A Watershed Database for National Parks in Southwestern Alaska and a System for Further Watershed-based Analysis

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Introduction

This document describes a project designed to delineate and quantitatively describe watersheds located within or flowing into or out of national park lands in the National Inventory and Monitoring program's Southwest Alaskan Network (SWAN) of parks. The parks included in this study are Aniakchak National Monument & Preserve, Katmai National Park & Preserve, Lake Clark National Park & Preserve, and Kenai Fjords National Park. This effort was undertaken to support decision-making processes related to the Inventory and Monitoring program's goals. A variety of environmental and physical attributes were collected for each watershed using remotely sensed data in the form of a geographic information system (GIS). The GIS data used is from a variety of sources with variable quality. The nature of GIS analysis is such that many times a newer, higher-resolution dataset may become available during the course of any given study. For this reason, a set of scripts and methods are provided, making the incorporation of newer datasets as easy as possible. The goal is to provide an initial analysis of park hydrology as well as a means for updating the database with a minimal amount of effort.

It was necessary to choose a watershed size (stream order) that would provide sufficient detail for each park and allow useful comparison of basins within the parks while minimizing the complexity of the study. Review of standards for hydrologic unit delineation being used for the National Hydrography Dataset (NHD) (FGDC, 2002), suggested that the officially designated level 5 watersheds would provide the level of detail desired while minimizing redundancy. At this time, official NHD 5^{th} level watersheds have not been delineated for hydrologic units within the parks. It is beyond the scope of this project to provide a complete hydrologic unit dataset for each NHD cataloging unit located within the parks. Thus, this project focused on the delineation of level 5 watersheds with the majority of their area within park boundaries, while also providing the flexibility to modify watersheds to match NHD boundaries when they become available (if desired). Though limited streamline data will be created by this project, it is not expected to completely match the final streamline data in the NHD. Every effort has been made to force hydrologic flow models (gridded models of stream routing) to match other available datasets (including scanned topographic maps and digitized streamline datasets).

Quality of Data

Data quality is fairly consistent between parks, though some differences are noted below. Quality of data for various data types (hydrography, climate, surface geology, etc) are also discussed. Overall, the Alaskan Nat'l Parks suffer from a lack of high resolution surface type characterization, though general geography and topography is fairly represented.

The base data used to generate watershed boundaries is the National Elevation Dataset (NED). The 2-arcsecond DEM was resampled to produce a 60-meter per pixel DEM, and was judged to provide sufficient detail to delineate primary hydrologic features for all 5th level watersheds. It has been noted that a DEM with a resolution of 5 – 20 meters per pixel, depending on terrain complexity, is required to accurately model the distribution of values such as slope, aspect, and curvature (Kienzle, 2004). However, overall trends and basin averages derived from this 60-meter dataset are expected to be useful, especially for inter-basin comparison. Also, primary topographic characteristics such as relief and maximum and minimum elevation are expected to be accurate (vertical accuracy for NED is listed as 7 to 15 vertical meters in the metadata). In addition to the modest scale, the widespread occurrence of glaciers makes DEM interpretation difficult. Specifically, elevation values taken from the NED represent the ground elevation in unglaciated areas, but DEM elevations in glaciated areas represent glacier surface elevations, rather than the ground surface below the ice. This can confound normal flow algorithms and can also make true tributary delineation difficult in areas where ice flow does not conform to underlying topographic expression. DEM training was employed, when necessary, to fix major hydrologic discrepancies in glacial areas, but no effort was made to estimate sub-glacial topography.

Surficial geology is represented at 1:1,584,000 scale for the entire state of Alaska. This is a digital version of two USGS maps titled Miscellaneous Geologic Investigations (West) I-357 and Miscellaneous Geological Investigations (East) I-357. Though the scale is relatively coarse, the dataset distinguishes between several dozen surficial geology types. Volcanic rocks are classed separately, though bedrock type is not specified in regions of non-volcanic bedrock outcrop. Some alignment errors were noted with features such as glaciers and lakes, but they did not seem to be systematic in nature (e.g. – data was not shifted in one direction), but are likely a result of the very small scale at which the original maps were created. The resulting bedrock percentages from this analysis are likely to be questionable for smaller watersheds, but general trends in surficial geology are still discernable, making it especially useful for comparing between watersheds.

Land cover data at 30 meter per pixel resolution is available for all SWAN parks. All 30 meter data was derived from Landsat TM5 and TM7 data, except for the Aniakchak land cover map, which was based on the older Landsat MSS data. The dates of acquisition for the Landsat images vary within and between parks from 1976 to 2001. Data for all maps was typically augmented by aerial photography, auxiliary datasets (e.g. – forest fire burn maps) and field verification. There are, however, some difficulties when using these datasets for hydrologic analysis. The primary limitation of the datasets is their aerial extent. The land cover datasets do not provide information for lands outside of the park boundaries, and the land cover map for Aniakchak does not provide complete coverage of the land within the park. Additionally, the classification schemes for each land cover map differ, making inter-park comparisons difficult without reclassification. Coarse scale (1 km pixel resolution) land cover data is available from the Eros Data Center in the form of the North American Land Cover Characteristics Database, which is based on data from the Advanced Very High Resolution Radiometer (AVHRR). A script was modified to collect this data and add it separately to the watershed attribute tables, but this data was not included in the provided watershed databases. AVHRR data is available with multiple classification schemes, though each scheme is still derived from the same dataset. More information can be found at:

http://edcdaac.usgs.gov/glcc/nadoc2_0.asp

Precipitation and temperature are represented by the 4 km per pixel PRISM climate model for Alaska, produced at Oregon State University and available from Climate Source Inc. (http://www.climatesource.com/). The data is based on weather station averages from the 1961 to 1990 time period. The dataset has been evaluated extensively elsewhere (e.g. – see Simpson, et. al., 2002). It was generally observed that the PRISM climate data is the best currently available estimate of statewide climate for Alaska. The temperature and precipitation grids provide sufficient detail to examine climate differences between the watersheds delineated for this project and also provide insight into climate variability *within* some of the larger basins. These datasets could be used to estimate climate means for smaller watersheds, but isolated orographic or maritime effects and in-basin variability would not be well represented for basins smaller than about 150 square km. This dataset provides no information about temporal changes in climate, but a dataset has been made available for the conterminous United States that uses more contemporary data (1971-2000). It is unclear whether a similar dataset for Alaska will be created, but such a dataset may provide an interesting tool for examining recent changes in climate.

Hydrologic Observations

Kenai Fjords National Park

Basin types in Kenai Fjords are primarily influenced by size and the percentage of glacial cover, with the two major types being larger basins dominated by ice (often >60% ice) versus small watersheds dominated by bedrock, alluvium, and colluvium. The majority of the systems in the park are too small to be considered fifth level watersheds (defined as watersheds larger than 163 but smaller than 1,012 square km). Most of the watersheds large enough to be considered fifth level do not have surface channels, but are tidewater glacier systems (e.g. McCarty and Bear Glaciers) or glacial systems which have retreated to positions just above sea-level (e.g. Yalik Glacier) with minimal fluvial development downstream of the glacial terminus. The many smaller watersheds, grouped into 12 frontal areas*, do have flowing water. These are quite small, steep and minimally vegetated. The Kenai Fjords watersheds have the highest mean slopes, on average, of all of the southwest network parks. Watersheds are generally begin in ice or bare rock and flow through a thin band of sparsely vegetated or forested slopes in bedrock-controlled channels to a terminus at the ocean. The development of non-glacial fluvial morphology (e.g. floodplains) within the park is almost nonexistent, with the exception of the northernmost portion along the Resurrection River and the Nuka River in the warmer southern portion of the park. Most of the Resurrection River's watershed, however, falls outside of the park boundaries. This makes the Nuka River the largest surface stream completely within the park, though it is one of the smallest watersheds delineated for the southwest network. The larger Fox River/Sheep Creek system, which begins inside the park, does exhibit several miles of surface-water channelization with some floodplain development before flowing to the Kachemak Bay. However, park boundaries only encompass the upper, ice-covered portion of that watershed system.

**frontal areas* are regions between major watersheds that are generally composed of many small streams

Katmai National Park & Preserve

Katmai National Park & Preserve (KATM) exhibits the greatest variety of watershed structure in the southwest network of parks. Though the park has hundreds of miles of coastline along the Shelikof Straight, the majority of the park's land drains west to Kvichak Bay via two lake-dominated watersheds draining generally to the west. These watersheds, the Naknek River and Alagnak River, also drain all of the major lakes inside the park (including Lake Brooks, Iliuk Arm, Naknek Lake, Lake Coville, Lake Grosvenor, Nonvianuk Lake, Kukaklek Lake, Kulik Lake, and Battle Lake). These two watersheds are generally split between steep, bedrock-controlled uplands, rounded glacio-fluvial midlands, and flat glacio-fluvial lowlands which are dotted with lakes and wetlands. Significant volcanic rock deposits and a number of active glaciers differentiate the headlands of the Savonoski River, the main tributary of the Naknek River, from the headlands of the Alagnak and it's major tributary, the Nonvianuk River.

Another notable hydrologic system in the park is Katmai River. The Katmai River provides a striking example of braided river morphology. Over 10% of the watershed's area is braided, but even more striking than the high percentage of braided area is the width of the braided system which, near its confluence with Soluka Creek, is over 9 kilometers wide. The glacially carved volcanic peaks that form the divide for much of the Katmai River, along with tidal forcing at the watershed's lower end, are primarily responsible for this unique morphology by shedding sediment at a rate that overwhelms the capabilities of the river to incise its lower reaches. An unnamed system of rivers draining into nearby Kukak Bay exhibit similar morphology to the Katmai River, though on a smaller scale.

The Kemishak River, along with the Little Kemishak River, Strike Creek, the Douglas River, and the Big River form the core of the northeastern hydrologic system in KATM. These watersheds boast some of the coldest mean temperatures and highest mean precipitation rates in the region. The rivers exhibit moderate topography, except for the Douglas River, whose relief and glacial cover make it more similar to watersheds like the Katmai River in the southern portion of the park. These rivers are mostly underfit streams flowing in valleys previously occupied by glaciers. The primary surficial geology type in this part of the park is split between bedrock in the uplands, glacial deposits at mid-elevations, and moderately developed fluvial systems in the lowlands. The Douglas River, Swikshak River, and a number of smaller unnamed streams form a distinctive compound radial drainage pattern around the extensively glaciated twin volcanoes of Mt. Douglas and Fourpeaked Mountain.

Finally, the southwestern portion of KATM is drained by the King Salmon River, which is formed near the park boundary at the confluence of Contact Creek and Takayofo Creek. Takayofo Creek is joined by Angle Creek before it empties into the King Salmon River. Both of these streams are characterized by steep uplands and moderate glaciation. Contact Creek, in contrast, has relatively low total relief and no active glaciation. These sub-watersheds of the King Salmon River have relatively low temperatures and moderate precipitation compared to others in the park.

Lake Clark Nat'l Park & Preserve

The most notable hydrologic system in Lake Clark National Park & Preserve (LACL) is the Lake Clark watershed itself. The Newhalen River, which flows from Lake Clark to Iliamna Lake, has a drainage area of over 9,000 square kilometers when it enters Iliamna Lake. Much of this area is within LACL (approximately 7,700 square km) and nearly half of the land encompassed by LACL eventually drains through this relatively short channel. The Lake Clark/Newhalen River watershed is split between three major watershed groups: the relatively warm, low relief watersheds of the Chulitna and Koksetna Rivers; the cool, high relief, glacially-fed Tanalian River, Kijik River, and Currant Creek; and the cold, glacier and bedrock-dominated Chokotonk and Tlikakila Rivers. A prominent climate gradient exists across the Lake Clark/Newhalen River system, with the greatest precipitation and lowest temperatures in the northeast, and the lowest precipitation and warmest temperatures to the southwest.

The northern portion of LACL is drained primarily by two systems divided by the Alaska Range: the Stony River on the west and the Chakachamna River on the east. The Stony River system has several major tributaries inside LACL: the Telaquana, Necons and Tlikakila Rivers, as well as Tired Pup Creek. The Chakachamna River system consists of the Chilligan River, Neacola River, and Another River. The sub-watersheds of these two systems are all cold, high elevation basins with active glaciers. The mean temperatures of these basins are lower, and mean elevations higher, than most other watersheds in the southwest network. Several notable trends exist across this northern portion of the park. Though the upper tributaries of both the Stony and Chakachmna Rivers are topographically similar, the lower tributaries of the Stony River are generally lower in elevation and slope than those of the Chakachamna. Also, a precipitation gradient across this region provides the eastern reaches of the Chakachamna (near Chakachamna Lake) and the Neacola tributary with much higher precipitation and, as a result, a much higher percentage of glacial cover. The lower channels of the Stoney River, and its tributary, the Telaquana River, flow primarily over glacial drift and fluvial deposits, in contrast to the primarily bedrock controlled channels of the Chakachamna.

The west-central portion of LACL is drained by the Chilikadrotna and Upper Mulchatna Rivers, which show strikingly similar morphology to the Telaquana. All three of these watersheds begin in high valleys with active glaciers. Meltwater then flows through bedrock-controlled channels into medium-sized lakes. The lakes then drain onto low relief glacial outwash plains, where the channels form extensive meander belts.

Fifteen watersheds and frontal areas were delineated along the eastern part of LACL. The Big, Drift, Crescent, and Tuxedni Rivers are the four largest watersheds. All four share similar climates and show extensive glaciation, though the Big River differs from the others in several ways. The upper reaches of the Big River lack the extrusive igneous rock exposures seen in the other watersheds (the Drift and Crescent Rivers drain the recently active Mount Redoubt, while the Tuxedni drains the northern flanks of Iliamna). The rivers all exhibit a similar morphology, with glacially-filled valleys at the summits, bedrock-controlled channels below, and tidally influenced floodplains on flats along the Cook Inlet.

Aniakchak Nat'l Monument & Preserve:

Hydrologic systems in Aniakchak primarily fall into three groups. The Aniakchak River, with several smaller streams flowing to the Aniakchak and Kujulik Bays, comprise a system of relatively warm, moist watersheds. This region is characterized by bedrock control of geomorphology with minimal regions of aerially exposed sediment deposition. This results in rather steep watersheds with little floodplain development. This contrasts with the watersheds which begin in the western portion of the monument. These watersheds, including the Meshik River and Birthday and Reindeer Creeks, exhibit well developed depositional plains, with extensive wetland areas. The headwaters of these streams are formed in the steep volcanic slopes of Aniakchak Crater, while the middle and lower reaches of these watersheds flow over old glacial, fluvial, and marine deposits. Finally, the northern watersheds, including Cinder River and Pumice Creek, are characterized by moderate rainfall and temperatures compared to other watersheds in Aniakchak. Surficial geology in this northern area is mixed, but is split mostly between bedrock and modified moraine material.

Recommendations for future steps and applications

The watershed boundaries and characterizations created by this study provide the highest detail watershed delineations to date. The tools and instructions aim to make the incorporation of new data relatively simple. The data collected for each watershed should provide ample opportunities for basin-driven research in Alaskan national parks. Some examples of using the data and the tools to incorporate new data are outlined below.

One of the most powerful products of this project is the suite of Arc Macro Language (AML) scripts. Using these scripts, the user can modify the number and location of any or all basin outlets. It's also easy to create a new dataset focusing on a set of basins relevant to a specific project. The process of regenerating the descriptive statistics for each basin has been automated. This may be useful, for instance, if the user wishes to know the attributes of one fork of a river that was not delineated separately in the initial analysis (e.g. Angle Creek in Katmai is included with Takayofo Creek. The user may wish to examine the properties of Angle Creek alone). This can be accomplished by simply inserting a new outlet point just upstream of the confluence of the branches.

The user may also wish to add new datasets to the analysis. If a new soil dataset is created, for example, soil data may be collected in future runs by adding a line to the shape2shed script. Instructions for doing this are included in the script and in the accompanying instruction document. The provided scripts allow for the summation of gridded datasets (such as PRISM precipitation grids), and will also create basin-by-basin area summaries of single-value polygon features and length summaries for single-value linear features. An example of a single-value polygon feature is the outline of a forest fire. The shape2shed script can be modified to summarize the aerial extent of the fire in each watershed. Note, if a map contains boundaries of multiple fires, and each fire is to be considered separately (i.e. – each fire needs a separate entry in the watershed attribute table), the boundaries for each fire must be split into individual files (coverages or shapefiles are acceptable) before summarizing them. The same is true for linear features. If, for example, the total length of trails in each watershed is to be found, a simple modification to the shape2shed script can be made to include a query on the trails layer. If, however, the user wishes to know the length totals of summer and winter trails separately, those trails must be broken into separate files before they are added to the analysis.

The scripts also provide a tool for making modifications to the digital elevation models (DEMs) themselves through use of the trainer.aml script. This script allows for the direct modification of the DEMs and may be useful, for example, in cases of major channel piratization, outlet migration, or glacial recession. A new streamline can be digitized from aerial photos or from GPS measurements. The streamline can then be "burned" into the DEM using trainer.aml. Further instructions are available in the instructions document.

References

Federal Geographic Data Committee (FGDC) 2002, Federal standards for delineation of hydrologic unit boundaries, FGDC Proposal, Version 1.0, 52 pages.

Kienzle, Stefan, 2004, The effect of DEM raster resolution on first order, second order, and compound terrain derivatives, *Transactions in GIS*, 8(1): 83-111.

Simpson, James J., Gary L. Hufford, Michael D. Fleming, Jared S. Berg, and Justin B. Ashton, 2002, Long-term climate patterns in Alaskan surface temperature and precipitation and their biological consequences, *IEEE Transactionson Geoscience and Remote Sensing*, Vol. 40, No. 5, p. 1164-1184.