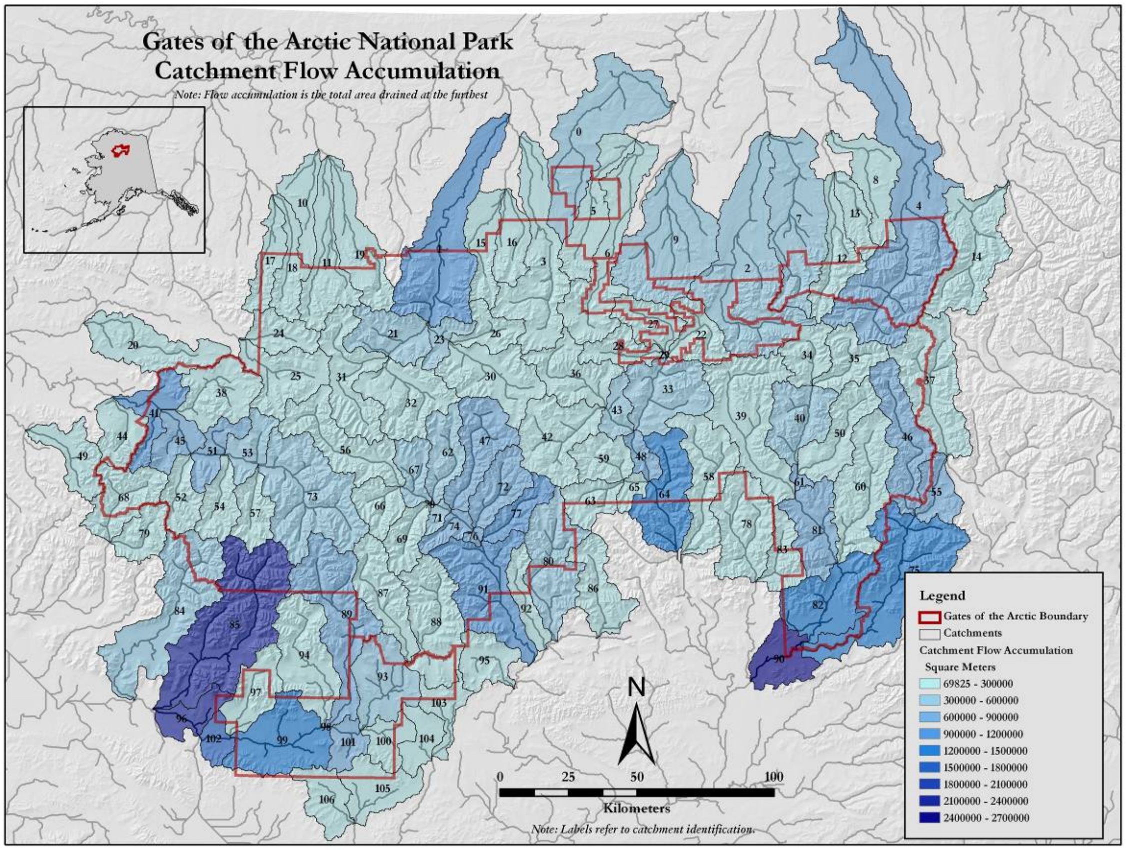

Figure 13: Maximum Catchment Flow Accumulation (square meters)

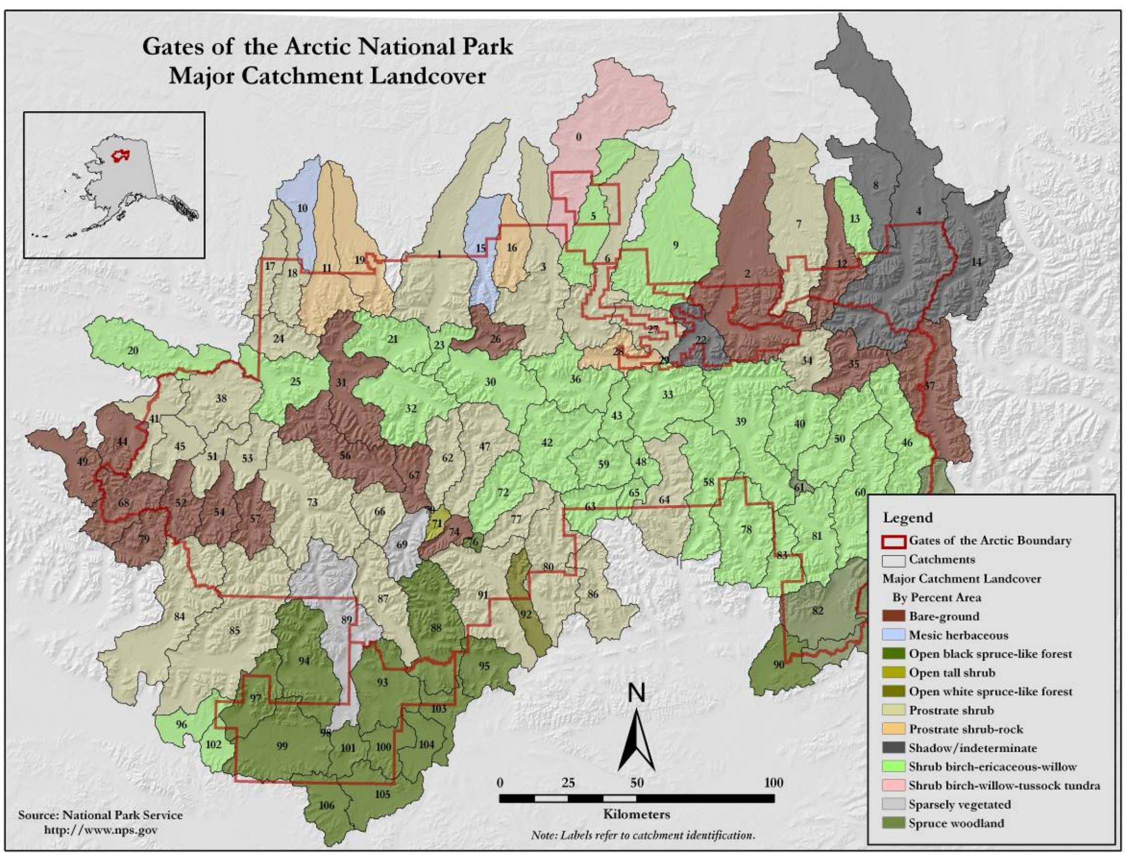

Figure 14: GAAR Major Landcover (by percent area)

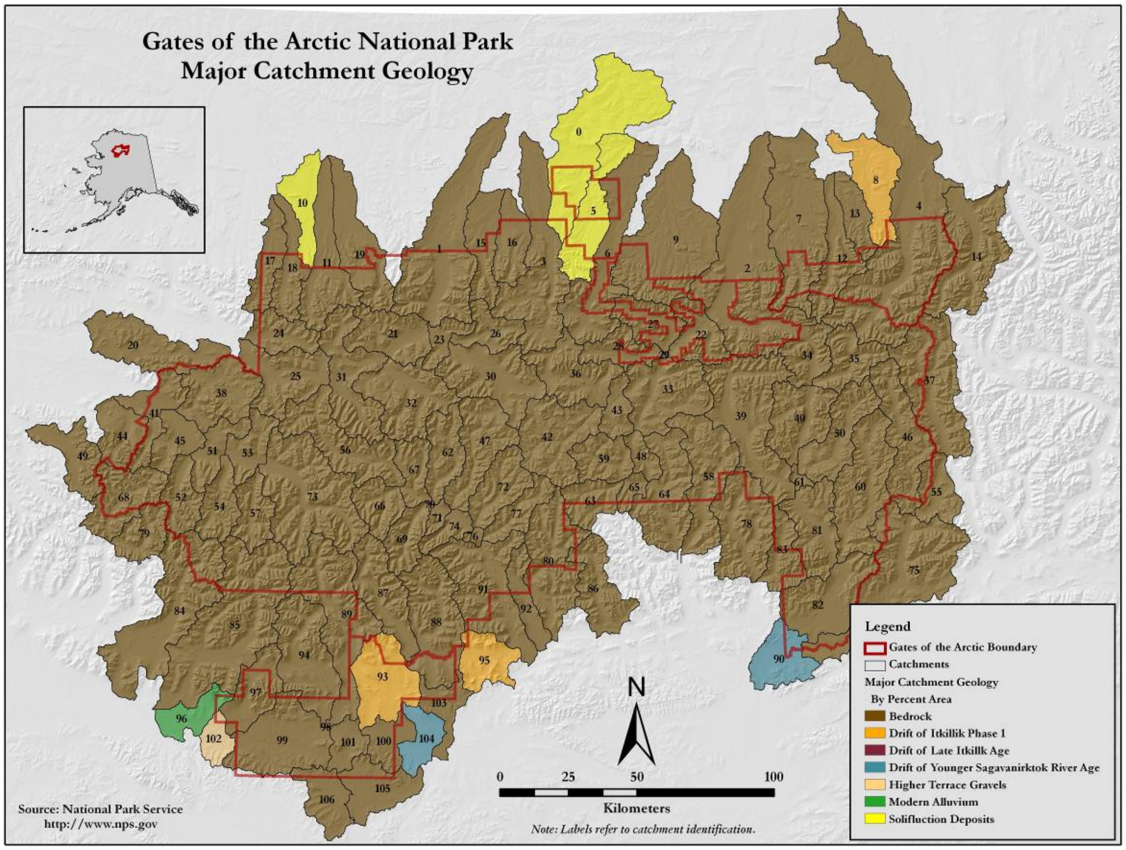

Figure 15: Major Geology Type (by percent area)

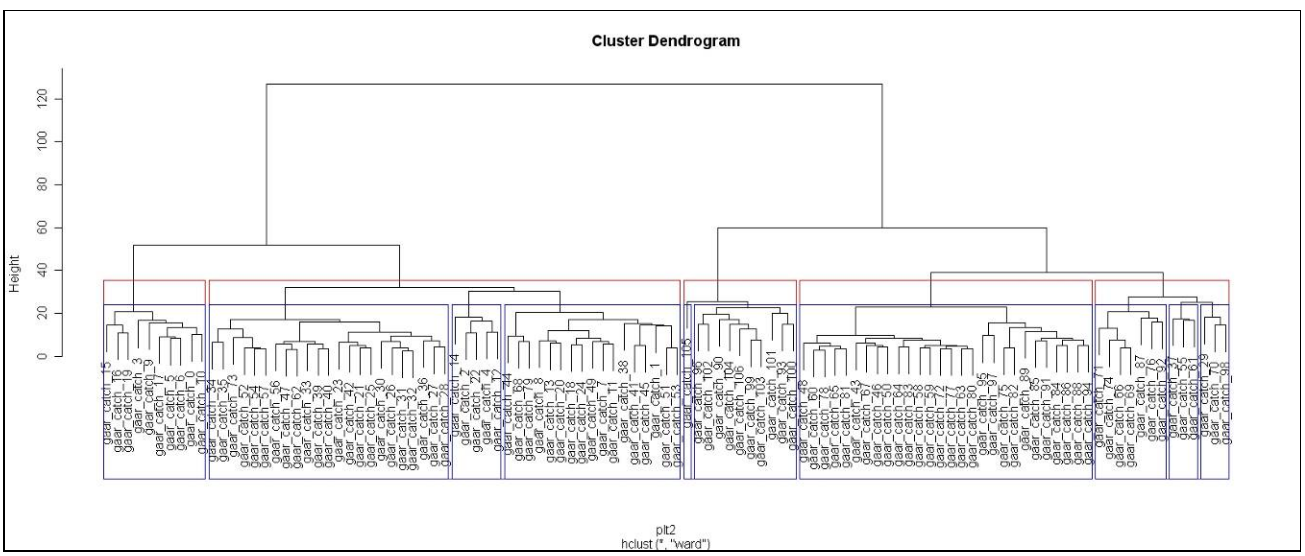

Figure 16: GAAR Cluster Dendrogram (Red = Five-Cluster, Blue = Ten-Cluster)

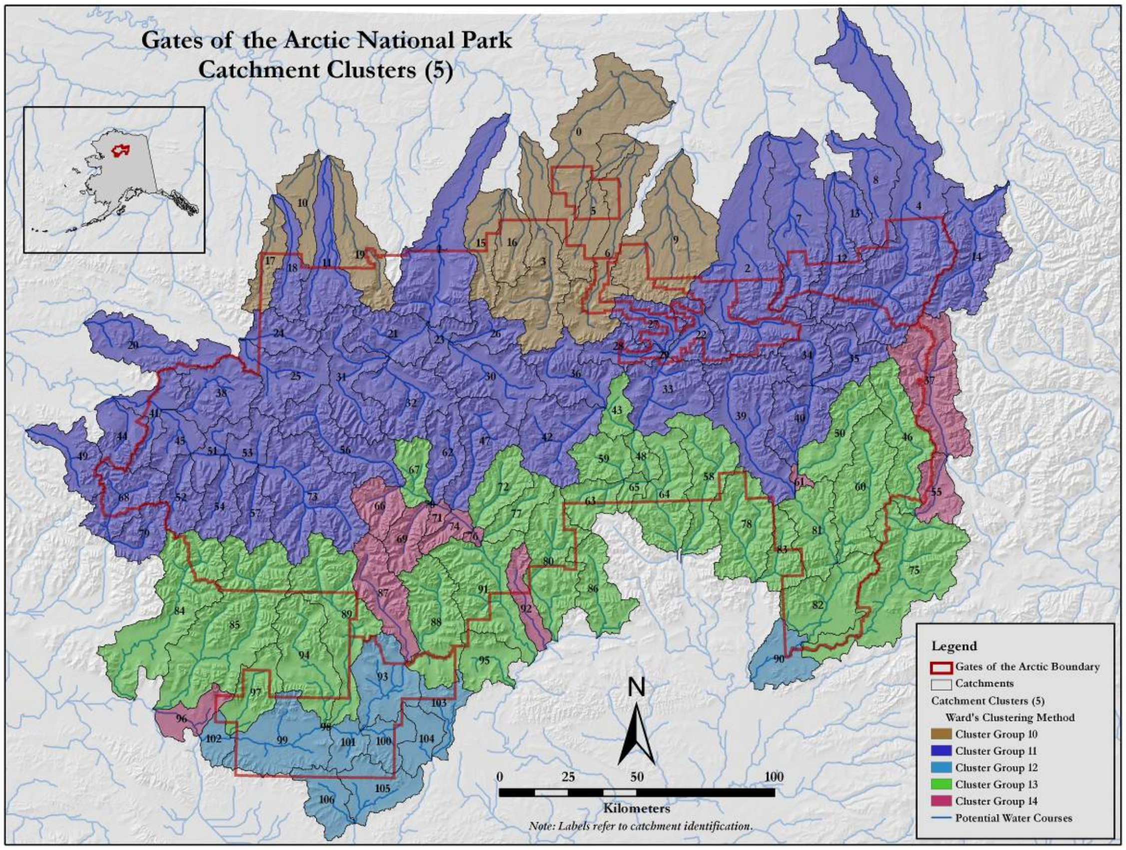

Figure 17: GAAR Catchment Clusters - Five Groups

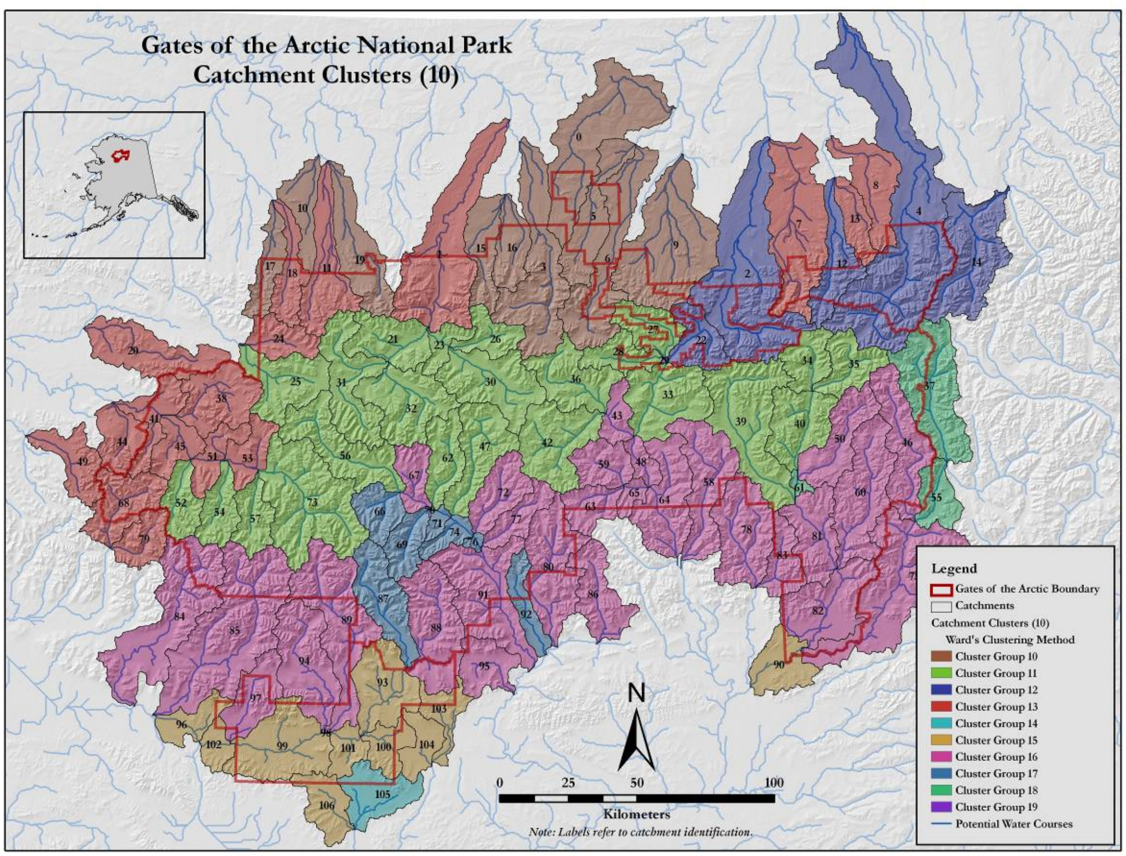

Figure 18: GAAR Catchment Clusters - Ten Groups

Appendix

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Study Area Projection

Horizontal coordinate system
Projected coordinate system name: NAD_1983_Albers
Geographic coordinate system name: GCS_North_American_1983
Map Projection Name: Albers Conical Equal Area
Standard Parallel: 55.000000
Standard Parallel: 65.000000
Longitude of Central Meridian: -154.000000
Latitude of Projection Origin: 50.000000
False Easting: 0.000000
False Northing: 0.000000
Planar Coordinate Information
Planar Distance Units: meters
Coordinate Encoding Method: coordinate pair
Coordinate Representation
Abscissa Resolution: 0.000512
Ordinate Resolution: 0.000512
Geodetic Model
Horizontal Datum Name: North American Datum of 1983
Ellipsoid Name: Geodetic Reference System 80
Semi-major Axis: 6378137.000000
Denominator of Flattening Ratio: 298.257222

Catchment Variable Tables

Table 1: Catchment Variables (Percent landcover and geology not shown due to space constraints)

Catchment ID	Aspect (Compass)	Slope (Degrees)	FAC (m2)	Elevation (m)	Major Lancover	Major Geology
gaar_catch_0	168.1	4.5	345895.0	463.2	lc14	g222
gaar_catch_1	175.9	11.3	1170025.0	846.8	lc19	g12
gaar_catch_2	178.6	12.2	459668.0	940.1	lc25	g12
gaar_catch_3	174.0	11.7	289165.0	987.0	lc19	g12
gaar_catch_4	178.6	12.7	678316.0	978.2	lc31	g12
gaar_catch_5	183.4	7.0	152148.0	747.9	lc15	g222
gaar_catch_6	168.8	10.0	248225.0	932.4	lc19	g12
gaar_catch_7	177.1	9.8	304843.0	896.3	lc19	g12
gaar_catch_8	182.9	6.7	141065.0	803.2	lc31	g915
gaar_catch_9	175.2	8.2	349313.0	800.9	lc15	g12
gaar_catch_10	186.3	3.2	90794.0	618.9	lc21	g222
gaar_catch_11	169.0	11.0	168315.0	1065.6	lc17	g12
gaar_catch_12	181.1	19.0	123514.0	1269.9	lc25	g12
gaar_catch_13	185.3	12.6	73172.0	973.7	lc15	g12
gaar_catch_14	175.9	20.1	241004.0	1323.1	lc31	g12
gaar_catch_15	157.7	10.2	112211.0	982.8	lc21	g12
gaar_catch_16	183.0	10.3	92400.0	1057.4	lc17	g12
gaar_catch_17	178.1	11.1	85808.0	887.4	lc19	g12
gaar_catch_18	187.3	11.2	92334.0	979.8	lc19	g12
gaar_catch_19	185.4	9.2	171819.0	995.4	lc17	g12
gaar_catch_20	192.3	8.8	179959.0	768.4	lc15	g12
gaar_catch_21	175.7	16.9	495950.0	1087.7	lc15	g12
gaar_catch_22	190.0	20.4	98227.0	1109.0	lc31	g12
gaar_catch_23	168.4	16.4	310442.0	1037.2	lc15	g12
gaar_catch_24	194.8	16.0	82492.0	1084.8	lc19	g12
gaar_catch_25	179.3	14.3	156997.0	1076.8	lc15	g12
gaar_catch_26	198.9	18.3	73082.0	1194.4	lc25	g12
gaar_catch_27	174.7	18.6	92075.0	1140.8	lc19	g12
gaar_catch_28	165.9	18.0	74144.0	1104.7	lc17	g12
gaar_catch_29	116.3	4.4	166981.0	579.8	lc15	g797
gaar_catch_30	178.1	14.7	191604.0	1083.0	lc15	g12
gaar_catch_31	178.2	19.1	182689.0	1196.2	lc25	g12
gaar_catch_32	178.0	18.5	185362.0	1228.8	lc15	g12
gaar_catch_33	188.4	16.9	449618.0	970.0	lc15	g12
gaar_catch_34	182.7	20.9	85543.0	1201.8	lc19	g12
gaar_catch_35	192.2	23.6	100419.0	1286.3	lc25	g12
gaar_catch_36	177.1	17.0	147061.0	1077.5	lc15	g12
gaar_catch_37	175.4	20.8	248868.0	1065.2	lc25	g12
gaar_catch_38	186.8	13.4	154542.0	984.8	lc19	g12
gaar_catch_39	174.8	17.4	277291.0	985.5	lc15	g12
gaar_catch_40	179.2	21.9	473491.0	974.4	lc15	g12
gaar_catch_41	172.8	12.3	1054757.0	776.0	lc19	g12
gaar_catch_42	177.3	17.4	186811.0	1038.3	lc15	g12
gaar_catch_43	175.4	13.8	387075.0	823.1	lc15	g12
gaar_catch_44	179.2	14.3	92026.0	867.7	lc25	g12
gaar_catch_45	150.4	10.2	802350.0	761.5	lc19	g12
gaar_catch_46	173.7	20.3	842171.0	981.2	lc15	g12
gaar_catch_47	184.8	19.4	694923.0	995.1	lc19	g12
gaar_catch_48	181.7	15.8	875077.0	639.0	lc15	g12
gaar_catch_49	182.7	13.0	105290.0	709.9	lc25	g12
gaar_catch_50	195.3	17.2	141567.0	967.7	lc15	g12
gaar_catch_51	174.4	13.9	644748.0	969.2	lc19	g12
gaar_catch_52	180.1	21.0	81405.0	1024.8	lc25	g12

Table 2: Catchment Variables (Percent landcover and geology not shown due to space constraints)

Catchment ID	Aspect (Compass)	Slope (Degrees)	FAC (m2)	Elevation (m)	Major Lancover	Major Geology
gaar_catch_53	175.8	14.2	485412.0	977.8	lc19	g12
gaar_catch_54	177.7	20.3	86256.0	1055.1	lc25	g12
gaar_catch_55	189.2	14.6	665259.0	727.3	lc04	g12
gaar_catch_56	174.5	22.8	188866.0	1079.6	lc25	g12
gaar_catch_57	183.8	23.5	82920.0	1137.3	lc25	g12
gaar_catch_58	181.6	17.0	190940.0	835.0	lc15	g12
gaar_catch_59	169.3	19.4	88432.0	833.0	lc15	g12
gaar_catch_60	187.9	18.1	221882.0	816.9	lc15	g12
gaar_catch_61	182.3	10.8	763840.0	559.6	lc04	g12
gaar_catch_62	182.8	19.1	520340.0	961.2	lc19	g12
gaar_catch_63	182.6	18.3	76585.0	980.0	lc15	g12
gaar_catch_64	176.4	17.6	1250088.0	759.5	lc19	g12
gaar_catch_65	170.6	16.8	192866.0	741.4	lc15	g12
gaar_catch_66	179.5	23.5	80026.0	1096.0	lc19	g12
gaar_catch_67	178.9	18.9	339120.0	946.1	lc25	g12
gaar_catch_68	183.7	22.1	138819.0	700.4	lc25	g12
gaar_catch_69	179.7	25.2	77943.0	1090.8	lc24	g12
gaar_catch_70	82.2	9.2	417822.0	447.4	lc02	g12
gaar_catch_71	138.4	16.4	539663.0	764.3	lc13	g12
gaar_catch_72	192.3	18.6	843738.0	860.1	lc15	g12
gaar_catch_73	181.5	21.2	326519.0	1137.0	lc19	g12
gaar_catch_74	168.1	20.7	736318.0	870.3	lc25	g12
gaar_catch_75	184.6	13.0	1227066.0	671.0	lc04	g12
gaar_catch_76	132.2	17.3	853613.0	563.2	lc02	g12
gaar_catch_77	192.3	19.8	927123.0	944.0	lc19	g12
gaar_catch_78	174.1	18.7	193884.0	742.6	lc15	g12
gaar_catch_79	186.9	22.2	83406.0	718.3	lc25	g12
gaar_catch_80	177.1	20.0	466055.0	830.9	lc19	g12
gaar_catch_81	163.3	16.7	899549.0	739.1	lc15	g12
gaar_catch_82	181.3	11.9	1308303.0	566.6	lc04	g12
gaar_catch_83	187.1	19.6	83072.0	825.2	lc15	g12
gaar_catch_84	181.1	16.4	326532.0	549.1	lc19	g12
gaar_catch_85	179.1	19.4	2133765.0	653.6	lc19	g12
gaar_catch_86	176.4	18.6	130812.0	751.9	lc19	g12
gaar_catch_87	166.2	20.6	147962.0	788.9	lc19	g12
gaar_catch_88	176.8	18.4	215535.0	714.8	lc02	g12
gaar_catch_89	174.6	18.7	653239.0	736.5	lc24	g12
gaar_catch_90	185.3	4.7	2643406.0	332.5	lc02	g971
gaar_catch_91	163.1	18.3	1170139.0	706.0	lc19	g12
gaar_catch_92	146.2	13.4	71603.0	520.3	lc03	g12
gaar_catch_93	165.3	7.6	526990.0	361.2	lc02	g915
gaar_catch_94	166.4	15.6	204092.0	520.6	lc02	g12
gaar_catch_95	171.6	11.5	95433.0	508.4	lc02	g915
gaar_catch_96	174.0	5.7	2133765.0	233.9	lc15	g0
gaar_catch_97	176.8	13.9	114185.0	466.2	lc02	g12
gaar_catch_98	119.3	0.2	925781.0	126.7	lc02	g12
gaar_catch_99	173.1	8.1	1343722.0	282.9	lc02	g12
gaar_catch_100	146.1	5.5	70799.0	305.7	lc02	g12
gaar_catch_101	173.3	6.6	654886.0	297.6	lc02	g12
gaar_catch_102	190.8	5.2	1503312.0	209.8	lc15	g30
gaar_catch_103	173.1	7.4	139458.0	468.6	lc02	g12
gaar_catch_104	165.9	2.5	69825.0	294.4	lc02	g971
gaar_catch_105	186.8	4.1	121348.0	272.7	lc02	g12
gaar_catch_106	170.1	6.4	94286.0	299.4	lc02	g12

Landcover Types

Table 3: Landcover Types

Landcover Descriptions	Landcover Codes
Dense-open white spruce forest	lc01
Open black spruce-like forest	lc02
Open white spruce-like forest	lc03
Spruce woodland	lc04
Spruce-lichen woodland	lc05
Closed paper birch-aspen forest	lc06
Closed balsam poplar forest	lc07
Open paper birch-aspen forest	lc08
Open balsam poplar forest	lc09
Closed spruce-broadleaf forest	lc10
Open spruce-broadleaf forest	lc11
Closed tall shrub	lc12
Open tall shrub	lc13
Shrub birch-willow-tussock tundra	lc14
Shrub birch-ericaceous-willow	lc15
Closed low willow	lc16
Prostrate shrub-rock	lc17
Prostrate shrub-lichen	lc18
Prostrate shrub	lc19
Dry herbaceous	lc20
Mesic herbaceous	lc21
Wet herbaceous	lc22
Aquatic herbaceous	lc23
Sparsely vegetated	lc24
Bare-ground	lc25
Silty water	lc26
Clear water	lc27
Snow/Ice	lc28
Sand dunes	lc29
Mosaic/pattern vegetation	lc30
Shadow/indeterminate	lc31
no data (region outside of study)	lc32
other (not defined)	lc33

Geology Types

Table 4: Geology Types

Geolgoy Code	Formation Code	Geologic Description
g0	al2	MODERN ALLUVIUM
g11	bdis	BEDROCK DISCONTINOUS
g12	bed	BEDROCK
g15	lake	LAKE
g21	al1	LOW ALLUVIAL TERRACE DEPOSITS
g24	als	ALLUVIUM, SILTY
g27	tg1	LOWER TERRACE GRAVELS
g30	Ttg2	HIGHER TERRACE GRAVELS
g33	io3	OUTWASH OF LATE ITKILLIK AGE
g35	io1	OUTWASH OF ITKILLIK PHASE 1
g36	io1	OUTWASH OF ITKILLIK PHASE 1
g37	so?	SAGAVANIRKTOK OUTWASH
g39	io1?	OUTWASH OF ITKILLIK PHASE 1
g42	no	FAN MOUNTAIN OUTWASH
g43	ao?	OUTWASH OF ANAKTUVUK RIVER AGE
g81	gr	GRAVEL DEPOSITS, UNDIFFERENTIATED
g88	sa	SAND DEPOSITS
g94	at	ACTIVE TALUS
g132	pg	PIEDMONT GRAVEL
g136	sa	SAND DEPOSITS
g180	f	FAN DEPOSITS
g187	af	DEPOSITS OF STEEP ALPINE FANS
g188	tr2	TALUS RUBBLE
g222	s	SOLIFLUCTION DEPOSITS
g237	av	AVALANCHE TRACKS AND DEPOSITS
g241	(s)	SOLIFLUCTION DEPOSITS
g246	tr	TALUS RUBBLE
g248	c	COLLUVIUM
g270	fl	FLOW DEPOSITS
g279	ls	LANDSLIDE DEPOSITS
g284	fd	FAN-DELTA DEPOSITS
g301	fs	SILT FANS
g303	us	UPLAND SILT DEPOSITS
g305	si	ORGANIC SILT DEPOSITS
g312	tr	TALUS RUBBLE
g315	rg	ROCK-GLACIER DEPOSITS
g339	m	MUSKEG
g365	fd	FAN-DELTA DEPOSITS
g376	g	GLACIERS
g420	pr	PROTALUS RAMPART DEPOSITS
g468	dt	DELTAIC DEPOSITS
g470	sdt?	DELTAIC DEPOSITS OF SAGAVANIRKTOK RIVER AGE
g602	sgl/sd	GLACIAL LAKE DEPOSITS OVER DRIFT
g675	b	BEACH DEPOSITS
g700	l	LACUSTRINE DEPOSITS
g749	nd2	DRIFT OF FAN MOUNAIN PHASE II
g794	im	MELTWATER DEPOSITS
g797	id3	DRIFT OF LATE ITKILLIK AGE
g851	id2	DRIFT OF ITKILLIK PHASE II
g902	igl	GLACIAL-LAKE DEPOSITS OF ITKILLIK AGE
g911	(id)	ITKILLIK DRIFT
g912	d	DRIFT UNDIVIDED
g915	id1?	DRIFT OF ITKILLIK PHASE 1
g971	sd2	DRIFT OF YOUNGER SAGAVANIRKTOK RIVER AGE
g974	Tgd?	DRIFT HIGHLY ERODED GLACIAL DEPOSITS
g980	(id)	ITKILLIK DRIFT
g981	id?	ITKILLIK DRIFT
g982	(id)	ITKILLIK DRIFT
g983	Tgmd?	DRIFT OF GUNSIGHT MOUNTAIN AGE
g999	ad	DRIFT OF ANAKTUVUK RIVER AGE

References