EVENT BASED MODELING STUDYING THREE SUB-BASINS IN THE KENAI RIVER WATERSHED

By

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Abstract

Streams in the Kenai River watershed are characterized by a fish-rich environment, with competing interests between commercial industry and recreational users. Resource managers strive to balance the needs of both these user groups while maintaining the sustainability of the resource. The ability to estimate future river conditions could help maintain the resource, and a strong, sustainable economy on the Kenai Peninsula.

This research used the U.S. Army Corps of Engineers Hydrological Modeling System (HMS), which transforms rainfall to river discharge. The main goal was to define a set of parameters that were calibrated using an event based strategy, and concurrent rainfall and discharge data. The model was calibrated and validated in three sub-basins located in different environmental settings (i.e. lowlands, mid, and high elevation). In addition, the Kenai River watershed, as a whole, was modeled.

Due to limited concurrent datasets, a combination of current and historic rainfall and discharge data was used in the calibration. Over the period of time between the historic data and the current data, no major changes in the watershed were detected.

Model results at the sub-basin and watershed scale provided reasonable results over the modeling period. Each sub-basin maintained errors below 10% for the calibration and only slight increase in the error for the verification trials. It was found that during an extreme precipitation event, the model did not perform within reasonable bounds.

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Chapter 1 Introduction

1.1 Applications of Hydrologic Modeling

The Kenai Peninsula relies on their rivers for both recreation, and economic opportunities. Czarneski and Yaeger (2014) state in their Kenai River Center publication:

> Healthy rivers, lakes and oceans are vital to healthy economies and good local standards of living, particularly on the Kenai Peninsula where so much of the economy and culture is centered on the water.

The importance of the health of the water systems is not only recognized by government agencies, but also by the local industry. The Kenai River Sportfishing Association (2016), discuss how their goals strive to maintain the health of the Alaska fisheries. This goal can be achieved through the sustainable harvest of the resource and the protection of the habitat so the resource needs to survive. With the strong reliance on a resource that is supported by the watershed, a deep understanding of the watershed can provide a cornerstone for a sustainable economy on the Kenai Peninsula.

Though many agencies in the area study the basin, most focus on the environmental water quality of the anadromous streams in the watershed. Not only is the quality of the water important, it is also important to have estimates of water quantity and peak discharge values for these streams. This is the most important application of hydrological models. The application has evolved from the Rational Method proposed by Mulvany in 1850 to estimate peak discharges for sewer design, to modern multi-dimension, unsteady flow, used for complex stream power potential (Todini, 2007).

The goal of this work is to develop and provide a tool that can be used by other researchers to help answer hydrological related questions about the Kenai River Watershed.

1.2 Study Location

For the hydrological modeling study three specific sub-basins in the Kenai River Watershed were selected, along with the Kenai River Watershed as a whole. The sub-basins selected represent three hydrologic regimes present in the watershed, low, middle, and steep gradient. Beaver Creek, located near Kenai, Alaska, is representative of a lowland, low gradient, wetlands stream. Russian River is a middle gradient valley stream, and Ptarmigan Creek is a steep gradient mountain stream. In Figure 1 the study area is shown in reference to North America. Figure 2 focuses on the Kenai River Watershed and shows the outlined sub-basin areas along with the selected, focus sub-basins. Figure 3 highlights the full extent of the Kenai River Watershed with the sub-basins outlined.

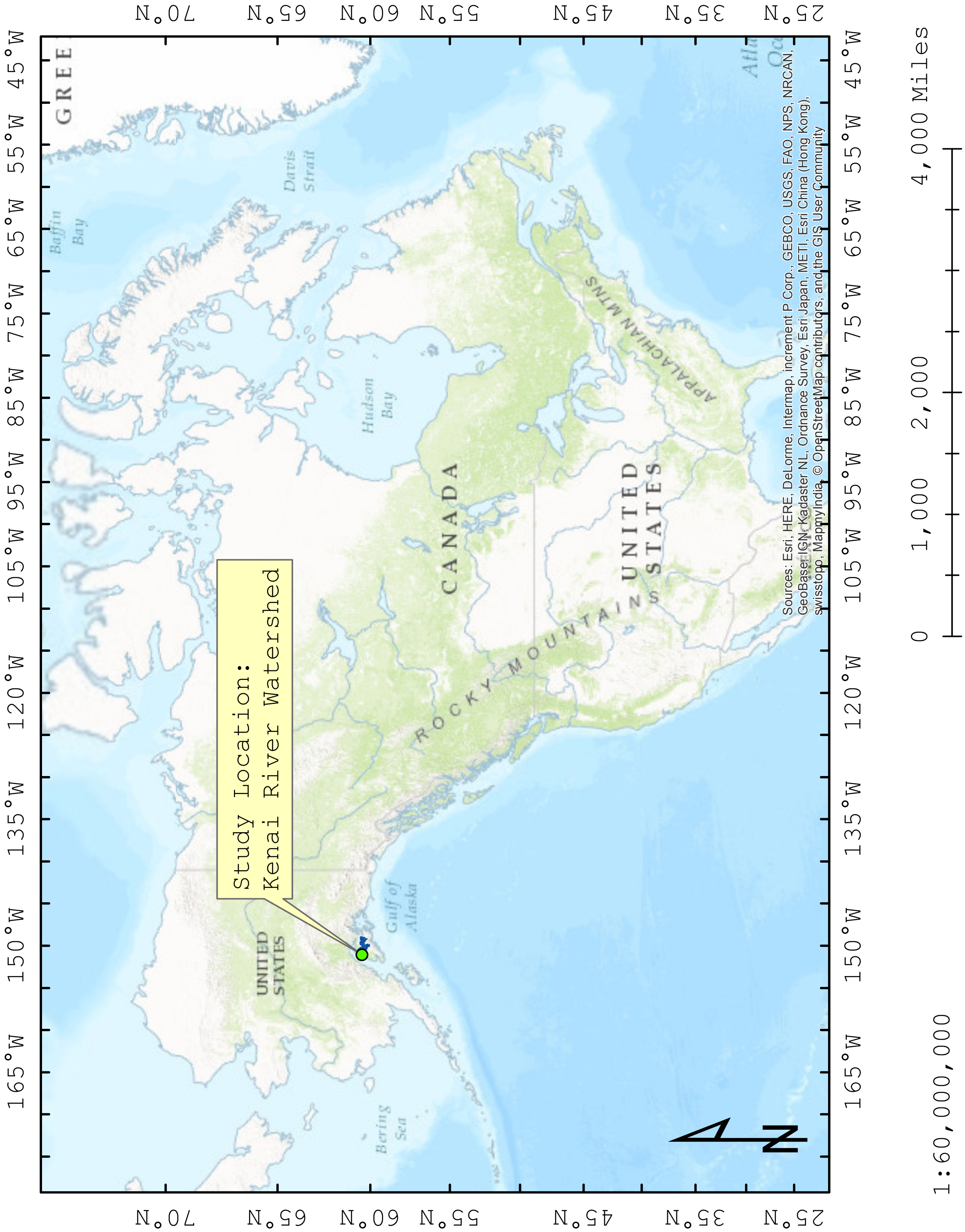

Figure 1. Kenai River Watershed Study Location

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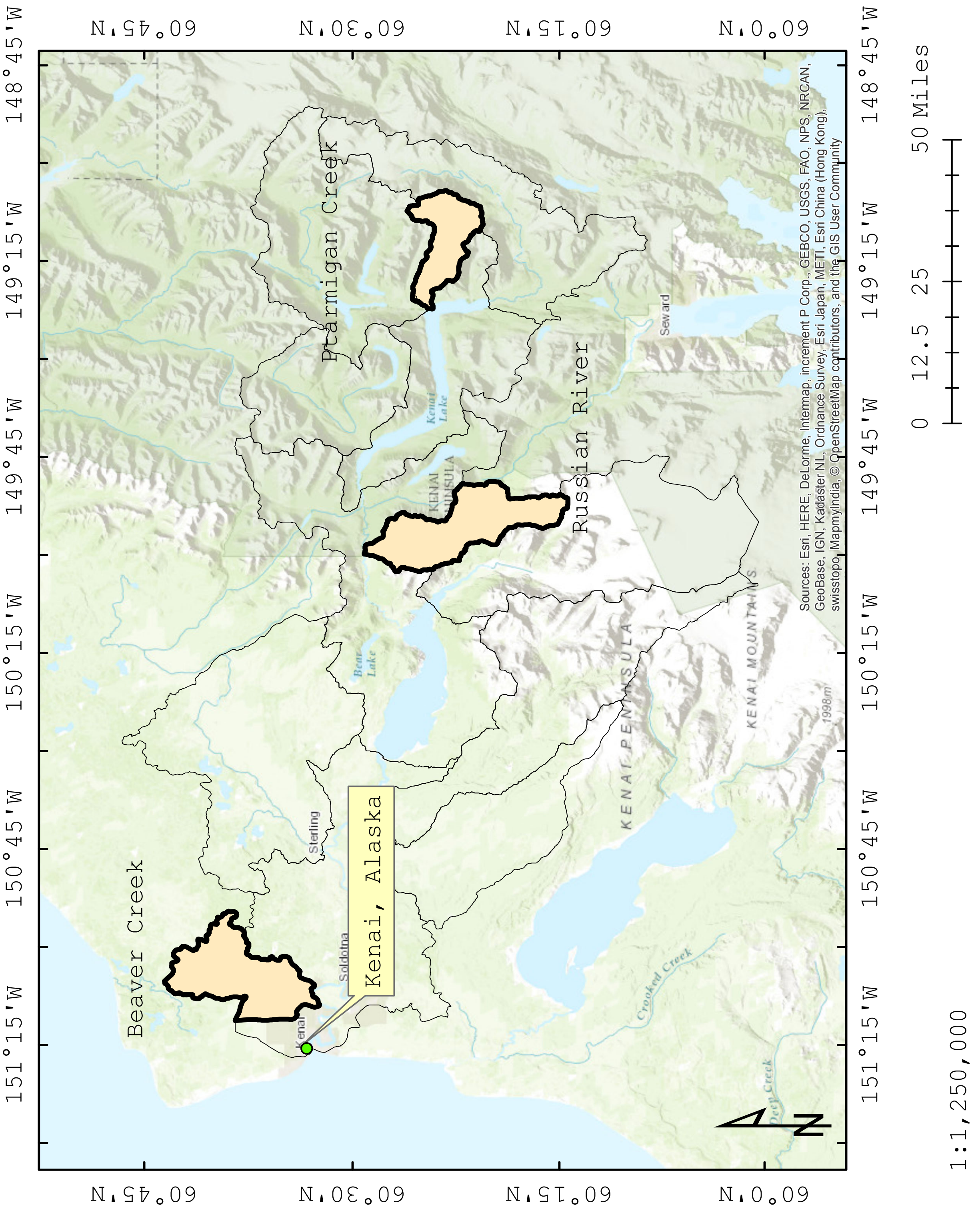

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Figure 2. Representative Sub-Basins Located in the Kenai Peninsula with Outlined Sub-Basins in the Kenai River Watershed

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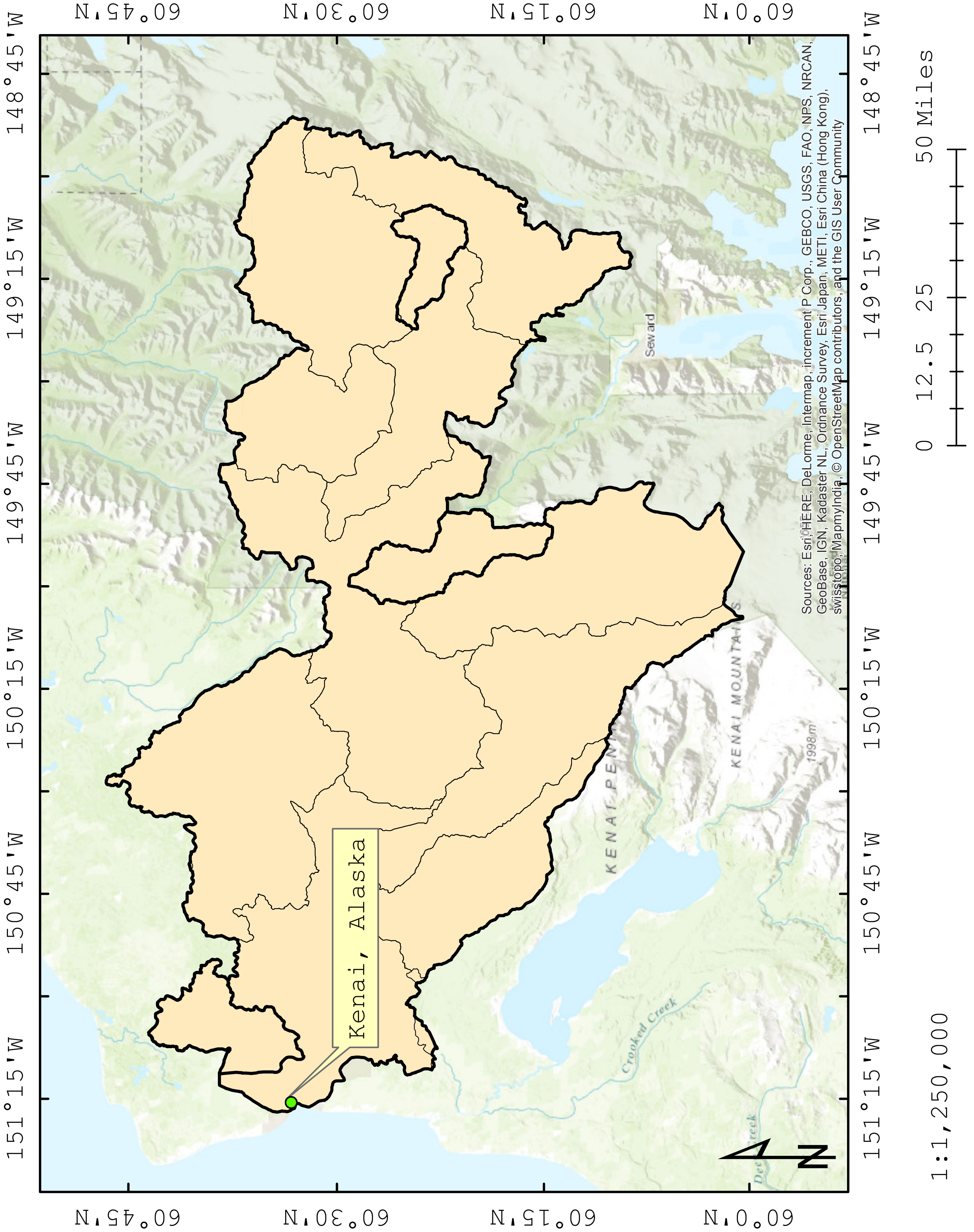

Figure 3. Full Extents of the Kenai River Watershed with Outlined Sub-Basins

The Kenai River Watershed Covers 2153 sq. miles of the Kenai Peninsula. It has two large lakes that are part of the Kenai River system. Kenai Lake in the upper reaches of the watershed has a surface area of 21.5 sq. miles and a volume of approximately 180 billion cubic feet. The second lake, Skilak Lake, is located in the middle reaches of the Kenai River. It has a surface area of 38 sq. miles and a volume of approximately 255 billion cubic feet (Spafard & Edmundson, 2000). The lake locations within the Kenai River Watershed can be seen in Figure 4.

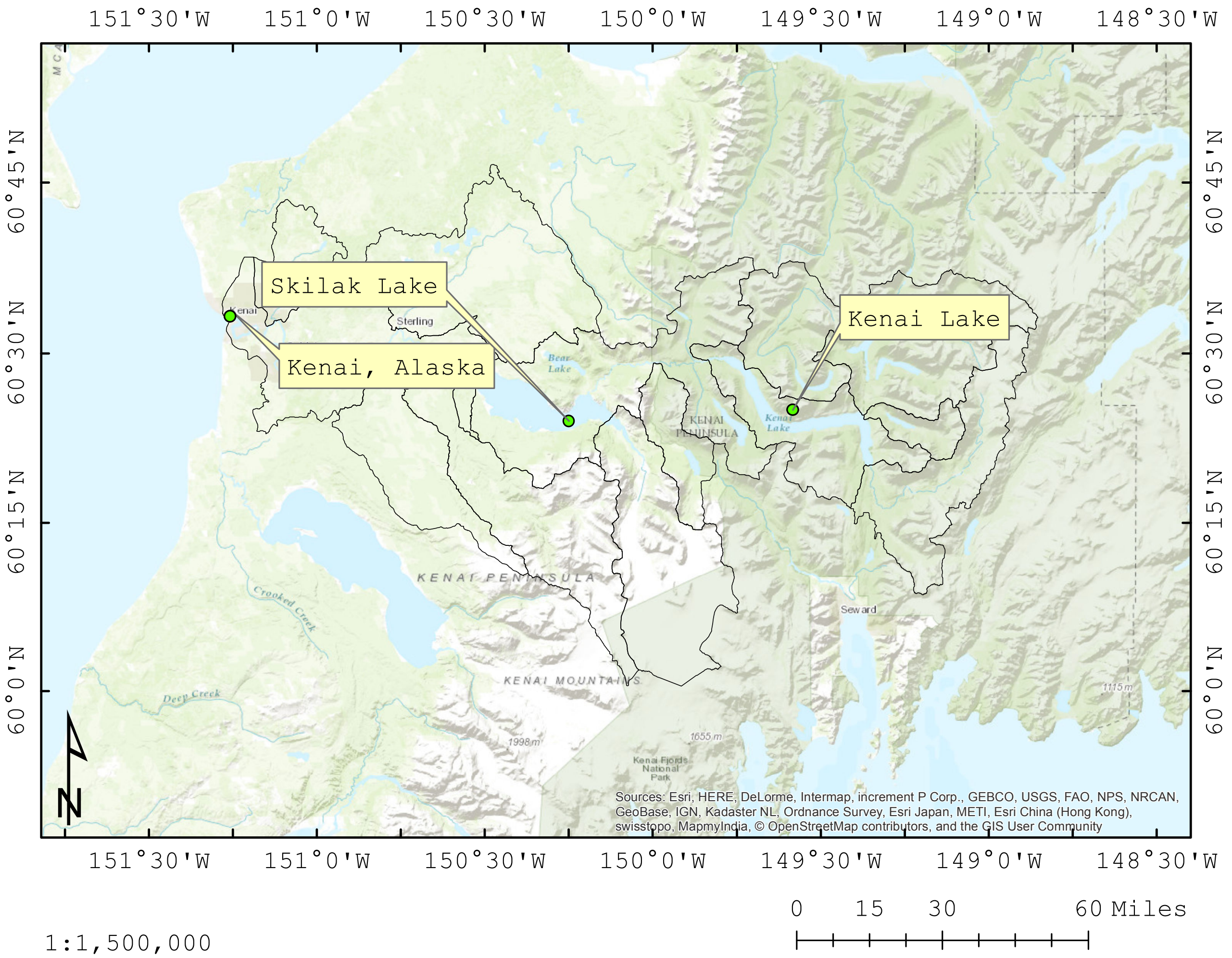

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Figure 4. Location of Kenai Lake and Skilak Lake with Respect to the Kenai River Watershed, Sub-Basins, and Kenai, Alaska

1.3 Reason for Hydrologic Modeling

The communities on the Kenai Peninsula have long survived thanks to the resources available to them in their region. Commercial and recreational fishing accounts for a large percentage of those workers. In 2014, 3,400 maritime jobs were available and almost half of those jobs were in self-employed commercial fishing. The study also shows that 62% of the gross earnings from commercial fishing, about 72 million dollars, came solely from the harvest of salmon (Kenai Peninsula Economic Development District Inc., 2016). Though many regulations are currently in place to help protect and insure the healthy future of the sport and commercial fisheries, most are based on protecting the environmental quality of the water. New factors are becoming a concern in the area though that were not previously considered in the management of the watershed. Changes in precipitation patterns could pose a large concern for the watershed. The Kenai Peninsula Borough states that their average total precipitation in the Kenai area is 19.27 inches (Kenai Peninsula Borough, 2016). Studies on the drying of the wetlands in the Kenai Peninsula Lowland, and throughout south-central Alaska were published in 2009 (Berg, Hillman, Dial, & DeRuwe, 2009; Klein, Berg, & Dial, 2005). Berg states that since 1968 available water from precipitation has declined 55% due to changes in evapotranspiration rates and precipitation amounts. With the large dependence by the communities of the peninsula on the salmon runs that spawn in the rivers of the Kenai Peninsula and the decrease in available water, the hydrologic system needs to be modeled to provide a tool so that future changes in streamflow can be estimated based on predicted changes in precipitation. With the heavy economic dependence on fisheries in the Kenai River Watershed, a modeling tool is needed to help predict the effects of future precipitation, development, and landscape changes, on the watershed.

1.4 Modeling Approach

To accomplish the objective, the U.S. Army Corps of Engineers Hydrologic Engineering Center Hydrological Modeling System (HEC-HMS) was selected as the modeling platform. With sparse current, and coinciding precipitation and discharge data available the model was calibrated to rainfall events that also had available discharge measurements for the time period. This method was applied to each of the three sub-basins, then to the watershed as a whole.

Chapter 2 Literature Review

Several studies have been conducted using HEC-HMS around the world. The research conducted has spanned several pressing issues for various communities. These studies utilize this modeling package through various methods, to determine several differing key parameters.

Though several water related studies have been conducted on the Kenai Peninsula, no published reports are available on the hydrologic modeling of this important watershed. The key studies in the area relate to the environmental aspects of the watershed, and preserving the water quality and habitat for the species that depend the drainage basin.

2.1 Review of HEC-HMS Literature

There are two time-scales that hydrologic models use: event based, and continuous. The differences between event based and continuous hydrologic modeling, and the different characteristic that each approach explore are based on the application of the model (Chu & Steinman, 2009). Each approach will examine particular hydrologic aspects of the basin being studied. Modeling a basin using an event based approach will characterize the fine scale parameters of a basin, and how the basin will respond to an individual precipitation event. The response to an individual rainfall event is characterized by the quantity of surface runoff, and peak timing. The continuous hydrologic modeling approach is useful for summarizing how a basin will respond over several rainfall events and dry periods.

These methods have been utilized to help estimate possible answers to many hydrologic questions around the world. In a study of climate change and water resources in Nepal, HEC-HMS was utilized to study the potential effects of climate change on the hydrology in the Bagmati River basin of Nepal (Babel, Bhusal, Wahid, & Agarwal, 2014). To obtain the possible outcomes from the HEC-HMS hydrologic model of the basin, downscaled precipitation and temperature model outputs were utilized as inputs into the hydrologic model The model was calibrated and verified by using observed daily flow measurements, and comparing them to the model output values.

Another study conducted looked at the growing impact of land-use change and urbanization in Malaysia (Amini, Ali, Ghazali, Aziz, & Akib, 2011). The effects of the land-use changes on the stream flow in the Damansara Watershed in Malaysia was studied using HEC-HMS. The area's growth has caused noticeable increases in the streamflow and even occasional flooding in the area. Using known streamflow data, the model was calibrated and utilized to estimate the impact of forecasted growth in the region on the peak streamflow over the entire watershed.

HEC-HMS has also been utilized in investigating potential water harvesting locations in Pakistan (Ghani et al., 2013). To gather the needed data to populate the model, the study group utilized Geographic Information System (GIS), Remote Sensing data, HEC-HMS and an interface software to import GIS data into HEC-HMS. Through the use of these tools, Ghani et al. (2013) determined several locations where water could be harvested from to supply water to the regions agricultural and domestic needs.

A study of the Lake Santa Ana watershed in Zacatecas, Mexico utilized watershed modeling techniques to quantify the amount of basin modification that had occurred and the basin modification limits (Gaytan, Anda, & Nelson, 2008). The HEC-HMS model was calibrated with historical precipitation and discharge data, and lake bathymetry data was utilized to determine the effect of the lake in the watershed system. The calibrated model was used to study the effects of increasing the basin area by a factor of 10.

The exploration of the effects of watershed scale and sub-basin delineation on the calibrated parameters used in the HEC-HMS model has also been investigated (Zhang, Y. Wang, Li, & X. Wang, 2013). Through the study of the Clear Creek Watershed in the upper Mississippi River basin, Zhang et al. (2013) found that most of the calibrated parameters were sensitive to basin delineation. The change in sub-basin delineation affected peak discharge, and flow volume, though depending on the basin researched the magnitude and sign of the change varied. The hydrologic processes also change due to the change in parameters, but the parameters falsely represent the basin hydrologic values (Zhang et al., 2013).

The study of several hydrologic model's effectiveness for predicting pre- and post-fire peak discharge has been researched (Kinoshita, Hogue, & Napper, 2014). The study revealed several inconsistencies between the predictions the models had produced. Kinoshita et al. (2014) found that HEC-HMS provides good results after calibration of the model, and is beneficial with its flexibility in watershed setup for the study of land surface changes such as wild fire.

2.2 Previous Studies on the Kenai Peninsula

Protecting the waters of the Kenai Peninsula is the core focus of several organizations that reside in the area (Czarnezki & Yaeger, 2014). The Kenai River Center in conjunction with the Kenai Watershed forum have studied the watershed and its possible environmental hazards to the system. From their studies the Kenai watershed is very sensitive to the changing environment. These changes are a sum of changes in precipitation amount and distribution, both solid and liquid, along with changes in the glacial influence in the system. To protect this river system, the Kenai River Center and Kenai Watershed Forum work to inform officials with their research to help make informed decisions on environmental protection regulations.

Drying and succession of the lowlands in the Kenai Peninsula is occurring (Klein et al., 2005). Aerial photographs from 1950 and 1996, along with reports from field studies were examined to estimate the observed drying of the lowlands on the Kenai Peninsula. Klein et al., (2005) analyzed the data to determine if the drying on the lowlands could be attributed to human interaction or an increase in burned areas. To do this the data points were categorized visually into four categories: water, wet, open, and wooded. The water category was for open water such as lakes. The wet category was for wetlands. The open category was open area without water. The wooded category was for forest. They then compared the percentage of area that each category held. They found from this analysis that for burned areas of the peninsula there was 7% less area in the water category, 88% less wet area, 31% less open area, and 30% more wooded area. For the unburned area on the peninsula there was 22% less water area, 87% less wet area, 37% less open, and 27% more wooded area. Based on these results the changes seen were attributed to changes in climate.

Woody invasion of the Kenai Peninsula lowland has been documented (Berg et al., 2009). Aerial photography is utilized to compare historic land cover with more current land cover in the area to quantify the changes from wet sphagnum-sedge peat to woody vegetation. By reviewing the historical weather record at the Kenai Airport, the estimated water balance showed that between the two study time periods, 1944-1967 and 1968-2007, there was a decline of 82mm in the total water balance. Two-thirds of that decline was due to decreased precipitation, while the remaining third was attributed to increased evapotranspiration. The change in herbaceous area was a decrease of approximately 7% per decade. Based on the aerial photographs of the study sites Berg et al., (2009) concludes that black spruce and shrubs are invading the Kenai wetland at an increasing rate. This is due to peatland becoming dry enough to allow the encroachment of black spruce.

A closer study of trends of precipitation and temperature were conducted on the Kenai Peninsula in 2013 (Bauret & Stuefer, 2013). In this study precipitation and temperature data from the peninsula were analyzed to determine if there were any trends in the mean annual temperature, total annual precipitation, precipitation annual maximum, and the frequency of occurrence of heavy precipitation events. To accomplish the objective, the Mann-Kendall trend test was utilized. Bauret and Stuefer (2013) found that the mean annual temperature was increasing at several locations, especially when reviewing 40- and 50-year trends, but there are isolated exceptions. The total annual precipitation is decreasing, but reliable data for the 40- and 50-year trends is sparse. No trends were present for the annual maximum precipitation events and heavy precipitation frequency. A shift in seasonal heavy precipitation was found though, from late summer to fall.

Glacial shrinkage in the Kenai Peninsula was researched in 2006 (VanLooy, Forster, & Ford, 2006). To access the shrinkage of the glaciers, remote sensing and digital elevation models were utilized. The comparison of 2000 Shuttle Radar Topographic Mission data with that of the United States Geological Surveys 1950 digital elevation models. From this comparison VanLooy et al., (2006) found that the Harding Icefield and Grewingk-Yalik Glacier Complex are thinning at a rate of 0.61 m/yr between 1950 and 1999. The volume of the glaciers in the peninsula were found to decrease by 72.1km^3 over this time period.

Publication that reviewed or researched the surface hydrology of the Kenai River Watershed were not found during this research.

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Chapter 3 Model Description and Key Definitions

3.1 Model Description and Required Parameters

HEC-HMS is utilized to model the complete hydrologic process of dendritic watershed systems (US Army Corps of Engineers, 2016). The model is a physically based model used to estimate stream discharge based on rainfall runoff. To accomplish this, the program requires precipitation data as the primary input to the model. The precipitation is applied to the basin area to obtain a volume of possible rainfall runoff. Through the use of these rainfall runoff estimates urban flooding analysis, flood frequency, flood warning system planning, reservoir spillway capacity, and stream flow are able to be determined with the modeling package (Halwatura & Najim, 2013). In order to complete the modeling, several parameters are needed to complete the process. The model requires input precipitation, observed stream flow for calibration, base flow, impervious surface values, surface storage values, canopy storage values, stream transformation values, soil infiltration, lake storage, and evapotranspiration information, along with geographical information for basin delineation.

3.2 Precipitation

Precipitation is the major input into the HEC-HMS model. The model can utilize historical precipitation or synthetic design storms. The precipitation data can be input in incremental values of various duration, constant amount, or based on precipitation frequency forecasts information (Bedient, Huber, & Vieux, 2013).

3.3 Stream Flow

Historical streamflow is key to creating a model that can represent reality. This information is used to calibrate the parameters utilized in the modeling effort that are not explicitly known from previous studies specific to the focus area, or determined by field measurements.

3.4 Baseflow

Base flow is described as the portion of the streamflow that originates from groundwater runoff (Todd & Mays, 2005). This information can be determined by recession analysis which identifies the portion of the streamflow that is due to the base flow (Dingman, 2015). Accurate information on the base flow is critical to obtaining modeled outputs similar to that of the observed data.

3.5 Impervious Surface

Impervious surface is the land that does not allow for infiltration of the precipitation into the soil (United States Geological Survey [USGS], 2016). These surfaces include urban development such as paved surfaces and artificial structures. Other areas that are included in impervious surfaces are lakes and streams. The precipitation that falls on these areas contributes directly to the stream flow.

3.6 Surface Storage

Surface storage counts for a major portion of the available water storage in a watershed. The amount of surface storage available depends on the ground cover that the precipitation falls through prior to becoming run off into a stream. Determining this value is very difficult due to the large areas that contribute to it (Bowling, Kane, Gieck, Hinzman, & Lettenmaier, 2003). Bowling et al. (2003) discusses the difficulties with direct measurements of surface storage due to including numerous lakes, ponds and wetlands in the calculation.

3.7 Canopy Storage

Canopy storage is one of the first interceptions that precipitation incurs on its path to a stream. This value is dependent on the type of foliage present in the study area. The interception loss (canopy storage) is the amount of precipitation that remains on the surface of the foliage and branches (Pike, Redding, Moore, Winkler, & Bladon, 2010).

3.8 Transform

The transform is a method of transforming the excess rainfall into surface runoff (Leventhal, 2013; Bedient et al., 2013). Several methods have been developed to obtain the surface runoff, each with a varying degree of input data.

3.9 Infiltration

The infiltration is one of losses used when calculating the excess precipitation. The infiltration is the movement of water from the surface into the soil (Bedient et al., 2013). This parameter is one of the most difficult parameter to obtain due to its great dependence on soil type and water conditions.

3.10 Lake Storage

Many basins contain large reservoirs that store runoff. The effect of this storage on the response of runoff on the streamflow can be great. Large lakes can drastically lag the flood wave caused by excess precipitation. To define the relationship that lake has with the stream network, the lake bathymetry, and in and outflow discharge measurements are needed to develop an elevation-storage-discharge relationship (Bedient et al., 2013).

3.11 Evapotranspiration

Evapotranspiration is a lumped parameter that accounts for the evaporation of standing water and the transpiration of water from plants in the basin (Wurbs & James, 2002). As much as 70% of rainfall in the United States can be lost due to evapotranspiration (Bedient et al., 2013). The use of this value in modeling is dependent on the length of time being modeled, though. Bedient et al. (2013) discuss that evapotranspiration is important for long-term studies and large scale studies. During a normal storm with rainfall intensities of 0.5 in/hr, evapotranspiration is near 0.01 in/hr, and is thus neglected for flood flow studies.

3.12 Flood Routing

Flood routing is a group of parameters used to describe how a flood wave moves through a stream channel. Five methods of routing are available in HEC-HMS they are: Muskingum, Modified Puls, Kinematic wave, Muskingum-Cunge, and Lag. For the Kinematic wave model channel geometry is needed along with stream length, stream slope, and the Manning's "n" roughness coefficient (Bedient et al., 2013)

3.13 Basin Delineation

Basin delineation is simply determining the boundaries of watershed, or sub-basins being studied. This is determined through the use of elevation information in the area of interest. Many areas already have this information available through the National Hydrography Database. This dataset is used in a graphical information system (GIS) to determine area of each sub-basin in the study area.

Chapter 4 Data

4.1 Precipitation

4.1.1 Available Precipitation Data

Historic precipitation data was utilized for the calibration of the model where available. This data was gathered from the National Climactic Data Center (NCDC) historical archives of National Oceanic and Atmospheric Administration (NOAA) data. Precipitation gauges utilized from this data source are Grouse Creek Divide, Grandview, Summit Creek, Kenai Moose Pens, Sterling 6 SW, and Kenai Municipal Airport.

The Grouse Creek Divide weather station, ID number USS0049L14S is located in the Snow River sub-basin at a location of latitude 60.26N and longitude 149.34W. It has a 93% coverage over the period of record of October 1, 1988 to present (National Oceanic and Atmospheric Administration (NOAA), 2016a).

The Grandview weather station, ID number USS0049L09S is located in the Trail River sub-basin at a location of latitude 60.61N and a longitude 149.06W. It has a 100% coverage over the period of record of October 1, 1983 to present (NOAA, 2016b).

The Summit Creek weather station, ID number USS0049L19S is located in the Quartz Creek sub-basin at a location of latitude of 60.62N and a longitude of 149.53W. It has a 100% coverage over the period of record of September 30, 1989 to present (NOAA, 2016c).

The Kenai Moose Pens weather station, ID number USS0050L02S is located in the Moose River sub-basin at a latitude of 60.73N and a longitude of 150.48W. It has a 100% coverage over the period of record of October 1, 1983 to present (NOAA, 2016d).

The Sterling 6 SW weather station, ID number USC00508731 is located in the Lower Kenai River sub-basin at a latitude of 60.49N and a longitude of 150.92W. It has a 99% coverage over the period of record of February 14, 2011 to present (NOAA, 2016e).

The Kenai Municipal Airport weather station, ID number USW00026523 is located in the Lower Kenai River sub-basin at a latitude of 60.58N and a longitude of 151.24W. It has a 70% coverage over the period of record of May 1, 1899 to present (NOAA, 2016f).

4.1.2 Collected Precipitation Data

Two precipitation gauges were installed to supplement the available data in key locations in the watershed. One gauge was placed in the upper reaches of the Russian River, and the second gauge was located near the outlet of Ptarmigan Lake. These locations were selected based on their accessibility, gauge coverage, and ability to obtain land usage permits. The gauges utilized were an ONSET HOBO RG-3 data-logging, tipping bucket, precipitation gauge. This precipitation gauge is accurate to 0.01 inches of precipitation, and is capable of recording up to 160 inches of precipitation at a rate of up to 5 in/hr (Onset Computer Corporation, 2016). These gauges were calibrated to 0.01 inches prior to placement in the field. The gauge was set to record the precipitation occurrences on a 15-minute interval.

The Russian River gauge was placed near the outlet of Upper Russian Lake at a latitude of 60.36N and a longitude of 149.89W. The location is in an open field shielded by tall trees. The gauge is mounted and leveled to pole at a height of four feet. No alter shield was installed at the site. To deter wildlife from nearing the gauge an electric fence was installed around the perimeter of the gauge. The gauge has provided precipitation data from mid-May of 2015 through mid-September of 2015. The installation site near Upper Russian Lake can be seen in Figure 5 with precipitation gauge, and electric fence.

Figure 5. Upper Russian Lake Precipitation Gauge

The Ptarmigan Creek precipitation gauge was located near the outlet of Ptarmigan Lake at a latitude of 60.41N and a longitude of 149.30W. This location was altered from the original site location due to less than optimal site condition upon the installation of the gauge. This site was set up in the same manner as the Russian River gauge, but was located at the lake edge. Due to a user error during the initial set-up, the gauge only collected data from mid-August 2015 to mid-September 2015. The precipitation gauge site for Ptarmigan Lake can be seen in Figure 6 with two rainfall gauges and electric fencing. The complete map of precipitation gauge locations in the Kenai River Watershed can be found in Figure 7.

Figure 6. Ptarmigan Creek Precipitation Gauge

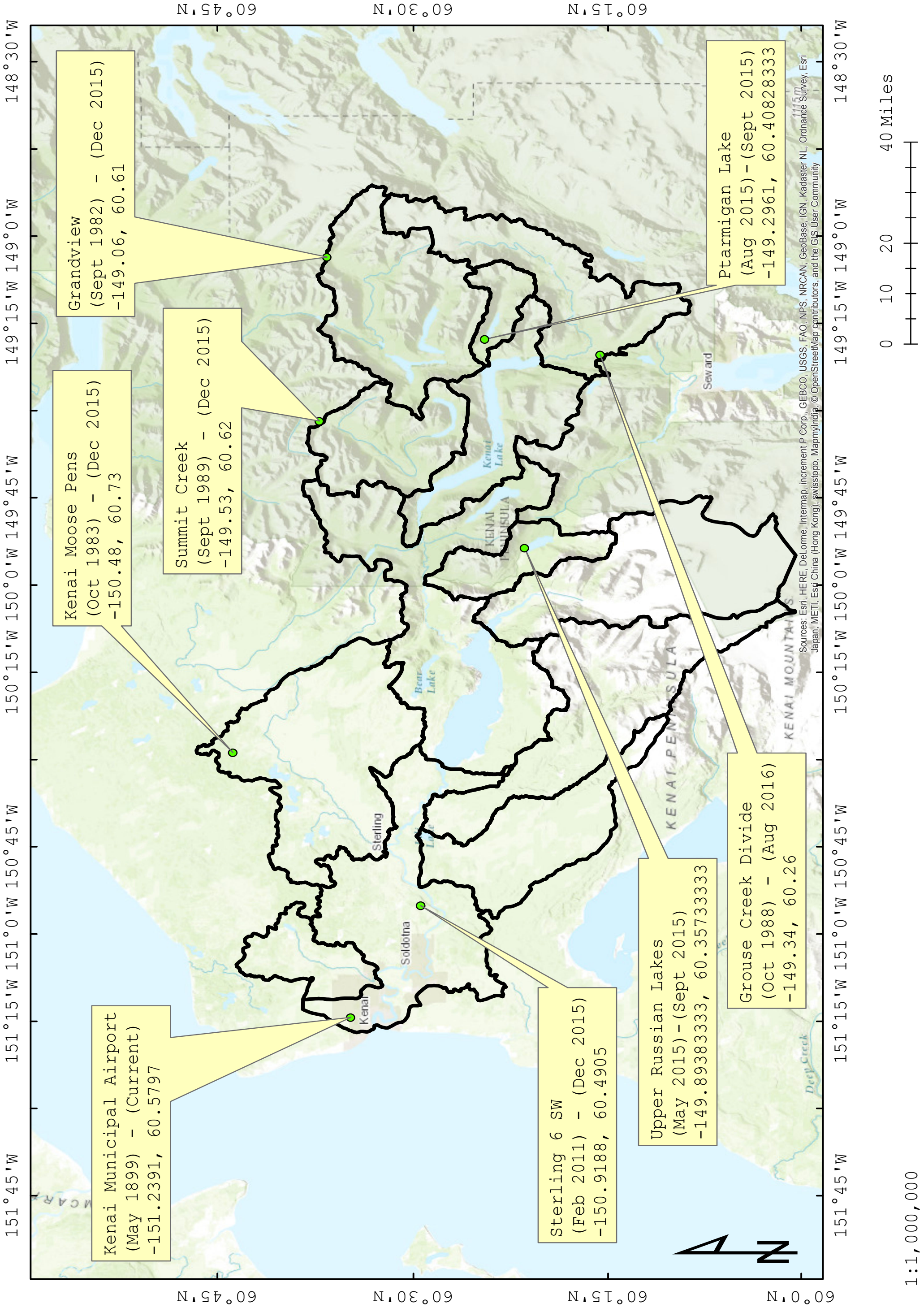

Figure 7. Meteorological Station Location in the Kenai River Watershed

4.2 Stream Flow

4.2.1 Available Stream Flow Data

Current and historical stream flow data are available through the United States Geological Survey (USGS) surface water database for varying time periods at each site. This information is available for the Snow River, Trail River, Kenai River at the outlet of Kenai Lake, Ptarmigan Creek, Quartz Creek, Russian River, Kenai River at the outlet of Skilak Lake Funny River, Beaver Creek, and the Kenai River at Soldotna,

The Snow River stream gauge, ID number USGS 15243900, is located at a latitude of 60.30N and a longitude of 149.34W. The daily stream measurements are available from August 16, 1970 to present (Unite States Geological Survey (USGS), 2016a)

The Trail River stream gauge, ID number USGS 15248000, is located at a latitude of 60.43N and a longitude of 149.37W. The daily stream flow measurements are available from the May 1, 1947 to September 13, 1974 (USGS, 2016b).

The Kenai River at the Outlet of Kenai Lake stream gauge, ID number USGS 15258000, is located at a latitude of 60.49N and a longitude of 149.81W. The daily stream flow measurements are available from the May 1, 1947 to present (USGS, 2016c).

The historic Ptarmigan Creek stream gauge, ID number USGS 15244000, was located at latitude 60.41N and longitude of 149.36W. The daily stream flow data is available for the May 1, 1947 through the September 13, 1958 (USGS, 2016d).

The Quartz Creek stream data, ID number USGS 602850149431500, was located at latitude 60.48N and longitude 149.72W. This data set consists of a single field measurement made on August 13, 2012 (USGS, 2016e).

The Russian River historic stream gauge, ID number USGS 15264000, was located at latitude 60.45N and longitude 149.98W. Daily stream flow measurements are available from the May 1, 1947 through September 13, 1954 (USGS, 2016f).

The Kenai River stream gauge at the outlet of Skilak Lake, ID number USGS 15266110, is located at latitude 60.47N and longitude 150.60W. Daily stream flow measurements are available from May 2, 1997 to present (USGS, 2016g).

The Funny River stream measurement, ID number USGS 15266210, was located at latitude 60.49N and longitude of 150.86W. This data set consists of a single field measurement on August 28, 2012 (USGS,2016h).

The historic Beaver Creek stream flow gauge, ID number USGS 15266500, was located at latitude 60.56N and longitude of 151.12W. The data set has daily stream flow data from October 1, 1967 through September 13, 1978 (USGS, 2016i).

The Kenai River stream flow gauge at Soldotna, ID number USGS 15266300, is located at latitude 60.48N and longitude 151.08W. The data set contains daily stream flow information from May 1, 1965 to present (USGS, 2016j).

The locations of the streamflow gauges used in this study are referenced to the Kenai River Watershed in Figure 8.

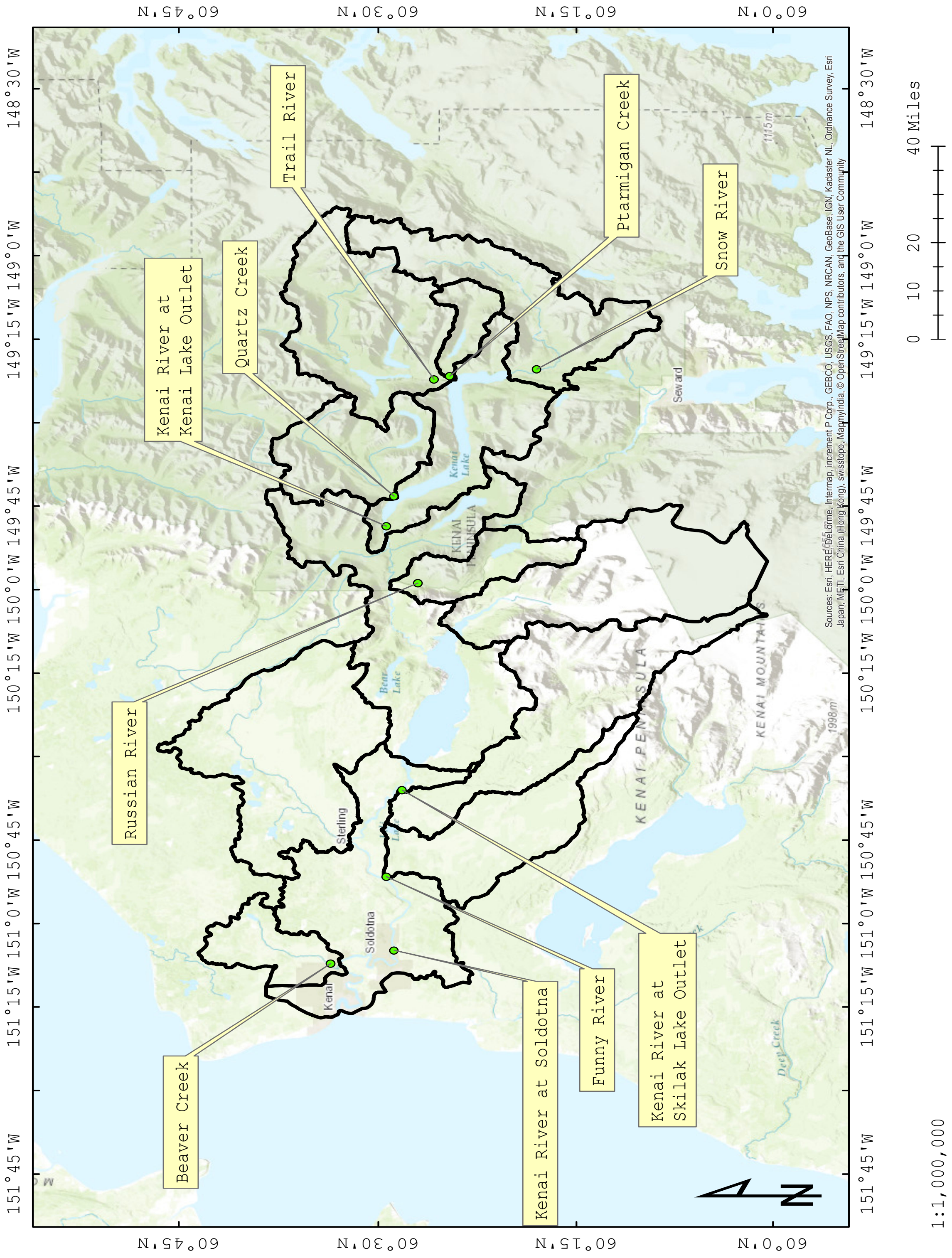

Figure 8. Stream Flow Gauge Locations in the Kenai River Watershed

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4.2.2 Collected Stream Flow Data

Stream flow was measured for the three sub-basins of interest in this study, Ptarmigan Creek, Russian River, and Beaver Creek. The monitoring, maintenance, and data collection at these locations was organized by the Kenai River Watershed forum. The devices used to monitor these sub-basins are the OTT Orpheus Mini pressure transducer. These devices monitored the water stage on the fifteen-minute interval. Manual stream flow measurements were taken at the three locations along with stream stage measurements to develop a rating curve to convert the pressure transducer data to discharge information. The pressure transducer and well casing installed into Russian River can be seen in Figure 9. The installed well casing can be seen in Figure 10 along with the Sontek M9 River Surveyor acoustic doppler current profiler (ADCP) used to measure stream discharge at Russian River.

Figure 9. Ott Pressure Transducer and Well Casing

Figure 10. Manual Discharge Measurement at the Russian River Stream Gauge using the Sontek M9 River Surveyor ADCP

4.3 Baseflow

Direct baseflow information for the sub-basins that compose the Kenai River Watershed is not available directly through publically available data sets. To obtain the baseflow input for the HEC-HMS the available discharge information was analyzed to determine the minimum of the minimum monthly flows, the average of the minimum monthly flow, and the maximum of the minimum monthly flows. Assuming that the minimum flow is representative of the baseflow, the average baseflow was determined, along with the bounds of the baseflow. For sub-basins that do not have streamflow data the baseflow information was determined by finding the difference in the upstream and downstream flows, then, removing any known baseflows from the difference. Finally the remainder of the flow difference was divided among the basins that did not have flow data by a weighted value based on the area of the individual sub-basin with respect to the total area of sub-basins without flow data. The baseflow analysis results for the month of July can be seen in Table 1. The results were then plotted to visualize the bound of the baseflow. These bounds can be seen in Figure 11.

Table 1 Kenai River Watershed Baseflow Data for July
For additional baseflow information see Appendix A.

Sub-Basin	Calculation Method	Base Flow (CFS)		
		July		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	39	112
Beaver Creek	Analysis	11	13	15
Moose River	Estimate	0	42	120
Funny River	Estimate	0	23	64
Killey River	Estimate	0	37	104
Middle Kenai River	Estimate	2480	2755	3133
Skilak River	Estimate	1796	1995	2518
Russian River	Analysis	75	121	158
Upper Kenai River	Estimate	88	479	508
Quartz Creek	Estimate	69	376	400
Trail River	Analysis	1170	1452	1640
Ptarmigan Creek	Analysis	123	168	222
Snow River	Analysis	1610	1948	2270
*Estimate values that are negative are set to 0				

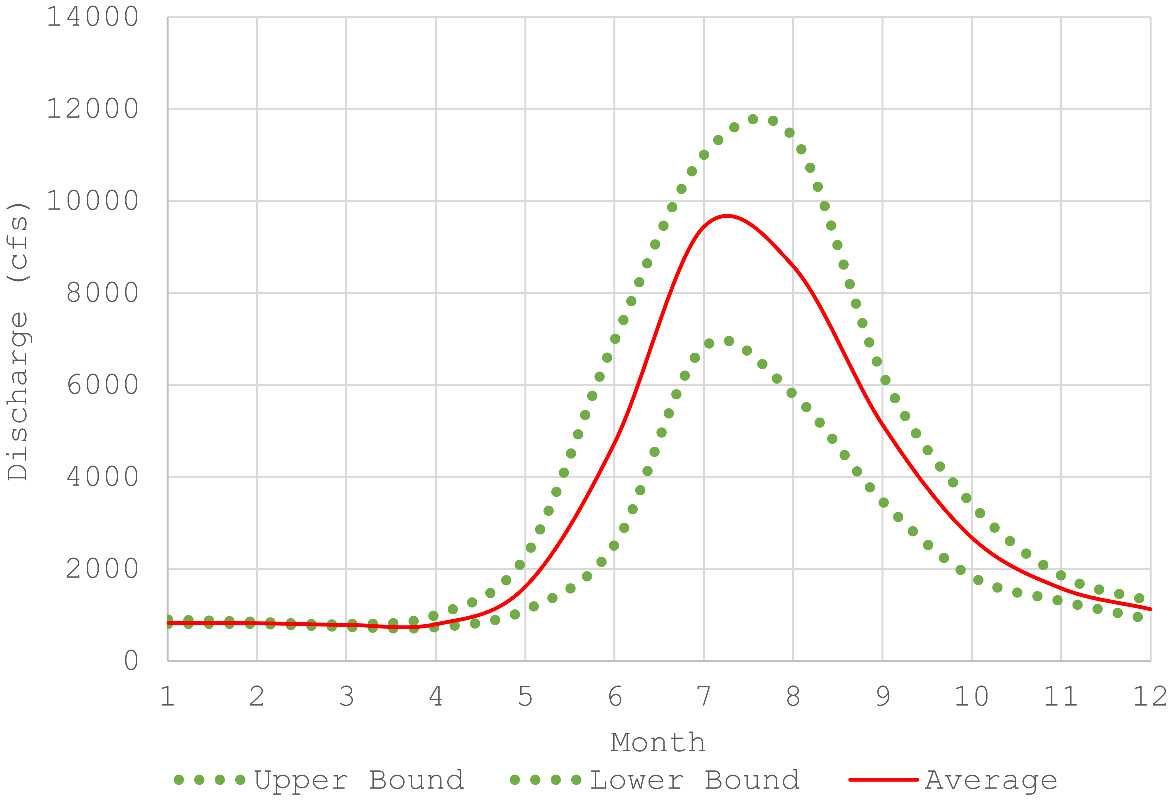

Figure 11. Lower Kenai River Baseflow Bounds

4.4 Impervious Surface

The impervious surface quantification for the Kenai River Watershed and sub-basins has been determined through the use of GIS. Two datasets were used in GIS for the quantification: the National Hydrography Database (NDH) water surface data, and the National Land Cover Database (NLCD) 2011 impervious development dataset (USGS, 2016k; USGS, 2016l). The impervious surface due to development and waterbody impervious areas were combined to create the sub-basin impervious area and then compared to the sub-basin area to determine the percentage of sub-basin area, impervious. Table 2 shows the impervious surfaces for each sub-basin in the Kenai River Watershed.

Table 2 Kenai River Watershed Basin Impervious Surface Percentages

	Total Impervious (%)	
Basin	Water & Ice (%)	Development (%)
Lower Kenai River	4.34	
	1.39	2.95
Beaver Creek	2.39	
	1.99	0.40
Moose River	2.26	
	2.15	0.11
Funny River	0.30	
	0.25	0.05
Killey River	15.45	
	15.45	0.00
Middle Kenai River	6.20	
	6.16	0.04
Skilak River	24.23	
	24.23	0.00
Russian River	1.80	
	1.80	0.00
Quartz Creek	1.19	
	1.04	0.15
Trail River	3.82	
	3.82	0.00
Upper Kenai River	7.14	
	7.14	0.00
Ptarmigan Creek	5.85	
	5.85	0.00
Snow River	29.41	
	29.41	0.00

4.5 Surface Storage

Data on the surface storage in the Kenai River Watershed is not available in published works. All values used in the modeling efforts were estimated and calibrated.

4.6 Canopy Storage

Data on the canopy storage in the Kenai River Watershed is not directly available. To determine the canopy storage initial values were chosen based on the foliage types in the sub-basins. These foliage types were then referenced to the British Columbia forest hydrology guide, which has published precipitation interceptions values for various forest types (Pike et al., 2010).

4.7 Stream Transform

The stream transform for each sub-basin is a calibrated time lag parameter. The calibration for this parameter was performed by comparing the modeling discharge peak time to the observed discharge peak time. The lagging of the peak was then applied to the model so that the modeled peak discharge time coincided with the observed discharge peak time. Table 3 displays the lag time transformations preformed on each basin in the watershed scale modeling effort.

Table 3 Kenai River Watershed Sub-Basin Transform Lag Time

Sub-Basin	Lag Time (min)
Snow River	1700
Ptarmigan Creek	1080
Trail River	3600
Quartz Creek	1200
Upper Kenai River	3600
Russian River	1700
Middle Kenai River	1600
Skilak River	3600
Moose River	2000
Killey River	3600
Funny River	2600
Lower Kenai River	4000
Beaver Creek	1600

4.8 Soil Infiltration

Soil infiltration and loss estimates are based on the soil type Soil Conservation Service (SCS) number and the impervious surface as found as described above. The soil type was determined by the United States Department of Agriculture (USDA) published soil survey (USDA, 2016). Most of the Kenai River Watershed has soil data available through the published studies starting 1918 that has continued through current updates.

4.9 Lake Storage

Lake storage and elevation information is available through the Alaska Department of Fish and Game (ADF&G). Lakes that are used in fish spawning or stocked by ADF&G have been surveyed and bathymetric maps were created (Spafard & Edmundson, 2000). These maps can be seen in the Appendix B. To determine the volume of storage at a given lake depth, the bathymetric maps were georeferenced and overlaid on mapping software. By tracing the depth contour lines and multiplying by the depth increments, the elevation-storage relationships were determined (Wetzel, 2001).

4.10 Evapotranspiration

Evapotranspiration for the Kenai River Watershed was not analyzed in this modeling effort. Since the model is calibrated to single storm events, the evapotranspiration is negligible (Bedient et al., 2013).

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Chapter 5 Watershed Modeling

5.1 Beaver Creek Sub-basin

The Beaver Creek sub-basin is located near Kenai, Alaska and is comprised of several small, low gradient drainages. The sub-basin was separated into four separate drainages that feed into the main channel. These areas are in the area of Timberlost Lake, Ootka Lake, Beaver Lake, and the Beaver Creek stream basin area. The division of these drainages was determined visually by topographic map as seen in Figure 12.

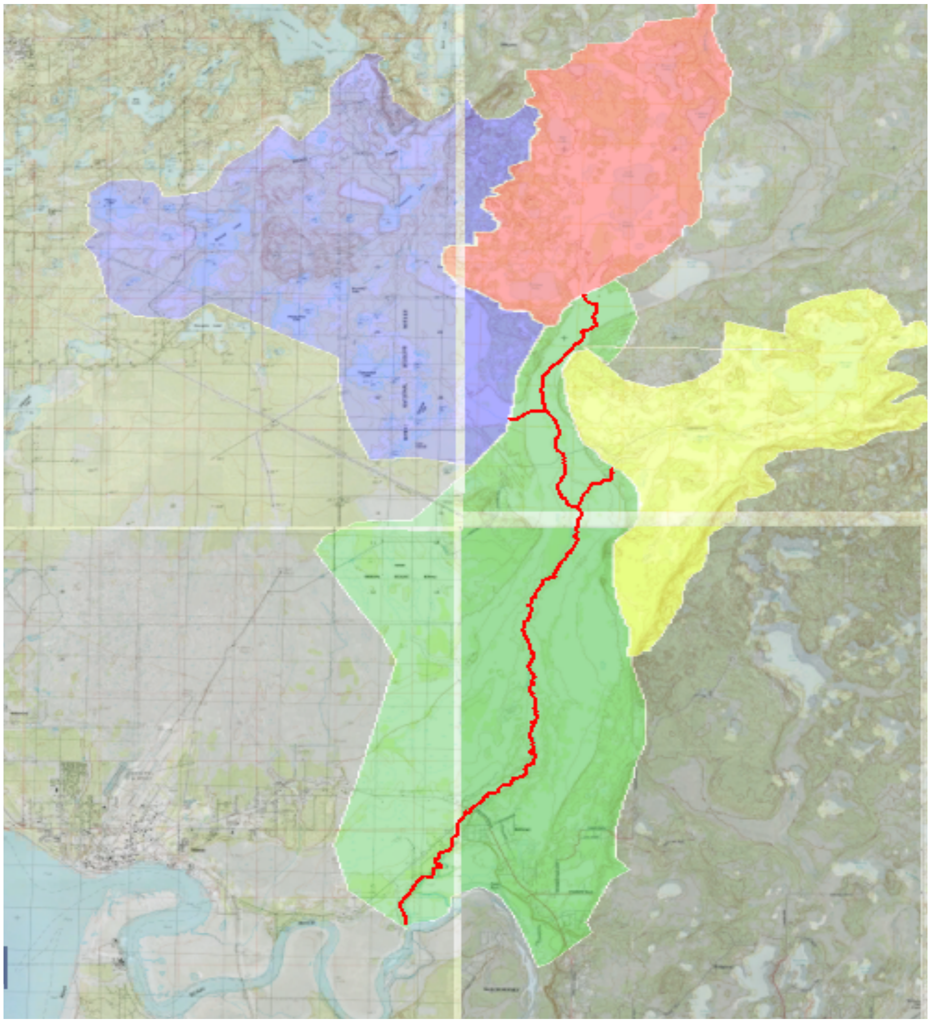

Figure 12. Beaver Creek Drainage Delineation

The Timberlost sub-drainage, highlighted in blue, has an area of 19.91 sq. miles. The Ootka sub-drainage, highlighted in red, has an area of 10.39 sq. miles. The Beaver sub-drainage, highlighted in yellow, has an area of 11.42 sq. miles. The Beaver Creek sub-drainage, highlighted in green, has an area of 26.44 sq. miles. The HEC-HMS model was organized based on the layout determined from the topographic map delineation. Figure 13 shows the layout utilized in the HEC-HMS model for the Beaver Creek sub-basin.

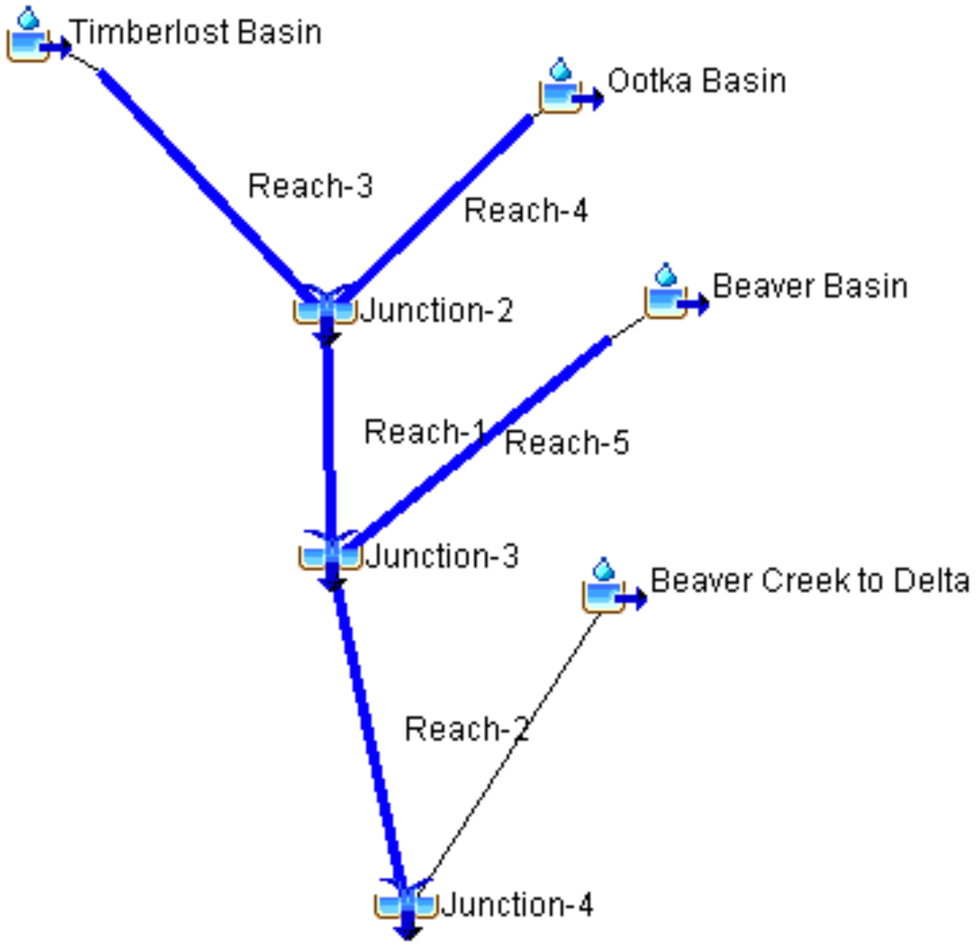

Figure 13. HEC-HMS Model Configuration for Beaver Creek

The input precipitation data for all sub-drainages within the Beaver Creek sub-basin were acquired from the Kenai Municipal Airport. This setup was utilized in the creation of three sets of parameters that distinguish the difference in the basin hydrology during the spring, summer, and fall hydrologic regimes. The following parameters are summarized in Appendix D.

5.1.1 Beaver Creek Spring Modeling

5.1.1.1 Timberlost Basin

Timberlost basin is one branch of the headwaters of Beaver Creek. The Timberlost sub-drainage simple canopy uses an initial storage of 20% and a maximum storage of 1 inch. The simple storage method applies a uniform storage over the entire selected area. This value was determined from the Canadian forest hydrology handbook, based on the through-fall of sitka spruce, western redceder, and western hemlock of 77% and a maximum storm interception of 0.6 inches (Pike et al., 2010). These values were then adjusted to account for the large quantities of brush in the area. It uses a simple surface with an initial storage of 90% and a maximum storage of 2 inches. This method applies a uniform storage value over the selected area. It uses the SCS loss method (Bedient et al., 2013) with a curve number of 65 and an impervious surface of 2%. The SCS curve number was determined using the by the soil type in the Beaver Creek area, Soldotna silty loam (United States Department of Agriculture (USDA), 2016), the hydrologic soil group, C (USDA, 1986), and the cover type, which is brush, weeds, and grasses. The SCS unit hydrograph transform lag time is 700 minutes.

5.1.1.2 Ootka Basin

The Ootka basin, the second branch of the Beaver Creek head waters. The Ootka sub-drainage simple canopy uses an initial storage of 60% and a maximum storage of 1 inch, and a simple surface with an initial storage of 25% and a maximum storage of 1 inch. It uses the SCS loss method with a curve number of 65 and an impervious surface of 2%. The SCS unit hydrograph transform lag time is 600 minutes.

5.1.1.3 Beaver Basin

The Beaver sub-drainage simple canopy uses an initial storage of 10% and a maximum storage of 0.3 inches, and a simple surface with an initial storage of 40% and a maximum storage of 1 inch. It uses the SCS loss method with a curve number of 65 and an impervious surface of 5%. The SCS unit hydrograph transform lag time is 400 minutes.

5.1.1.4 Beaver Creek Basin

The Beaver Creek sub-drainage simple canopy uses an initial storage of 10% and a maximum storage of 0.3 inches, and a simple surface with an initial storage of 60% and a maximum storage of 0.5 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 12%. The SCS unit hydrograph transform lag time is 3500 minutes.

In this portion of the sub-basin, the constant monthly baseflow is accounted for. The baseflow for the months of January through December in cubic feet per second are as follows: 14, 13, 13, 13, 41, 39, 16, 15, 17, 41, 21, 17.

5.1.1.5 Basin Reaches

Five reaches are utilized in the model design. Reaches 3 and 4 connect to junction 2 and combine the flows from the upper portions of the sub-basin as seen in Figure 13. The sub-basin utilizes the Muskingum-Cunge routing method. This method was chosen based on the available data for the sub-basin and the accessibility to determine unknown values. Reach 3 has a measured length of 2804ft, a slope of 0.003, a Manning’s n value of 0.08, and a rectangular channel width of 6.58ft. Reach 4 has a length of 12091ft, a slope of 0.003, Manning’s n of 0.08, and a rectangular channel width of 5.53ft.

Reach 1 connects junctions 2 and 3. It has a length of 9342ft, a slope of 0.003, a Manning's n of 0.08, and a rectangular channel width of 11.23ft.

Reach 5 connects Beaver basin to junction 3. It has a length of 4545ft, a slope of 0.0041, Manning's n of 0.076, and a rectangular channel width of 11.06ft.

Reach 2 connects junction 3 to junction 4 at the outlet of Beaver Creek to the Kenai River. It has a length of 47028ft, a slope of 0.0003, Manning's n of 0.08, and a rectangular channel width of 15.7ft.

5.1.2 Beaver Creek Summer Modeling

5.1.2.1 Timberlost Basin

The Timberlost sub-drainage simple canopy uses an initial storage of 20% and a maximum storage of 0.2 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.2 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 7%. The SCS unit hydrograph transform lag time is 2444 minutes.

5.1.2.2 Ootka Basin

The Ootka sub-drainage simple canopy uses an initial storage of 20% and a maximum storage of 0.2 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.2 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 5%. The SCS unit hydrograph transform lag time is 2200 minutes.

5.1.2.3 Beaver Basin

The Beaver sub-drainage simple canopy uses an initial storage of 29% and a maximum storage of 0.2 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.2 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 7%. The SCS unit hydrograph transform lag time is 1400 minutes.

5.1.2.4 Beaver Creek Basin

The Beaver Creek sub-drainage simple canopy uses an initial storage of 29% and a maximum storage of 0.4 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.47 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 5%. The SCS unit hydrograph transform lag time is 1200 minutes. The baseflow for January through December in cubic feet per second is as follows: 14, 13, 13, 13, 13, 15, 20, 15, 17, 41, 21, 17.

5.1.2.5 Basin Reaches

All basin reaches for the summer parameters utilize the Muskingum-Cunge routing method. This method is utilized for the availability of data for required parameters. The reach layout can be seen in Figure 13.

Reach 3 has a length of 2804ft, slope of 0.004, Manning's n of 0.008, and a rectangular channel width of 6.58ft. Reach 4 has a length of 12091ft, slope of 0.004, Manning's n of 0.08, and a rectangular channel width of 5.53ft. Reach 4 connects Ootka sub-basin to Beaver Creek sub-basin. The reach has a length of 12091ft, a slope of 0.003, a Manning's n of 0.08, and a rectangular channel width of 5.53ft. Reach 1 has a length of 9342ft, slope of 0.0035, a Manning's n of 0.066, and a rectangular channel width of 11.23ft. Reach 5 has a length of 4545ft, a slope of 0.0041, a Manning's n of 0.066, and a rectangular channel width of 11.06ft. Reach 2 has a length of 47028ft, a slope of 0.0031, a Manning's n of 0.066, and a rectangular channel width of 15.7ft.

5.1.3 Beaver Creek Fall Modeling

5.1.3.1 Timberlost Basin

The Timberlost sub-drainage simple canopy uses an initial storage of 20% and a maximum storage of 0.2 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.2 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 5%. The SCS unit hydrograph transform lag time is 2444 minutes.

5.1.3.2 Ootka Basin

The Ootka sub-drainage simple canopy uses an initial storage of 20% and a maximum storage of 0.2 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.2 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 5%. The SCS unit hydrograph transform lag time is 2200 minutes.

5.1.3.3 Beaver Basin

The Beaver sub-drainage simple canopy uses an initial storage of 29% and a maximum storage of 0.2 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.2 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 7%. The SCS unit hydrograph transform lag time is 1400 minutes.

5.1.3.4 Beaver Creek Basin

The Beaver Creek sub-drainage simple canopy uses an initial storage of 29% and a maximum storage of 0.4 inches, and a simple surface with an initial storage of 7% and a maximum storage of 0.47 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 5%. The SCS unit hydrograph transform lag time is 1200 minutes. The baseflow for January through December in cubic feet per second is as follows: 14, 13, 13, 13, 13, 15, 20 ,15, 17, 41, 21, 17.77

5.1.3.5 Basin Reaches

All reaches in the sub-basin uses the Muskingum-Cunge routing method. This method is utilized due to the available data for required parameters. The reach layout can be seen in Figure 13.

Reach 3 has a length of 2804ft, a slope of 0.004, a Manning's n of 0.008, and a rectangular channel width of 6.58ft. Reach 4 has a length of 12091ft, a slope of 0.004, a Manning's n of 0.08, and a rectangular channel width of 5.53ft. Reach 4 connects Ootka sub-basin to Beaver Creek sub-basin. The reach has a length of 12091ft, a slope of 0.003, a Manning's n of 0.08, and a rectangular channel width of 5.53ft. Reach 1 has a length of 9342ft, a slope of 0.0035, a Manning's n of 0.066, and a rectangular channel width of 11.23ft. Reach 5 has a length of 4545ft, a stream slope of 0.0041, a Manning's n of 0.066, and a rectangular channel width of 11.06ft. Reach 2 has a length of 47028ft, a slope of 0.0031, a Manning's n of 0.066, and a rectangular channel width of 15.7ft.

5.2 Russian River Sub-Basin

The Russian River sub-basin is split into two sub-drainages the Upper Russian that accounts for all the land upstream of the Outlet of Lower Russian Lake and then the Lower Russian sub-drainage that accounts for the area downstream of Lower Russian Lake. With a single discharge gauge in the basin located at the outlet of Lower Russian lake, the storage capacity of both Upper and Lower Russian Lakes is combined to create a synthetic lake. The Upper Russian sub-drainage is routed the stream length between Upper and Lower Russian lake. The Upper Russian sub-drainage has a total area of 192.96 sq. miles. The Lower Russian sub-drainage has an area of 64.32 sq. miles. The Upper Russian and Lower Russian sub-drainages both utilize the Upper Russian Lake precipitation gauge data for modeling. The configuration of the Russian River sub-basin in HEC-HMS can be seen in Figure 14.

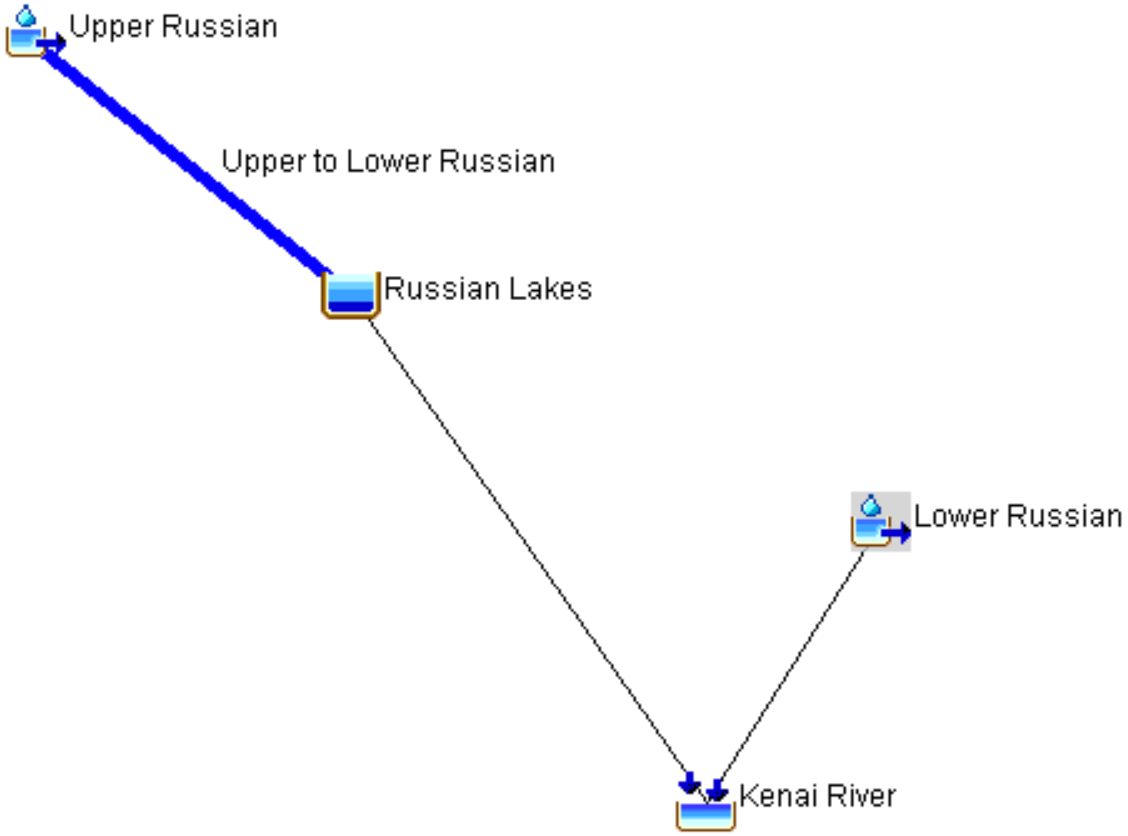

Figure 14. HEC-HMS Model Configuration for Russian River

5.2.1 Upper Russian Basin

The Upper Russian sub-drainage simple canopy uses an initial storage of 17% and a maximum storage of 0.8 inches. The value of 17% for the initial storage is based on the western hemlock – western red cedar through-fall published in the British Columbia forest hydrology handbook of close to 78% (Pike et al., 2010). The published value was then calibrated to account for variation between the forest site published and the Russian River basin. A simple surface with an initial storage of 20% and a maximum storage of 0.9 inches. The soil study near the Russian River found the area to have a soil type of starichkof peat. This soil has a hydrologic soil group of C and is combined grassy meadow and wooded land. Based on this information it uses the SCS loss method with a curve number between 70 and 72, and an impervious surface of 1%. The SCS unit hydrograph transform lag time is 1700 minutes. Baseflow for January through December in cubic feet per second is: 23, 20, 18, 21, 62, 159, 121, 107, 47, 68, 40, 27.

5.2.2 Lower Russian Basin

The Lower Russian sub-drainage simple canopy uses an initial storage of 1% and a maximum storage of 0.39 inches, and a simple surface with an initial storage of 20% and a maximum storage of 0.6 inches. It uses the SCS loss method with a curve number of 70 and an impervious surface of 1.5%. The SCS unit hydrograph transform lag time is 1630 minutes.

5.2.3 Russian Lakes

The Russian Lakes reservoir uses the outflow curve method (Wurbs & James, 2002). The Storage method used is the elevation-storage-discharge method. This method relates the elevation of the lake depth to its corresponding lake storage. The lake storage is then correlated to a discharge. The primary is storage-discharge and the initial conditions are set so the inflow is equal to outflow. Due to the absence of a discharge gauge at the outlet of Upper Russian lake, both Upper Russian lake and Lower Russian lakes were combined to create a composite lake. The composite lake combined the depth and volume of both lakes in the sub-basin. The composite lake elevation-storage data can be viewed in Table 4. The storage-discharge data for the composite lake can be found in Table 5.

Table 4 Composite Russian Lakes Elevation-Storage Data

Elevation Above Sea Level (ft)	Depth Line (ft)	Perimeter (ft)	Area (acre)	Depth (ft)	Volume (ac-ft)	Total Volume (ac-ft)
449	260	6234	13.29	20	265.80	273.00
469	240	8406	24.73	20	494.60	945.80
489	220	9502	39.55	20	791.00	5302.88
509	200	12844	71.62	20	1432.40	8991.02
529	180	16372	120.28	20	2405.60	11396.62
549	160	17952	185.89	20	3717.80	15114.42
569	140	19740	247.76	20	4955.20	20069.62
589	120	24385	329.68	20	6593.60	26663.22
609	100	28902	440.49	20	8809.80	35473.02
629	80	31614	563.36	20	11267.20	46740.22
649	60	33342	701.56	20	14031.20	60771.42
669	40	34831	875.53	20	17510.60	78282.02
684	20	36009	1007.81	15	15117.15	93399.17
689	5	39401	1007.81	5	5039.05	98438.22

Table 5 Composite Russian Lakes Storage-Discharge Data

Elevation (ft)	Storage (ac-ft)	Depth (ft)	Staff Gauge (ft)	Discharge (cfs)
449	449	0		0
469	918	0		0
489	1407	0		0
509	1916	0		0
529	2445	0		0
549	2994	0		0
569	3563	0		0
589	4152	0		0
609	4761	0		0
629	5390	0		0
649	6039	0		0
669	6708	0		0
681	7389	0		0
684	8073	1		0
687	8760	4	0	0
688	9448	5	1	48.8
689	10137	6	2	245.31
692	10140	9	5	834.84

5.2.4 Russian River Reach

The reach used to move water from the Upper Russian sub-drainage utilizes the Muskingum-Cunge method with no loss or gain method. The stream length is 44880ft, slope of 0.004, a Manning's n of 0.025, and a rectangular channel width of 45ft.

5.3 Ptarmigan Creek Sub-Basin

Ptarmigan Creek sub-basin has been split into two sub-drainages for the purpose of modeling. The Ptarmigan Creek upper accounts for the area of Ptarmigan Lake and upstream, while Ptarmigan Creek lower accounts for the area downstream of the lake. The area of Ptarmigan Creek upper is 101.21 sq. miles. Ptarmigan Creek lower has an area of 33.74 sq. miles. The model is arranged based on this information. The Ptarmigan Creek sub-basin uses the precipitation data from the Ptarmigan Lake precipitation gauge, and the Grandview precipitation gauge for dates that the Ptarmigan Lake gauge was inoperable. The configuration used in the HEC-HMS model for Ptarmigan Creek can be viewed in Figure 15.

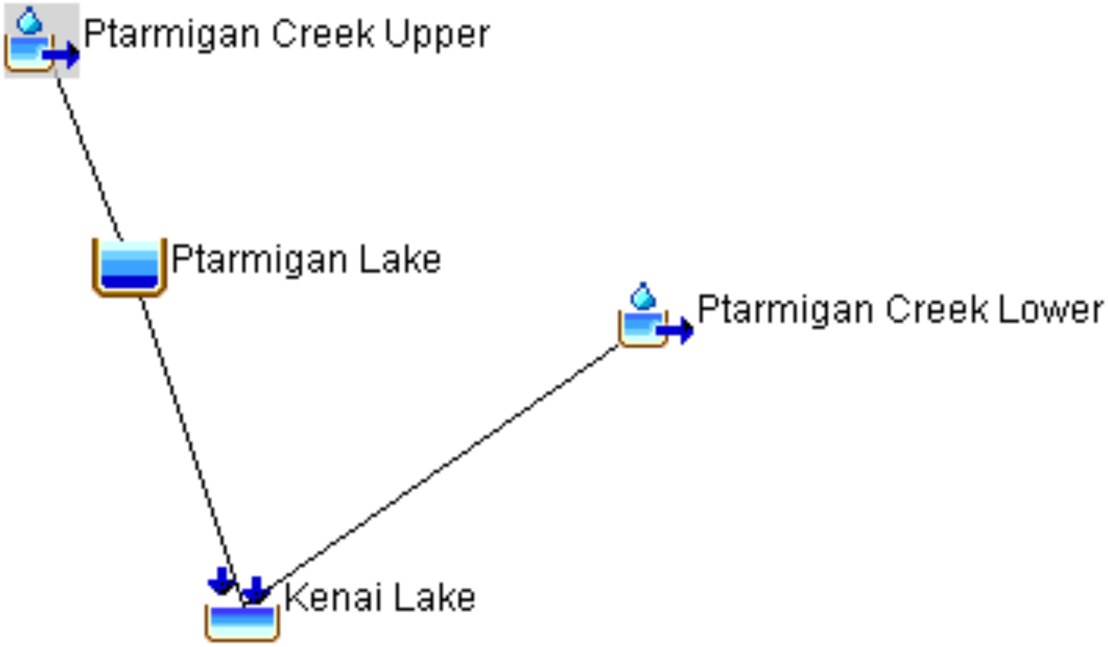

Figure 15. HEC-HMS Configuration for Ptarmigan Creek

5.3.1 Ptarmigan Creek Upper Basin

The Ptarmigan Creek Upper sub-drainage simple canopy uses an initial storage of 80% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 90% and a maximum storage of 0.3 inches. It uses the SCS loss method with a curve number of 69 and an impervious surface of 5.5%. The SCS unit hydrograph transform lag time is 1080 minutes. The baseflow for January through December in cubic feet per second is: 1, 1, 1, 1, 185, 181, 151, 122, 96, 112, 68, 1.

5.3.2 Ptarmigan Creek Lower Basin

The Ptarmigan Creek Lower sub-drainage simple canopy uses an initial storage of 70% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 40% and a maximum storage of 0.4 inches. It uses the SCS loss method with a curve number of 72 and an impervious surface of 2%. The SCS unit hydrograph transform lag time is 290 minutes.

5.3.3 Ptarmigan Lake

Ptarmigan lake uses the elevation-storage-discharge storage method. The method utilized is the outflow curve and has the primary storage-discharge, and initial conditions are set so that the inflow is equal to outflow conditions. The elevation-storage curve can be seen in Figure 16. Figure 17 shows the storage-discharge data.

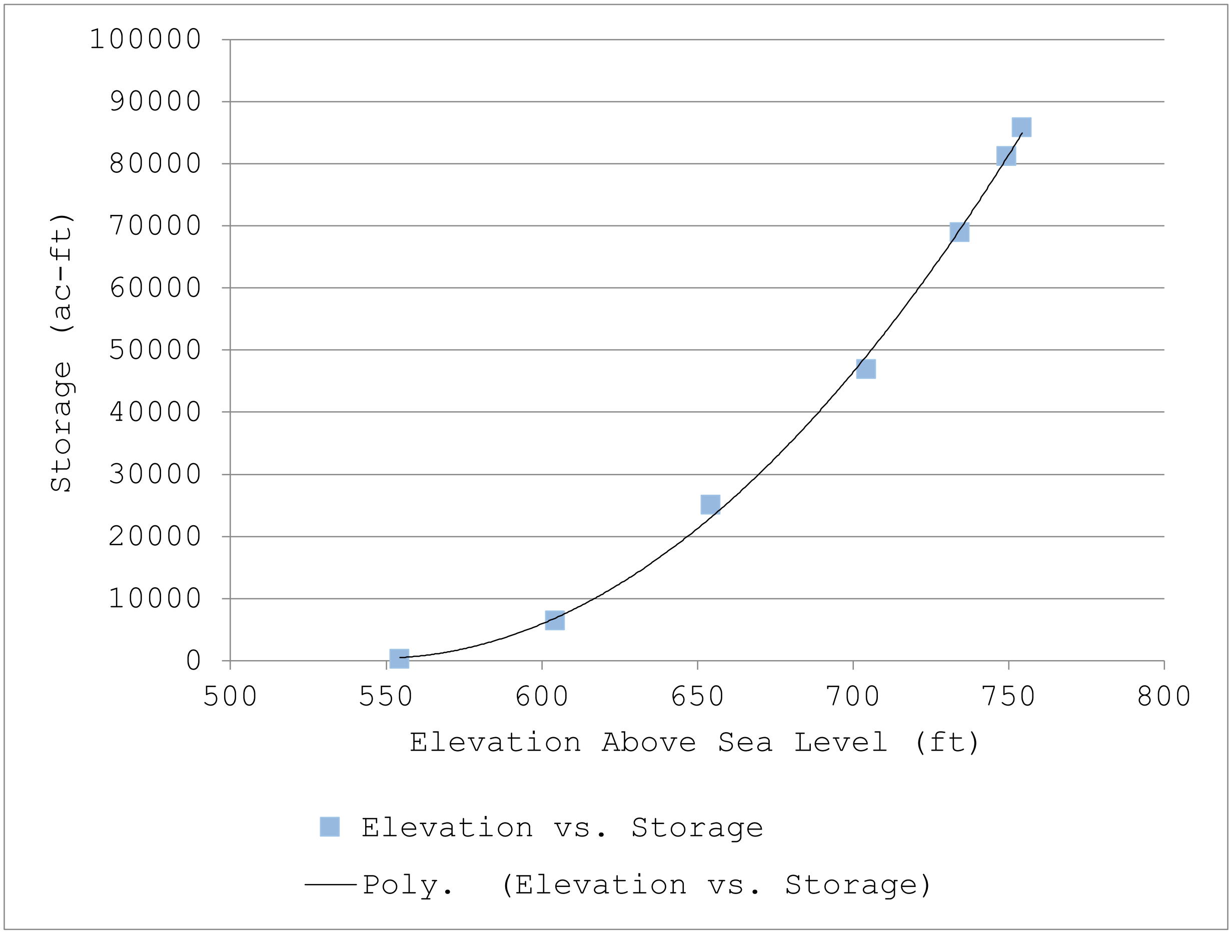

Figure 16. Elevation-Storage Data for Ptarmigan Lake Referenced to Sea Level. Regression equation can be found in Appendix C.

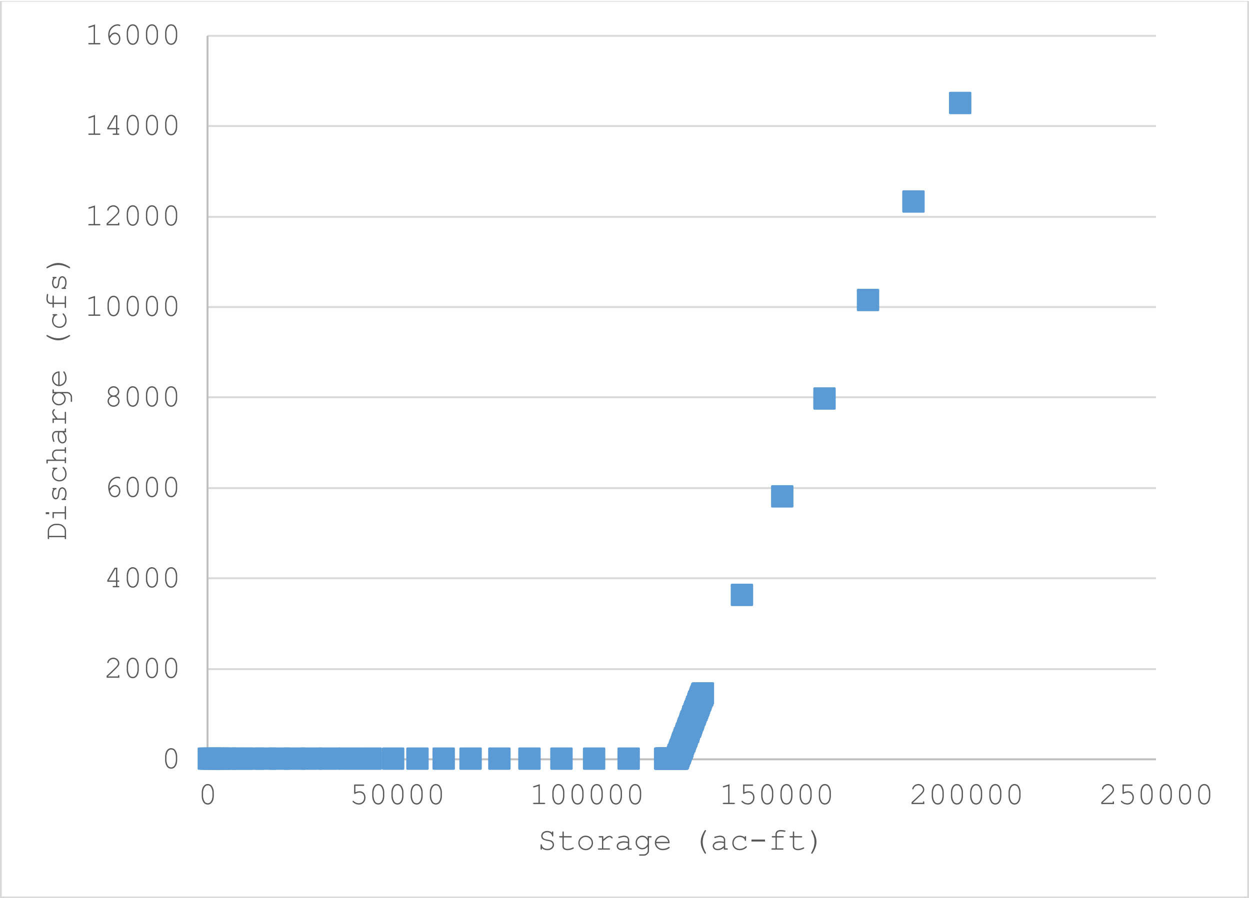

Figure 17. Ptarmigan Storage-Discharge Data

5.4 Kenai River Watershed

The Kenai River watershed model is divided into thirteen separate sub-basins. The sub-basins utilized for the delineation of the Kenai River watershed are the Snow River, Ptarmigan Creek, Trail River, Quartz Creek, Upper Kenai River, Russian River, Skilak River, Middle Kenai River, Moose River, Killey River, Funny River, Beaver Creek, and Lower Kenai River. The watershed also contains two large lakes along the Kenai River and one lake in the Ptarmigan Creek sub-basin and one lake in the Russian River sub-basin. Figure 18 displays the HEC-HMS model configuration for the watershed scale model.

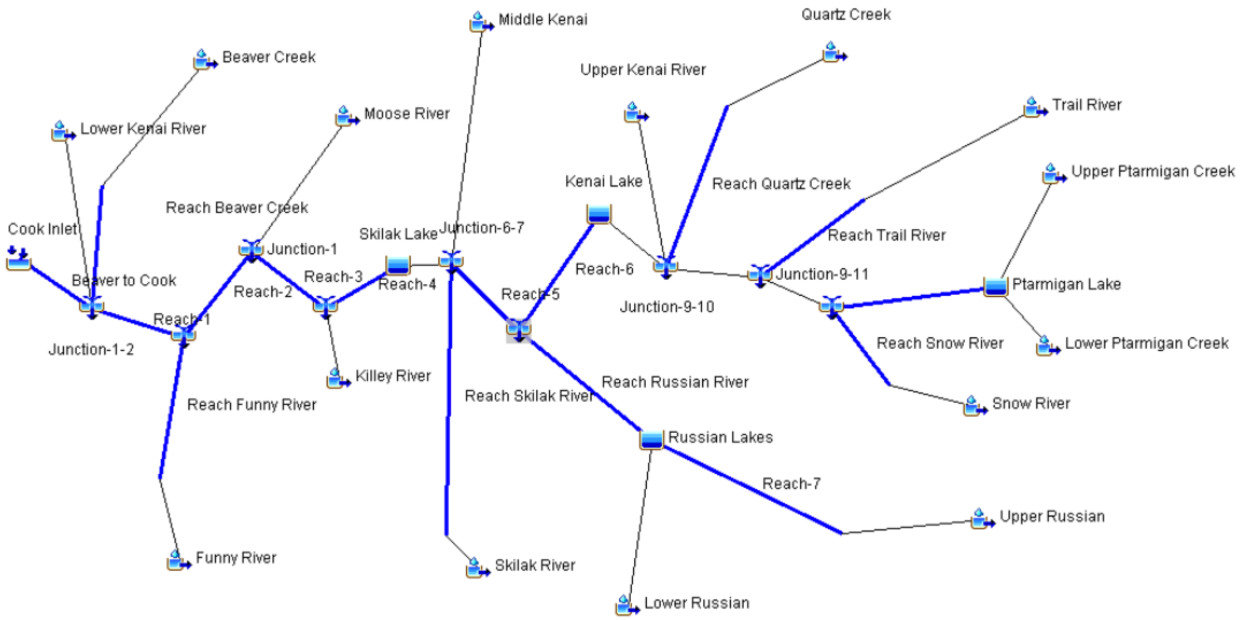

Figure 18. HEC-HMS Model Configuration for the

Kenai River Watershed

5.4.1 Snow River

The Snow River sub-basin has an area of 660.41 sq. miles. It uses the Grouse Creek Divide precipitation gauge for input data. It uses an initial storage of 100% and a maximum storage of 0.5 inches, and a simple surface with an initial storage of 100% and a maximum storage of 1.2 inches. It uses the SCS loss method with a curve number of 70 and an impervious surface of 29.41%. The SCS unit hydrograph transform lag time is 1700 minutes. The baseflow for January through December in cubic feet per second are as follows: 65, 56, 42, 63, 714, 159, 2270, 2100, 1440, 471, 160, 100. The snow River reach has a length of 26188ft, slope of 0.0094, Manning's n of 0.03, and a rectangular channel width of 223ft.

5.4.2 Ptarmigan Creek

The Ptarmigan Creek sub-basin is split into two separate sub-drainages as described in section 5.3. Both Upper Ptarmigan Creek and Lower Ptarmigan Creek use the Ptarmigan Lake precipitation gauge if available for the modeling dates, otherwise the Grandview precipitation gauge is used. The Upper Ptarmigan Creek sub-drainage has an area of 101.21 sq. miles. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.3 inches. It uses the SCS loss method with a curve number of 69 and an impervious surface of 5.58%. The SCS unit hydrograph transform lag time is 1080 minutes. The baseflow for January through December in cubic feet per second is: 15, 12, 10, 10, 50, 162, 222, 182, 120, 56, 37, 18.

The Lower Ptarmigan sub-drainage has an area of 33.74 sq. miles. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.4 inches. It uses the SCS loss method with a curve number of 72 and an impervious surface of 0.5%. The SCS unit hydrograph transform lag time is 290 minutes.

The values for Ptarmigan Lake are can be found in section 5.3.3 above. The Ptarmigan Creek reach uses the Muskingum-Cunge routing method. The reach length is 3785ft, slope of 0.033, a Manning's n of 0.03, and a rectangular channel width of 70ft.

5.4.3 Trail River

The Trail River sub-basin has an area of 813.67 sq. miles. It uses the Grandview precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.05 inches. It uses the SCS loss method with a curve number of 70 and an impervious surface of 3.82%. The SCS unit hydrograph transform lag time is 3600 minutes. The baseflow for January through December in cubic feet per second is: 80, 66, 64, 62, 380, 1250, 1640, 1450, 740, 395, 176, 90. The Trail River reach has a length of 4951ft, a slope of 0.0096, a Manning's n of 0.03, and a rectangular channel width of 82ft.

5.4.4 Quartz Creek

The Quartz Creek sub-basin has an area of 455.19 sq. miles. It uses the Summit Creek precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.5 inches. It uses the SCS loss method with a curve number of 72 and an impervious surface of 1.19%. The SCS unit hydrograph transform lag time is 1200 minutes. The baseflow for January through December in cubic feet per second is: 88, 51, 46, 59, 91, 21, 400, 439, 180, 246, 211, 98. The Quartz Creek reach routing parameters are a length of 1653ft, slope of 0.0143, a Manning's n of 0.03, and a rectangular channel width of 72ft.

5.4.5 Upper Kenai

The Upper Kenai sub-basin has an area of 587.93 sq. miles. It utilizes the Grandview precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.5 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.5 inches. It uses the SCS loss method with a curve number of 70 and an impervious surface of 7.14%. The SCS unit hydrograph transform lag time is 3600 minutes. The baseflow for January through December in cubic feet per second is: 112, 65, 58, 76, 115, 27, 716, 559, 230, 312, 268, 124.

5.4.6 Kenai Lake

Kenai lake, located at the outlet of the Upper Kenai sub-basin is one of the two large reservoirs along the Kenai River. The lake has a total storage capacity of 179 trillion cubic feet of storage (Spafard & Edmundson, 2000). The bathymetry of Kenai Lake can be viewed in Figure 19.

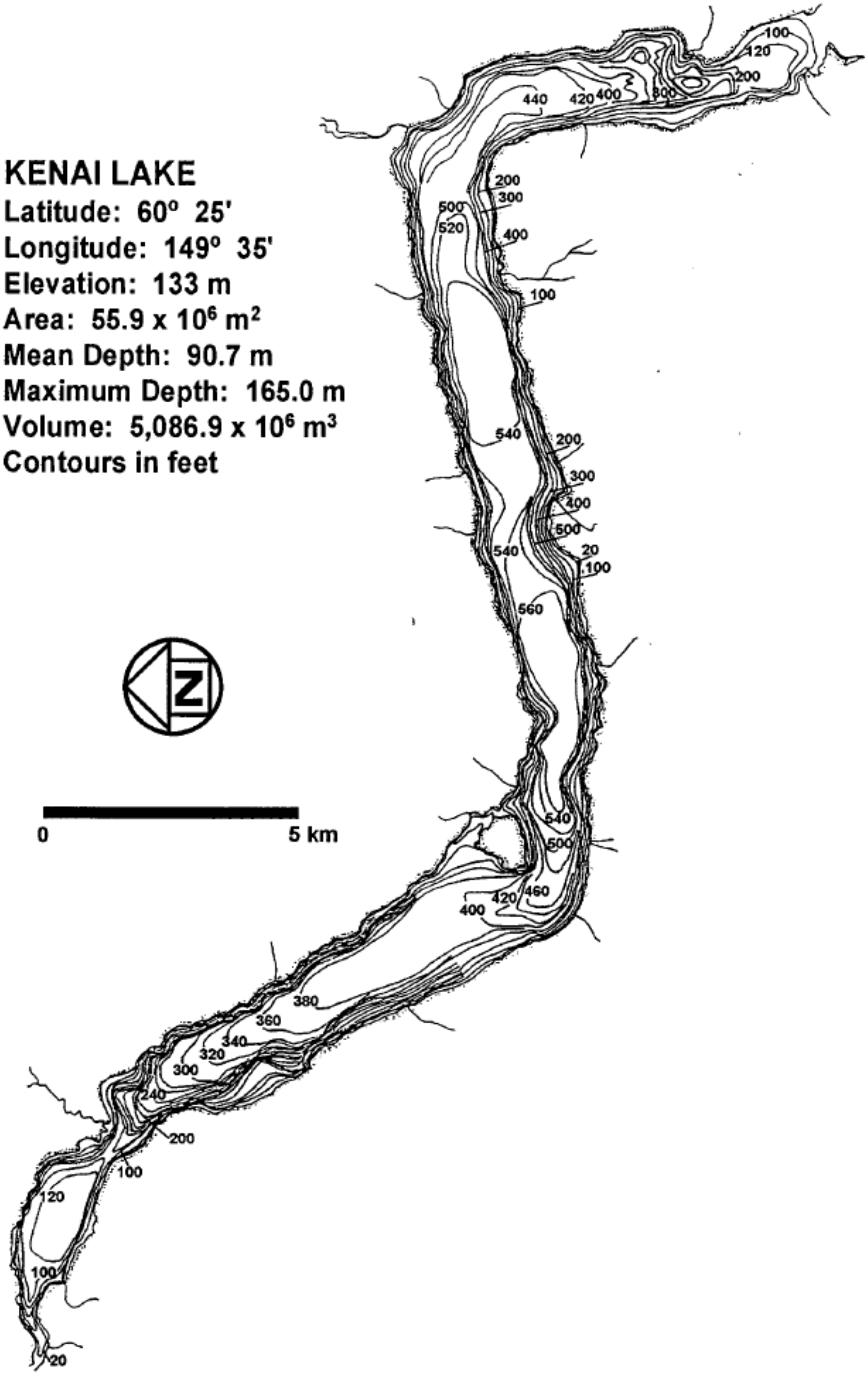

Figure 19. Kenai Lake Bathymetry (Spafard & Edmundson, 2000)

The reservoir method used is the outflow method and the storage method is the storage-discharge method. The initial conditions are set to inflow is equal to outflow. Table 6 displays the elevation-storage relationship for Kenai Lake. Figure 20 displays the storage-discharge relationship for Kenai Lake.

Table 6 Kenai Lake Elevation-Storage Relationship

Elevation Above Sea Level (ft)	Storage (ac-ft)
424.57	4544106.04
425.57	4553615.24
426.58	4563219.54
427.58	4572728.74
428.56	4582047.75
429.56	4591556.95
430.58	4601256.34
431.59	4610860.63
432.74	4621796.21
433.52	4629213.38
434.42	4637771.66
435.62	4649182.70
437.08	4663066.14

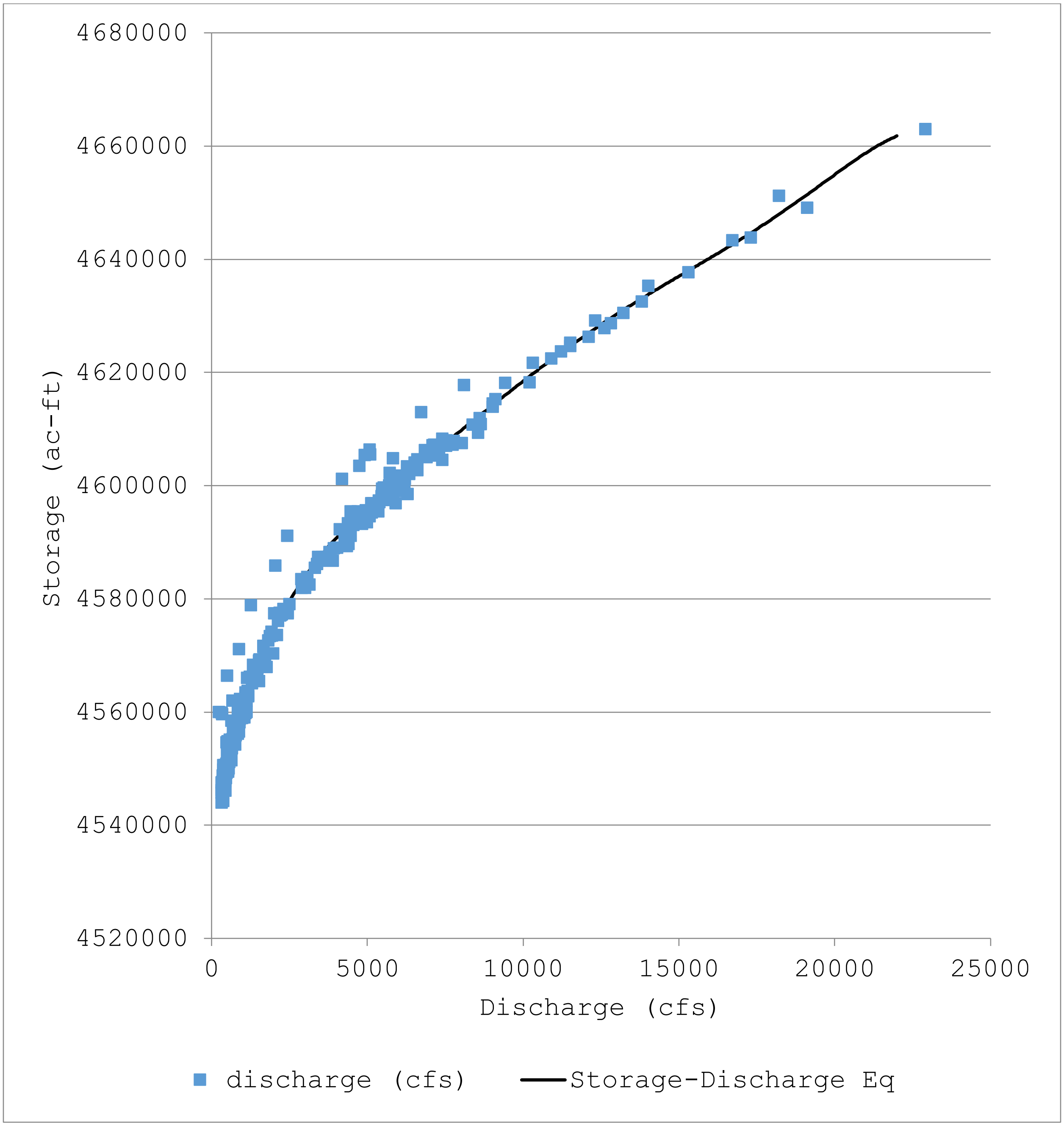

Figure 20. Kenai Lake Storage-Discharge Relationship. Regression equation can be found in Appendix C

5.4.7 Russian River

The Russian River sub-basin as divided into two sub-drainages as described above in section 5.2. Both sub-drainages use the Upper Russian Lake precipitation gauge for input data. The Upper Russian sub-drainage has an area of 192.96 sq. miles. The simple canopy uses an initial storage of 100% and a maximum storage of 0.8 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.9 inches. It uses the SCS loss method with a curve number of 70 and an impervious surface of 1.8%. The SCS unit hydrograph transform lag time is 1700 minutes. The baseflow for January through December in cubic feet per second is: 25, 23, 18, 21, 97, 189, 158, 74, 58, 93, 49, 28. The Muskingum-Cunge routing from the Upper Russian sub-drainage to Russian lakes is 44880ft, a slope of 0.004, Manning's n of 0.025, and a rectangular channel width of 45ft.

The Lower Russian sub-drainage has an area of 62.32 sq. miles. The simple canopy uses an initial storage of 100% and a maximum storage of 0.39 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.6 inches. It uses the SCS loss method with a curve number of 70 and an impervious surface of 1.8%. The SCS unit hydrograph transform lag time is 1630 minutes. The Russian Lakes follows the configuration described in section 5.2.3.

The Russian River reach uses the Muskingum-Cunge routing method. The reach length is 1097ft, a slope of 0.0112, a Manning's n of 0.025, and a rectangular channel width of 105 ft.

5.4.8 Skilak River

The Skilak River sub-basin has an area of 897.51 sq. miles. It uses the Upper Russian Lake precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.14 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.1 inches. It uses the SCS loss method with a curve number of 72 and an impervious surface of 24.23%. The SCS unit hydrograph transform lag time is 3600 minutes. The baseflow for January through December in cubic feet per second is: 300, 310, 227, 1815, 673, 1643, 2269, 2518, 2151, 1229, 533, 442. The Muskingum-Cunge reach routing has a length of 19387ft, a slope of 0.0046, a Manning's n value of 0.03, and a rectangular channel width of 162ft.

5.4.9 Middle Kenai

The Middle Kenai sub-basin has an area of 1244.37 sq. miles. It uses the Kenai Moose Pens precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.3 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.5 inches. It uses the SCS loss method with a curve number of 72 and an impervious surface of 6.2%. The SCS unit hydrograph transform lag time is 1600 minutes. The baseflow for January through December in cubic feet per second is: 415, 427, 313, 255, 930, 2268, 5248, 3478, 2971, 1698, 736, 610.

5.4.10 Skilak Lake

Skilak Lake is the second large lake along the flow path of the Kenai River. Skilak lake has a total storage capacity of 251 trillion cubic feet (Spafard & Edmundson, 2000). The bathymetry of Skilak Lake can be viewed in Figure 21.

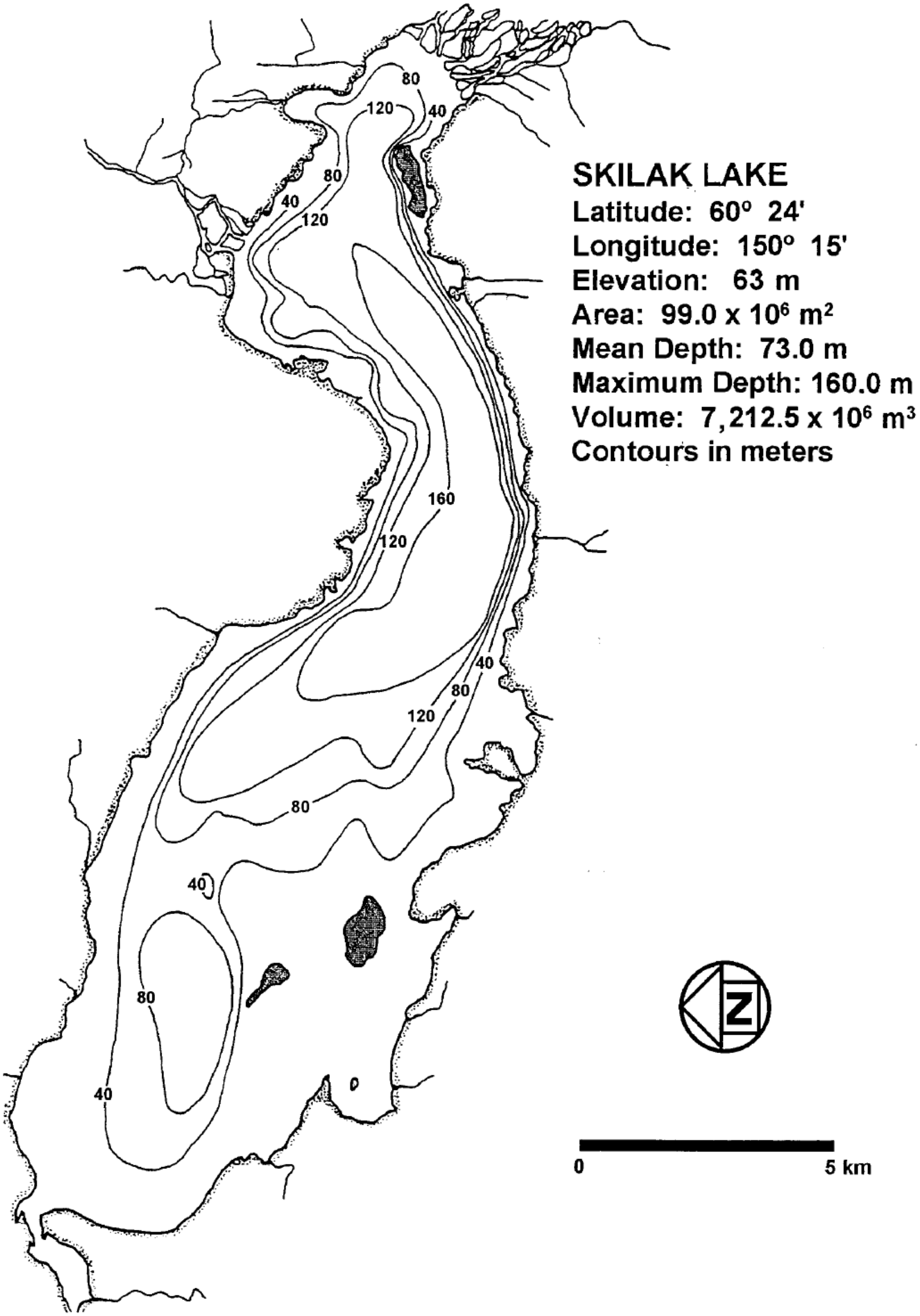

Figure 21. Skilak Lake Bathymetry (Spafard & Edmundson, 2000)

The lake uses the outflow curve method and the storage-discharge storage method and the initial conditions are set so inflow is equivalent to outflow conditions. The storage-discharge relationship for Skilak Lake can be seen in Figure 22.

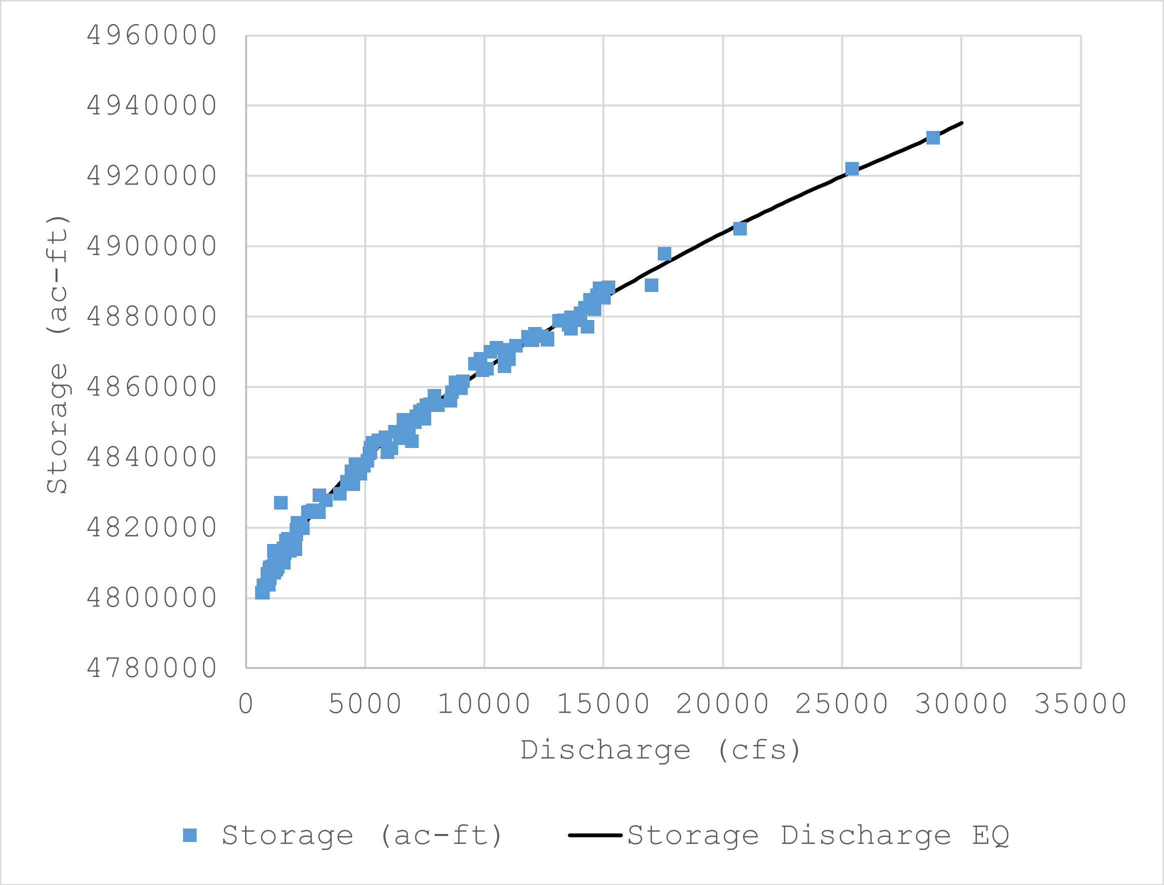

Figure 22. Skilak Lake Storage-Discharge Relationship. Regression equation can be found in Appendix C.

5.4.11 Moose River

The Moose River sub-basin has an area of 1061.19 sq. miles. It uses the Kenai Moose Pens precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.3 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.5 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 2.26%. The SCS unit hydrograph transform lag time is 2000 minutes.

The baseflow for January through December in cubic feet per second is: 0, 0, 7, 81, 0, 0, 120, 180, 0, 0, 0, 0.

5.4.12 Killey River

The Killey River sub-basin has an area of 908.92 sq. miles. It uses the Sterling 6 SW precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.1 inches. It uses the SCS loss method with a curve number of 72 and an impervious surface of 15.45%. The SCS unit hydrograph transform lag time is 3600 minutes. The larger impervious value is due to a small finger of the Harding Ice Field reaching into the headwaters of the basin. The baseflow for January through December in cubic feet per second is: 0, 0, 6, 70, 0, 0, 104, 156, 0, 0, 0, 0.

5.4.13 Funny River

The Funny River sub-basin has an area of 566.97 sq. miles. It uses the Sterling 6 SW precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.1 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 0.3%. The SCS unit hydrograph transform lag time is 2600 minutes. The baseflow for January through December in cubic feet per second is: 0, 0, 4, 43, 0, 0, 64, 96, 0, 0, 0, 0. The Funny River reach uses the Muskingum-Cunge routing method. The stream reach length is 248ft, a slope of 0.0091, a Manning's n of 0.03, and a rectangular channel width of 42ft.

5.4.14 Beaver Creek

The Beaver Creek sub-basin has an area of 250.69 sq. miles, as defined by GIS. It uses the Kenai Municipal Airport precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.4 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.8 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 2.5%. The SCS unit hydrograph transform lag time is 1600 minutes. The baseflow for January through December in cubic feet per second is: 12, 11, 10, 19, 27, 21, 15, 14, 16, 23, 19, 11. The Beaver Creek routing reach uses the Muskingum-Cunge routing method. The reach is 292ft, a slope of 0.001, a Manning's n of 0.035, and a rectangular channel width of 55ft.

5.4.15 Lower Kenai

The Lower Kenai sub-basin has an area of 952.23 sq. miles. It uses the Kenai Municipal Airport precipitation gauge for input data. The simple canopy uses an initial storage of 100% and a maximum storage of 0.1 inches, and a simple surface with an initial storage of 100% and a maximum storage of 0.8 inches. It uses the SCS loss method with a curve number of 65 and an impervious surface of 4.34%. The SCS unit hydrograph transform lag time is 4000 minutes. The baseflow for January through December in cubic feet per second is: 0, 0, 6, 75, 0, 0, 654, 168, 0, 0, 0, 0.

5.4.16 Kenai River Watershed Reaches

There are seven reaches that route water through the Kenai River. These reaches are arranged as seen in figure 18. Reach 6 routes water from Kenai Lake to the confluence of the Russian River. This reach uses the Muskingum-Cunge routing method. The reach length is 43560ft, a slope of 0.002, a Manning's n of 0.025, and a rectangular channel width of 159ft. Reach 5 routes water from the confluence of the Russian River and the Kenai River to Skilak Lake. The reach method is the Muskingum-Cunge method. The reach length is 45901ft, a slope of 0.003, a Manning's n of 0.025, and a rectangular channel width of 109ft. Reach 4 routes water from the outlet of Skilak Lake to the confluence with the Killey River. The reach length is 35390ft, a slope of 0.00001, a Manning's n of 0.025, and a rectangular channel width of 309ft. Reach 3 routes water from the Killey River Junction to the Moose River Junction. The reach length is 40235ft, a slope of 0.0014, a Manning's n of 0.025, and a rectangular channel width of 309ft. Reach 2 routes water between the junction of Moose River and the junction of Funny River. The reach length is 27945ft, a slope of 0.001, a Manning's n value of 0.025, and a rectangular channel width of 265ft. Reach 1 routes water from the junction of Funny River to the junction of Beaver Creek. The reach length is 101377ft, a slope of 0.001, a Manning's n value of 0.03, and a rectangular channel width of 424ft. The last reach routes water from the confluence of Beaver Creek with the Kenai to Cook Inlet. This reach has a length of 50583ft, a slope of 0.00002, a Manning's n of 0.03, and a rectangular channel width of 840ft.

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Chapter 6 Results

6.1 Beaver Creek Sub-Basin

6.1.1 Spring Beaver Creek

The spring modeling of Beaver Creek was found to be successful. The time period used to perform the calibration was May 27, 1972 through June 9, 1972. The validity of calibrating this model to historic data from the 1970's will be discussed later in the text. During this time period almost an inch of rain fell over the basin. The maximum error of the daily modeled discharge over this period of study is approximately 8%. The averaged discharge error for the calibration of the model is 2.8%, and the error in the volume of throughput during the time period is 1.6%. Table 7 displays the results from the spring calibration, while Figure 23 plots the observed discharge verses the modeled discharge for the calibration trial.

Table 7 Beaver Creek Spring Calibration

DATE	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
5/27/72	43.00	0.00	41.00	4.7
5/28/72	42.00	0.08	41.00	2.4
5/29/72	42.00	0.02	41.00	2.4
5/30/72	41.00	0.00	41.00	0.0
5/31/72	43.00	0.15	41.40	3.7
6/1/72	44.00	0.02	40.80	7.3
6/2/72	49.00	0.68	45.00	8.2
6/3/72	61.00	0.01	60.10	1.5
6/4/72	60.00	0.00	61.00	1.7
6/5/72	55.00	0.01	55.60	1.1
6/6/72	49.00	0.00	48.50	1.0
6/7/72	44.00	0.00	43.80	0.5
6/8/72	41.00	0.00	41.70	1.7
6/9/72	39.00	0.00	40.50	3.8

Averaged Error:				2.8
Volume Error	653.00		642.40	1.6

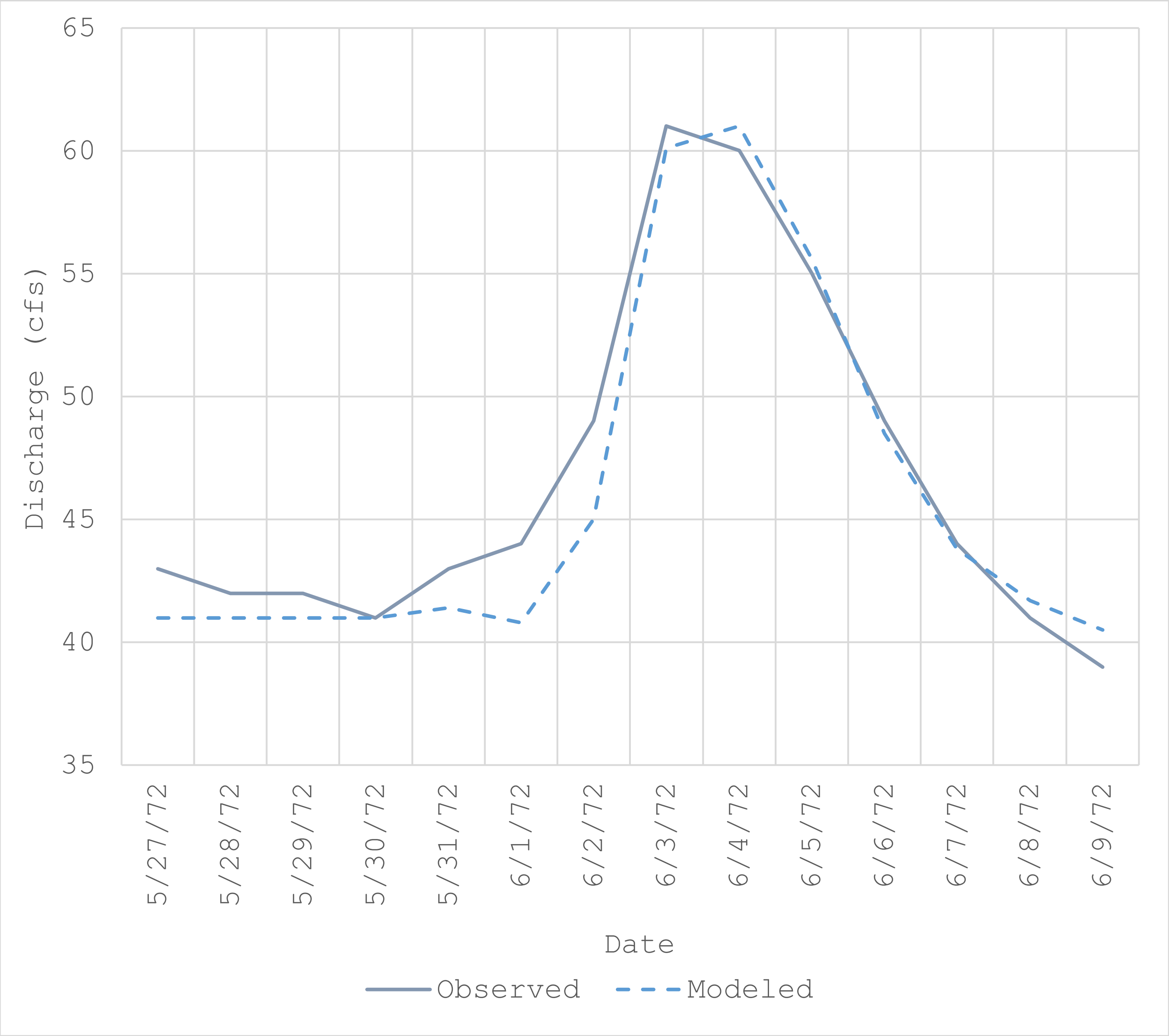

Figure 23. Beaver Creek Spring Calibration Results

6.1.2 Summer Beaver Creek

The summer modeling of the Beaver Creek proved to be successful. The summer modeling calibration window used is July 11, 1971 through July 18, 1971. The summer calibration trial verifies the spring calibration since the hydrologic parameters remained constant except for those accounting for summer growth of vegetation. On the second and third day of this period the there was a total of over a half inch of precipitation measured at the nearest precipitation gauge to the sub-basin. With this precipitation applied to all sub-drainages within the sub-basin the modeled outflow and observed discharge trended in the same patterns. The largest error on the daily discharge values for the modeling period is 7.4%. The average of the average discharge errors is 3.9% and the error in the volume is 1.4%. Table 8 shows the daily results from the summer calibration trial, while Figure 24 plots the observed discharge versus the modeled discharge for this modeling trial.

Table 8 Beaver Creek Summer Calibration Data

Date	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
7/11/71	21.00	0.00	20.00	4.8
7/12/71	20.00	0.06	20.00	0.0
7/13/71	25.00	0.52	26.20	4.8
7/14/71	32.00	0.00	31.30	2.2
7/15/71	28.00	0.00	29.30	4.6
7/16/71	26.00	0.00	25.50	1.9
7/17/71	24.00	0.00	22.70	5.4
7/18/71	23.00	0.00	21.30	7.4

Average Error				3.9
Volume Error	199.00		196.30	1.4

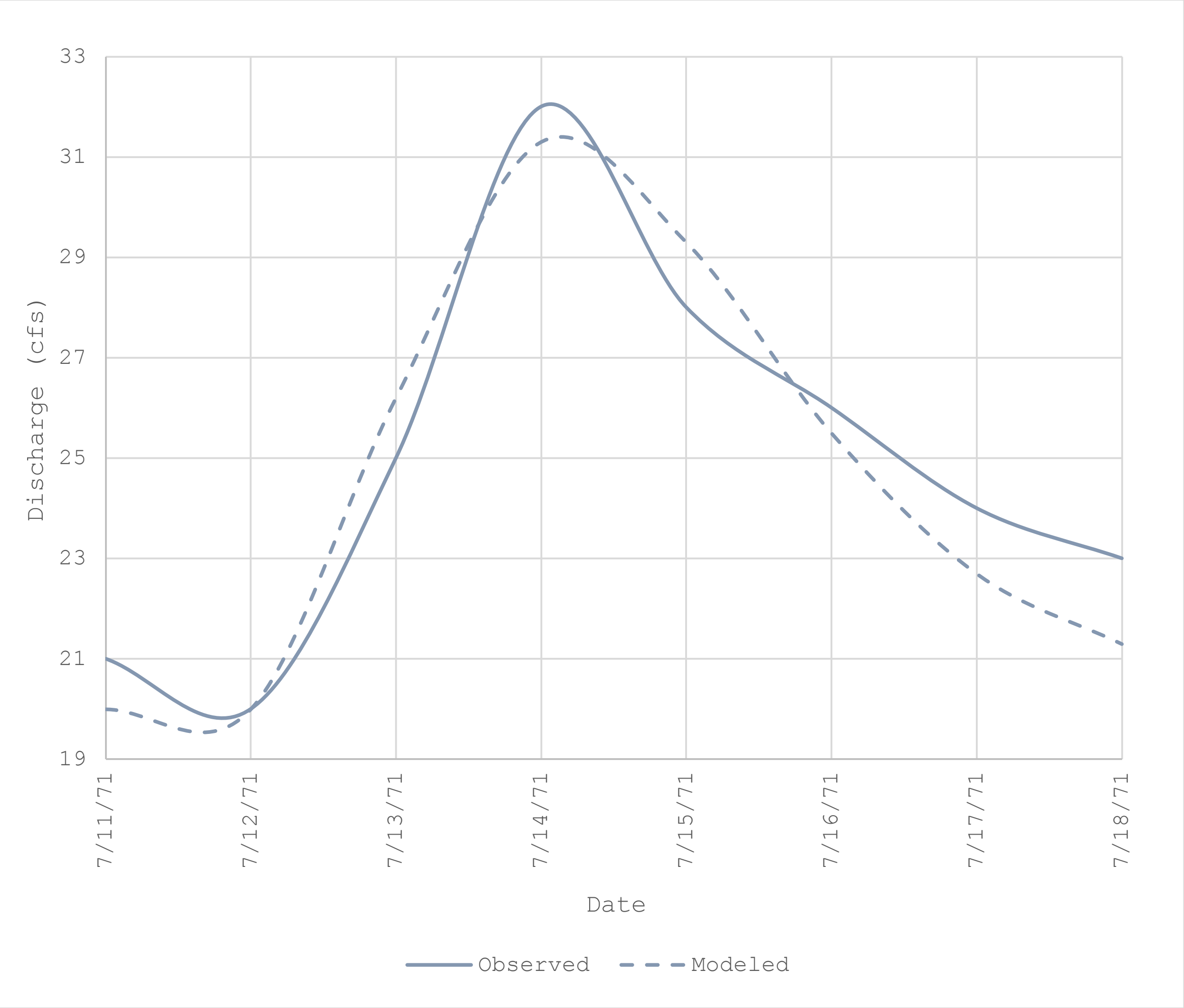

Figure 24. Beaver Creek Summer Calibration Results

6.1.3 Fall Beaver Creek

The fall calibration effort was the least successful out of the Beaver Creek modeling work. The adjustments made to the parameters between the seasonal modeling parameters were limited to mainly adjustments to the surface and canopy storages. The fall modeling trial verifies the summer calibration trial. The modeling period used for the fall study extends from August 28, 1970 through September 21, 1970. The length of the modeling period is extended due to the length of storm in the area. Storms of similar length to the spring and summer calibration periods were not available for times of coinciding precipitation and discharge measurements. The maximum daily error for fall modeling period is 24% and the average daily error is 9.4% and the error in the volume is 6.6%. The precipitation over this time occurred in two peaks and the total precipitation is 2.69 inches. Table 9 shows the results from the fall modeling calibration, and Figure 25 plots the observed discharge versus the modeled discharge.

Table 9 Beaver Creek Fall Calibration Data

Date	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
8/28/70	21.00	0.09	21.00	0.0
8/29/70	23.00	0.15	21.00	8.7
8/30/70	26.00	0.28	21.20	18.5
8/31/70	28.00	0.00	21.80	22.1
9/1/70	25.00	0.00	21.60	13.6
9/2/70	23.00	0.00	21.70	5.7
9/3/70	23.00	0.67	25.80	12.2
9/4/70	33.00	0.45	35.00	6.1
9/5/70	40.00	0.00	39.10	2.3
9/6/70	36.00	0.00	35.40	1.7
9/7/70	32.00	0.00	30.10	5.9
9/8/70	28.00	0.00	26.10	6.8
9/9/70	24.00	0.00	23.40	2.5
9/10/70	22.00	0.00	21.90	0.5
9/11/70	24.00	0.86	26.90	12.1
9/12/70	34.00	0.00	34.90	2.6
9/13/70	34.00	0.00	34.30	0.9
9/14/70	31.00	0.00	30.20	2.6
9/15/70	29.00	0.04	26.40	9.0
9/16/70	29.00	0.15	23.60	18.6
9/17/70	29.00	0.00	22.00	24.1
9/18/70	27.00	0.00	21.10	21.9
9/19/70	25.00	0.00	20.60	17.6
9/20/70	23.00	0.00	20.30	11.7
9/21/70	22.00	0.00	20.20	8.2

Average Error				9.4
Volume Error	691		645.6	6.6

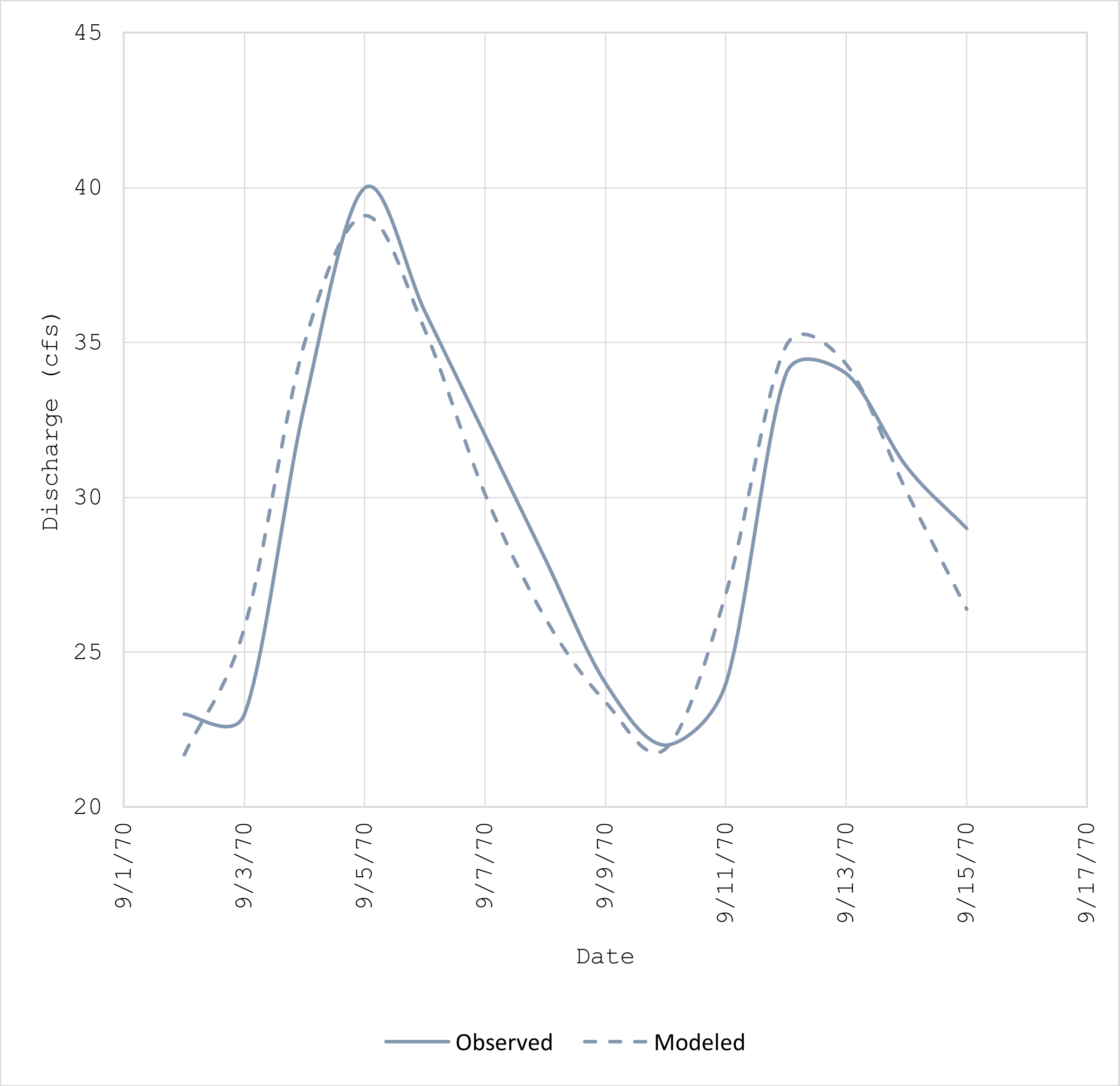

Figure 25. Beaver Creek Fall Calibration Results

6.3 Russian River Sub-Basin

The Russian River proved to be very successful for the modeling period used. The time used is August 15, 2015 through August 20, 2015. During this time, over one inch of precipitation fell on the sub-basin. The maximum daily error in the modeled discharge is 0.7% and the average daily error is 0.3% with an error in the volume of 0.2% over the modeling time period. Table 10 displays the daily results from the calibration trial, and Figure 26 plots the observed discharge versus the modeled discharge.

Table 10 Russian River Calibration Data

Date	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
8/15/15	107.69	0.13	107.00	0.6
8/16/15	108.44	0.47	107.70	0.7
8/17/15	112.32	0.48	112.70	0.3
8/18/15	115.46	0.00	115.30	0.1
8/19/15	112.60	0.00	112.70	0.1
8/20/15	110.76	0.00	110.70	0.1

Average Error				0.3
Volume Error	667.3		666.1	0.2

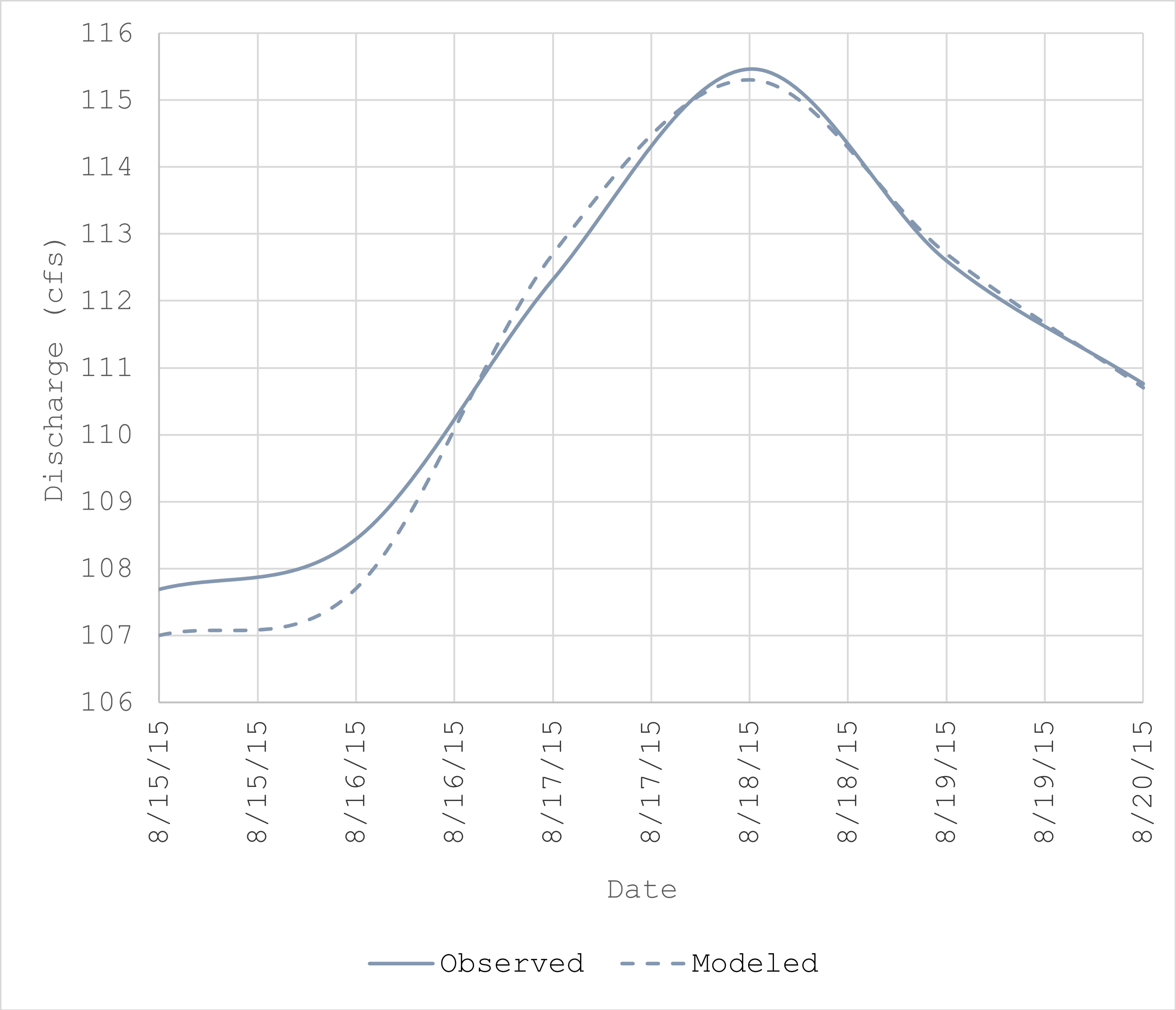

Figure 26. Russian River Calibration Results

To verify the Russian River calibration, the model was applied to a second storm. The time period modeled for the verification is July 15, 2015 to July 25, 2015. The verification of the Russian River showed an increase in both the average discharge error and the total volume error. The average error in the discharge increased to 10% and the error in the volume increased to 10.1%. Table 11 displays the results from the Russian River verification trial, and Figure 27 plots the observed discharge versus the modeled discharge.

Table 11 Russian River Verification Data

Date	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
7/15/15	146.80	0.06	121.00	17.6
7/16/15	144.40	0.10	122.10	15.4
7/17/15	143.80	0.00	123.00	14.5
7/18/15	143.40	0.00	122.60	14.5
7/19/15	140.60	0.00	122.20	13.1
7/20/15	137.00	0.00	121.70	11.2
7/21/15	134.70	0.00	121.50	9.8
7/22/15	133.90	0.63	128.10	4.3
7/23/15	140.20	0.00	133.70	4.6
7/24/15	137.90	0.00	131.50	4.6
7/25/15	135.90	0.63	135.20	0.5
Average Error:				10.0
Volume Error	1538.6		1382.6	10.1

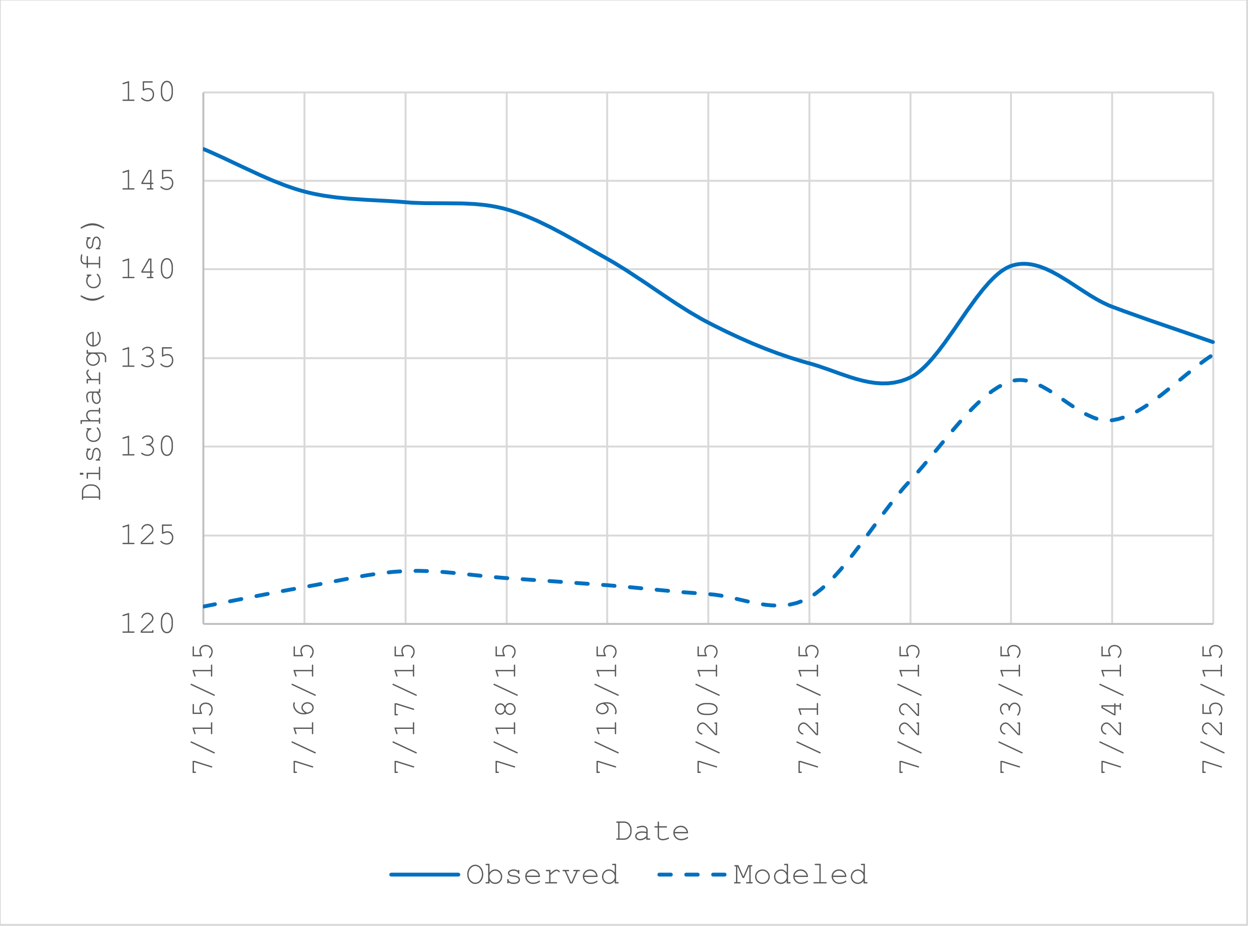

Figure 27. Russian River Verification Results

6.3 Ptarmigan Creek Sub-Basin

The Ptarmigan Creek calibration trends close to the observed data with minor fluctuation in the flow. The time period modeled in the calibration is August 16, 2015 through August 20, 2015. During this time almost one inch of rainfall occurred. The maximum modeled daily discharge error is 1.3% and the average daily discharge error is 0.6%. The error in the volume is 0.1%. Table 12 displays the daily results from the calibration trial, and Figure 28 plots the observed discharge versus the modeled discharge.

Table 12 Ptarmigan Creek Calibration Data

Date	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
8/16/15	124.06	0.16	122.40	1.3
8/17/15	136.15	0.61	135.39	0.6
8/18/15	153.08	0.19	153.50	0.3
8/19/15	155.98	0.00	157.59	1.0
8/20/15	148.73	0.00	148.69	0.0

Average Error				0.6
Volume Error	718.00		717.57	0.1

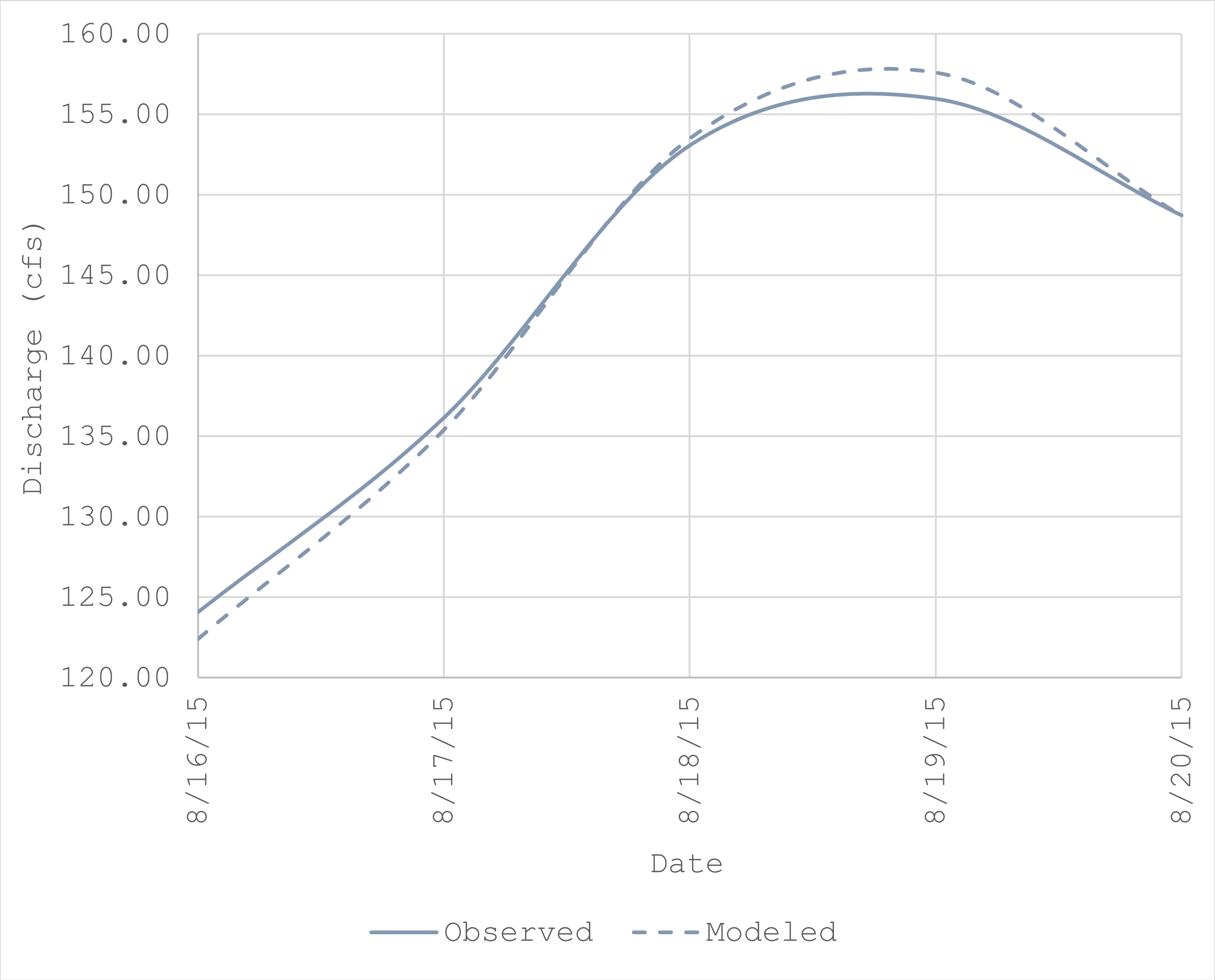

Figure 28. Ptarmigan Creek Calibration Results

The verification of the Ptarmigan Creek calibration occurred over the July 15, 2015 to July 25, 2015 time window. Since the time period was outside the available data window for the Ptarmigan Lake precipitation gauge, the data from the Grandview precipitation gauge was used for input data. There were increases in the error of both the average discharge error and the volume error. The average discharge error increased to 7.5% and the volume error increased to 7.4%. Table 13 displays the verification data, and Figure 29 plots the observed discharge versus the modeled discharge.

Table 13 Ptarmigan Creek Verification Data

Date	Observed (cfs)	Rainfall (in)	Modeled (cfs)	Error (%)
7/15/15	209.60	0.00	151.00	28.0
7/16/15	190.50	0.40	151.00	20.7
7/17/15	195.10	0.00	177.80	8.9
7/18/15	192.30	0.00	189.10	1.7
7/19/15	179.20	0.00	181.50	1.3
7/20/15	174.40	0.00	173.50	0.5
7/21/15	176.90	0.00	166.30	6.0
7/22/15	179.00	0.00	161.10	10.0
7/23/15	182.30	0.10	184.40	1.2
7/24/15	181.20	0.00	182.60	0.8
7/25/15	183.50	0.10	175.40	4.4
Average Error:				7.6
Volume Error	2044.00		1893.70	7.4

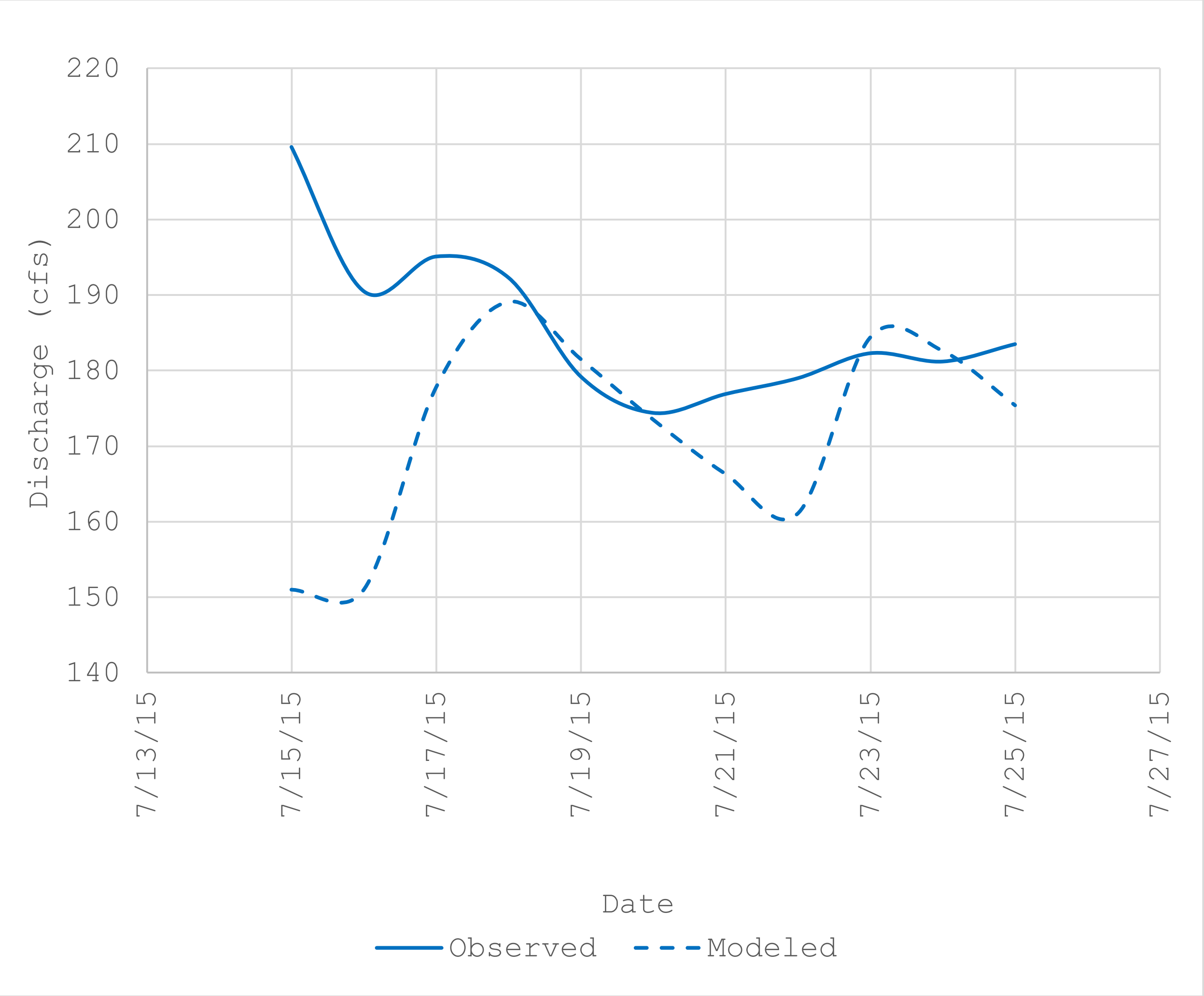

Figure 29. Ptarmigan Creek Verification Results

6.4 Kenai River Watershed

The Kenai River watershed has several factors that contribute to uncertainties within the basin. The modeling period used is July 15, 2015 through July 25, 2015 and August 11, 2015 through September 12, 2015. The initial calibration of the August-September modeling period proved unsuccessful. The averaged errors were near 40% and the volume of water was 3000 cfs below the observed value. After verifying all parameters utilized across the basin were within reason a second modeling period was selected in July of 2015. This time period modeling output trended with the observed data, but also remained low. To analyze where the issues lie in the watershed the outflow along the Kenai River was analyzed. From this, it was found that the largest portion of missing water in the modeled discharge was in the Middle Kenai area as seen in Figure 30.

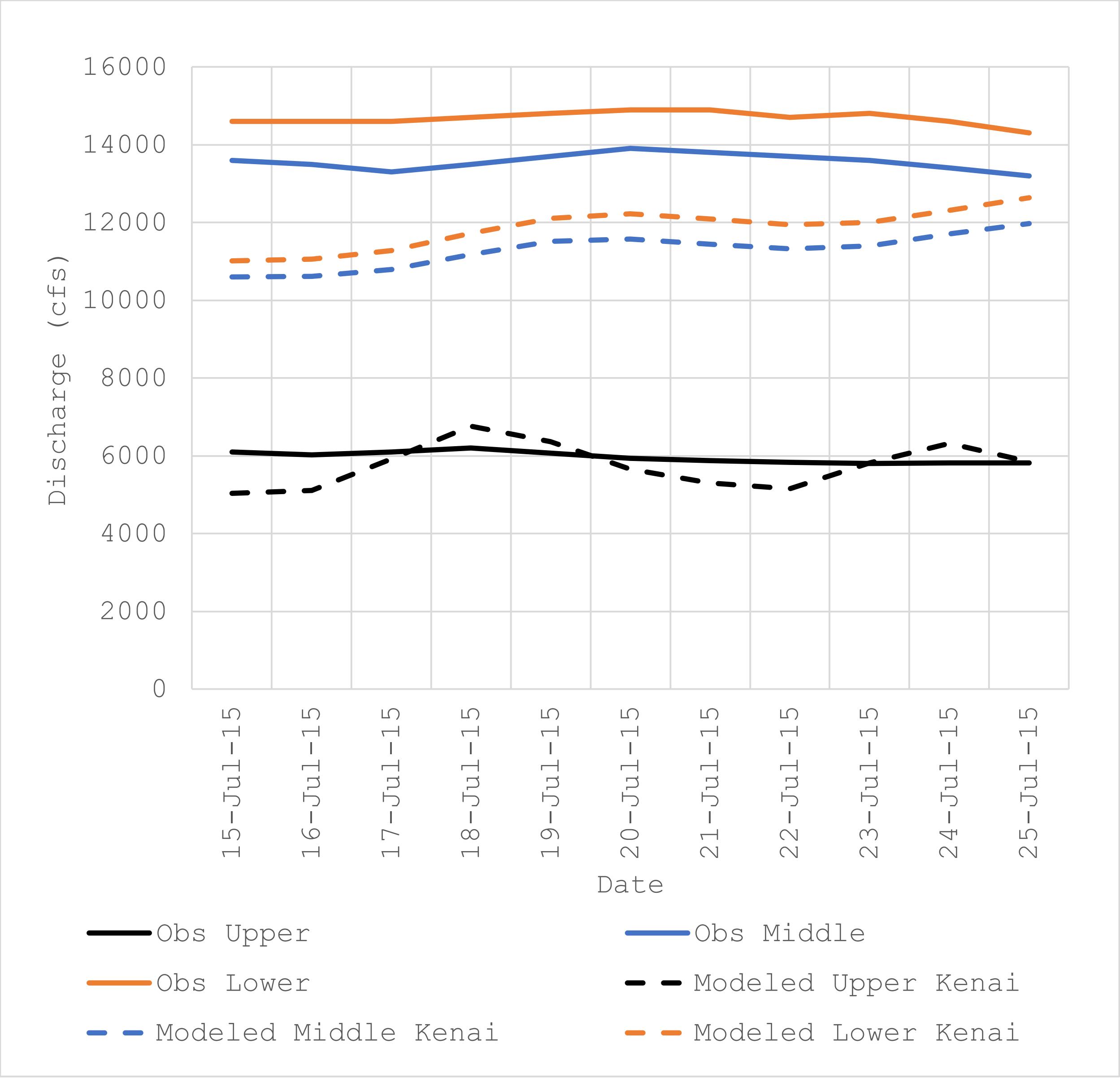

Figure 30. Kenai River Discharge Analysis

Since the modeled discharge trends with the observed normal flow conditions, the possibility of missing input to the basins was explored. The Middle Kenai area has three sub-basins that comprise it, Russian River, Skilak River, and Middle Kenai. Out of the three the Russian River, and Middle Kenai have available data. Skilak River does not have available data for calibration and it is covered by a substantial amount of glacier. The missing input into the model could be account by the presence of this glacier. To artificially stimulate the basin, the baseflow was increased to account for speculated glacial input. The baseflow in the Upper Kenai River sub-basin was increased by 208 cfs so the January through December baseflow in cubic feet per second is: 112, 65, 58, 76, 115, 27, 716, 559, 230, 312, 268, 124. The baseflow in the Middle Kenai River sub-basin was increased by 1935 cfs so January through December baseflow in cubic feet per second is: 415, 427, 313, 255, 930, 2268, 5248, 3478, 2971, 1698, 736, 610. The baseflow in the Lower Kenai River sub-basin was increased by 542 cfs so for January for December in cubic feet per second is: 0, 0, 6, 75, 0, 0, 654, 168, 0, 0, 0, 0. By implementing this increase the averaged error in the baseflow is 2.5%. These results are plotted in Figure 31.

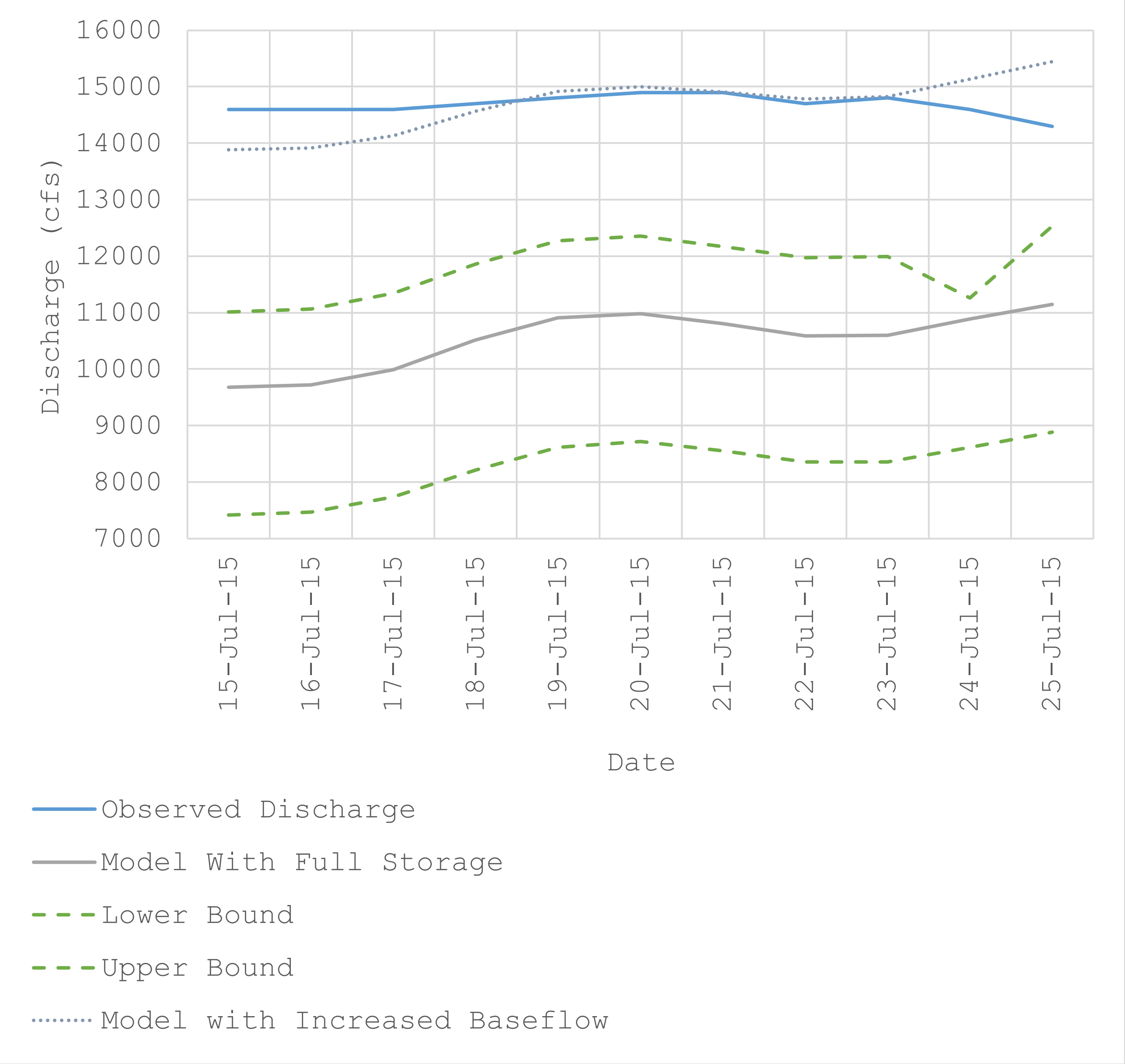

Figure 31. Kenai River Calibration Results with Increase Baseflow

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Chapter 7 Discussion

7.1 Model Successes and Limitations

7.1.1 Beaver Creek

The Beaver Creek sub-basin modeled scenarios perform well under standard open water seasons of late spring and summer with errors less than 4%. The model output follows the fluctuations in discharge over multiple peaks and low water levels. It was found that during the shoulder seasons in early spring and late fall the model does not perform as well, as the average error and volume error increased to 9.4% and 6.6%, respectively. The spring errors may be attributed to not accounting for snow melt in the basin. The fall errors may be caused by errors in the estimation of storage in the wetlands that comprise much of the sub-basin, or a differing precipitation than what was observed at the Kenai Municipal Airport.

With the calibration of the model using data from the 1970's, there is a question of the validity of the use of the calibration for current and future modeling. As Bauret & Stufer (2013) found, there has been a decrease in the precipitation trend since the mid 60's. The changes in the impervious surface due to changes in the land development were found to be 0.51% by interpolating the visual quantification of development from aerial photography (Trammell, personal communication, November, 2016). The 1950 human development impervious surface in Kenai was 0.05%. This increased to 1.04% by the 1980's. The human development impervious surface from 2013 was found to be 1.28%. Assuming a linear development of infrastructure between the 1950's and 1980's and interpolated human development impervious of 0.71% for the 1970's. With the increase in impervious surface boosting the rainfall-runoff, and the observed decrease in precipitation, the values help offset the errors introduced by these changes.

7.1.2 Russian River

The Russian River sub-basin model performs well under the open water season. The time period of late spring to early fall modeled well under the conditions present in the calibration year of 2015. Since there is limited flow data for lake discharge, extreme precipitations events, whether high or low, have the potential to introduce error in the outflows from the combined Russian Lakes.

7.1.3 Ptarmigan Creek

Ptarmigan Creek sub-basin has reliable modeled output under average precipitation events. The narrow, steep-gradient basin has a large lake. Due to the positioning of the lake and the runoff below the lake, the hydrograph increases steeply and then gradually decreases as the runoff is let out of the lake. During the open water season the model reproduces the peak flow due to lake outflow and the modeled rate of discharge decrease follows closely to the observed discharge. To achieve the steep rise in the hydrograph, the model required the lower basin have a high level of flashiness. Thus, under heavy rainfall events there are artificial peaks in the rise of the modeled hydrograph. This can be seen in the verification run of Ptarmigan Creek where the average errors increased to 7.6% and the volume errors increased to 7.4% from the less 0.6% errors seen in the calibration trial.

7.1.4 Kenai River Watershed

The watershed scale model has reproduced the trends of the watershed well under normal precipitation conditions, but the modeled discharge was much lower than the observed discharge. To reproduce the observed trends in discharge the modeling window has to be quite large to account for the long attenuation due to the two lakes in the Kenai River system. The base flow also had to be artificially stimulated to increase the modeled outflow to the observed outflow. This unorthodox method was explored only after all other hydrologic parameters and known input data was verified correct and reasonable. By doing this, it allowed the exploration of a semi-constant input into the watershed that was ungauged. It is speculated that the ungauged input that was simulated with this increase is due to glacial meltwater entering the system. It is documented that the glaciers in the Kenai River Watershed are thinning and decreasing in size as studied by VanLooy et al. (2006). The values used in the artificially stimulated base flow will fluctuate depending on the changes of the groundwater input, and the portion used to account for the melt of glacial and high snowpack. Near the end of the calibration modeling window the modeled discharge spikes well above the observed discharge. The spike is speculated to be due to the higher than average precipitation throughout the basin, combined with the coarse data available used to create the storage-discharge relationships for the lakes. The US climate data present the average precipitation in Kenai, Alaska for August – September is around 3 inches. During the modeling time period the basins that utilize the Kenai Municipal Airport data saw upwards of almost 7 inches. The average precipitation of the same time period in Moose Pass, which is near Ptarmigan Creek, is also close to 3 inches. The installed precipitation gauge reported close to 4.5 inches of precipitation. The average precipitation in Cooper Landing, near the Russian River has an average rainfall during the time period of between 2.5 and 3 inches of rain. During this time period, near 4.25 inches of rain were observed. Based on this information the precipitation across the watershed was higher than what is seen during average rainfall events. During a normal precipitation event, the model is expected to provide modeled outputs closer to the observed discharge over the modeling window being studied.

7.1.5 Model Uses

The sub-basin and water scale models have a variety of applications. With the use of modeled precipitation or predicted precipitation, the stream flows could be estimated for uses in fisheries studies. These studies can have an impact to economic planning for the communities in the Kenai River watershed. Another application of the model is for exploring the effects of changing urbanization in the watershed. As the towns in the watershed increase in size, the percentage of impervious surface of the areas will also increase with the development. This will cause increased runoff during precipitation events, resulting in increased stream flows. With the landscape changes seen on the peninsula, such as the wetland drying discussed by Berg et al. (2009), effects of the landscape changes on the stream flows can be examined.

Chapter 8 Future Research

8.1 Baseflow Study

During the watershed scale modeling it was found that the base flow in the basin fluctuates several thousand cubic feet per second. To create an accurate watershed scale hydrologic model a study of the baseflows in the watershed should be conducted to fill one gap in the current data available.

8.2 Glacial Influences

Three basins in the Kenai River watershed are glaciated at varying percentages of cover. The Skilak sub-basin is the most glaciated in the basin, followed by the upper parts of the Killey sub-basin, and the Snow River sub-basin. Obtaining knowledge of glacial input to the hydrologic system can provide another facet to improving the modeling.

8.3 Evapotranspiration

In the modeling of Beaver Creek, Russian River, and Ptarmigan Creek, the modeling time window is small enough for evapotranspiration to be negligible. The watershed scale model requires longer time-periods due to the lagging effect of the lakes in the system. To lengthen the modeling time period for the watershed scale model a knowledge of the evapotranspiration rates through the sub-basins will help complete the picture of the hydrology in the Kenai River watershed.

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Appendix A: Kenai River Watershed Baseflow

Table A.1January Baseflow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		January		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	0
Beaver Creek	Analysis	11	11	12
Moose River	Estimate	0	0	0
Funny River	Estimate	0	0	0
Killey River	Estimate	0	0	0
Middle Kenai River	Estimate	348	379	415
Skilak River	Estimate	252	275	300
Russian River	Analysis	20	23	25
Upper Kenai River	Estimate	77	98	112
Quartz Creek	Estimate	61	77	88
Trail River	Analysis	51	62	80
Ptarmigan Creek	Analysis	10	12	15
Snow River	Analysis	41	53	65
*Estimate values that are negative are set to 0				

Table A.2 February Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		February		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	11	0	0
Beaver Creek	Analysis	10	11	11
Moose River	Estimate	12	0	0
Funny River	Estimate	6	0	0
Killey River	Estimate	10	0	0
Middle Kenai River	Estimate	303	327	427
Skilak River	Estimate	220	237	310
Russian River	Analysis	18	20	23
Upper Kenai River	Estimate	74	72	65
Quartz Creek	Estimate	58	56	51
Trail River	Analysis	48	55	66
Ptarmigan Creek	Analysis	10	10	12
Snow River	Analysis	30	39	56
*Estimate values that are negative are set to 0				

Table A.3 March Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		March		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	32	28	6
Beaver Creek	Analysis	10	10	10
Moose River	Estimate	34	30	7
Funny River	Estimate	18	16	4
Killey River	Estimate	29	26	6
Middle Kenai River	Estimate	293	267	313
Skilak River	Estimate	213	193	227
Russian River	Analysis	18	18	18
Upper Kenai River	Estimate	5	56	58
Quartz Creek	Estimate	4	44	46
Trail River	Analysis	52	55	64
Ptarmigan Creek	Analysis	9	10	10
Snow River	Analysis	30	39	42
*Estimate values that are negative are set to 0				

Table A.4 April Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		April		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	29	37	75
Beaver Creek	Analysis	10	11	19
Moose River	Estimate	32	40	81
Funny River	Estimate	17	21	43
Killey River	Estimate	27	34	70
Middle Kenai River	Estimate	225	228	255
Skilak River	Estimate	163	165	185
Russian River	Analysis	20	21	21
Upper Kenai River	Estimate	71	75	76
Quartz Creek	Estimate	55	59	59
Trail River	Analysis	58	60	62
Ptarmigan Creek	Analysis	9	10	10
Snow River	Analysis	24	42	63
*Estimate values that are negative are set to 0				

Table A.5 May Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		May		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	101	17	0
Beaver Creek	Analysis	19	23	27
Moose River	Estimate	108	18	0
Funny River	Estimate	57	10	0
Killey River	Estimate	93	16	0
Middle Kenai River	Estimate	254	517	930
Skilak River	Estimate	184	375	673
Russian River	Analysis	30	62	97
Upper Kenai River	Estimate	64	0	115
Quartz Creek	Estimate	51	0	91
Trail River	Analysis	76	207	380
Ptarmigan Creek	Analysis	14	26	50
Snow River	Analysis	68	368	714
*Estimate values that are negative are set to 0				

Table A.6 June Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		June		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	0
Beaver Creek	Analysis	14	17	21
Moose River	Estimate	0	0	0
Funny River	Estimate	0	0	0
Killey River	Estimate	0	0	0
Middle Kenai River	Estimate	1049	1705	2268
Skilak River	Estimate	759	1234	1643
Russian River	Analysis	132	159	189
Upper Kenai River	Estimate	21	141	27
Quartz Creek	Estimate	16	111	21
Trail River	Analysis	590	886	1250
Ptarmigan Creek	Analysis	53	111	162
Snow River	Analysis	740	1189	1590
*Estimate values that are negative are set to 0				

Table A.7 July Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		July		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	39	112
Beaver Creek	Analysis	11	13	15
Moose River	Estimate	0	42	120
Funny River	Estimate	0	23	64
Killey River	Estimate	0	37	104
Middle Kenai River	Estimate	2480	2755	3133
Skilak River	Estimate	1796	1995	2518
Russian River	Analysis	75	121	158
Upper Kenai River	Estimate	88	479	508
Quartz Creek	Estimate	69	376	400
Trail River	Analysis	1170	1452	1640
Ptarmigan Creek	Analysis	123	168	222
Snow River	Analysis	1610	1948	2270
*Estimate values that are negative are set to 0				

Table A.8 August Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		August		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	168
Beaver Creek	Analysis	10	12	14
Moose River	Estimate	0	0	180
Funny River	Estimate	0	0	96
Killey River	Estimate	0	0	156
Middle Kenai River	Estimate	3037	3468	3478
Skilak River	Estimate	2200	2512	2518
Russian River	Analysis	53	63	74
Upper Kenai River	Estimate	590	538	559
Quartz Creek	Estimate	464	422	439
Trail River	Analysis	634	938	1450
Ptarmigan Creek	Analysis	107	143	182
Snow River	Analysis	765	1476	2100
*Estimate values that are negative are set to 0				

Table A.9 September Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		September		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	0
Beaver Creek	Analysis	12	15	16
Moose River	Estimate	0	0	0
Funny River	Estimate	0	0	0
Killey River	Estimate	0	0	0
Middle Kenai River	Estimate	1158	1888	2971
Skilak River	Estimate	838	1367	2151
Russian River	Analysis	34	47	58
Upper Kenai River	Estimate	451	456	230
Quartz Creek	Estimate	354	358	180
Trail River	Analysis	314	476	740
Ptarmigan Creek	Analysis	58	81	120
Snow River	Analysis	283	710	1440
*Estimate values that are negative are set to 0				

Table A. 10 October Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		October		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	0
Beaver Creek	Analysis	16	19	23
Moose River	Estimate	0	0	0
Funny River	Estimate	0	0	0
Killey River	Estimate	0	0	0
Middle Kenai River	Estimate	569	987	1698
Skilak River	Estimate	412	714	1229
Russian River	Analysis	45	68	93
Upper Kenai River	Estimate	301	354	312
Quartz Creek	Estimate	236	278	246
Trail River	Analysis	180	252	395
Ptarmigan Creek	Analysis	37	45	56
Snow River	Analysis	110	233	471
*Estimate values that are negative are set to 0				

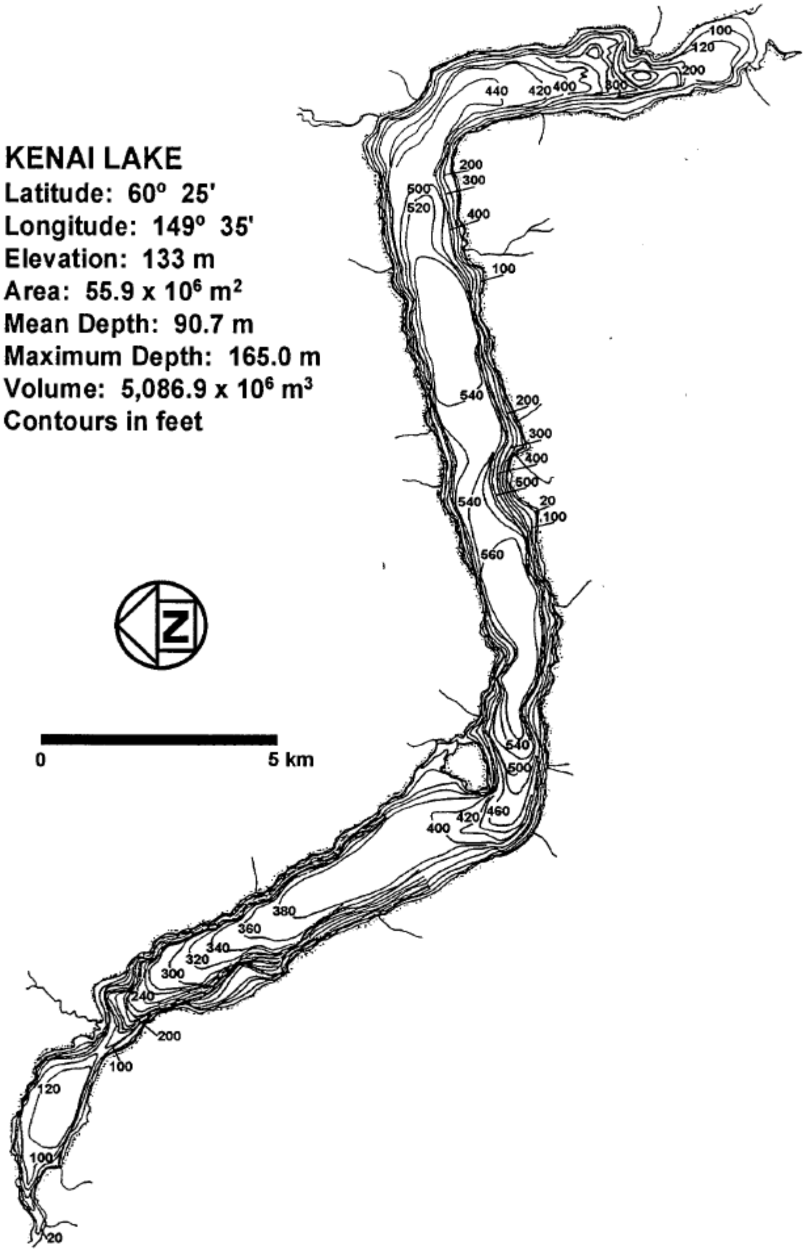
Table A.11 November Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		November		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	0
Beaver Creek	Analysis	11	15	19
Moose River	Estimate	0	0	0
Funny River	Estimate	0	0	0
Killey River	Estimate	0	0	0
Middle Kenai River	Estimate	617	706	736
Skilak River	Estimate	447	511	533
Russian River	Analysis	36	40	49
Upper Kenai River	Estimate	128	198	268
Quartz Creek	Estimate	100	155	211
Trail River	Analysis	100	139	176
Ptarmigan Creek	Analysis	4	29	37
Snow River	Analysis	78	116	160
*Estimate values that are negative are set to 0				

Table A.12 December Base Flow Information for the Kenai River Watershed

Sub-Basin	Calculation Method	Base Flow (CFS)		
		December		
		Minimum	Average	Maximum
Lower Kenai River	Estimate	0	0	0
Beaver Creek	Analysis	10	10	11
Moose River	Estimate	0	0	0
Funny River	Estimate	0	0	0
Killey River	Estimate	0	0	0
Middle Kenai River	Estimate	675	527	610
Skilak River	Estimate	488	382	442
Russian River	Analysis	26	27	28
Upper Kenai River	Estimate	93	102	124
Quartz Creek	Estimate	73	80	98
Trail River	Analysis	80	85	90
Ptarmigan Creek	Analysis	15	16	18
Snow River	Analysis	60	77	100
*Estimate values that are negative are set to 0				

Appendix B: Lake Bathymetry Maps



KENAI LAKE
Latitude: 60° 25'
Longitude: 149° 35'
Elevation: 133 m
Area: 55.9 x 10^6 m^2
Mean Depth: 90.7 m
Maximum Depth: 165.0 m
Volume: 5,086.9 x 10^6 m^3
Contours in feet

Figure B.1 Kenai Lake Bathymetry (Spafard & Edmundson, 2000)

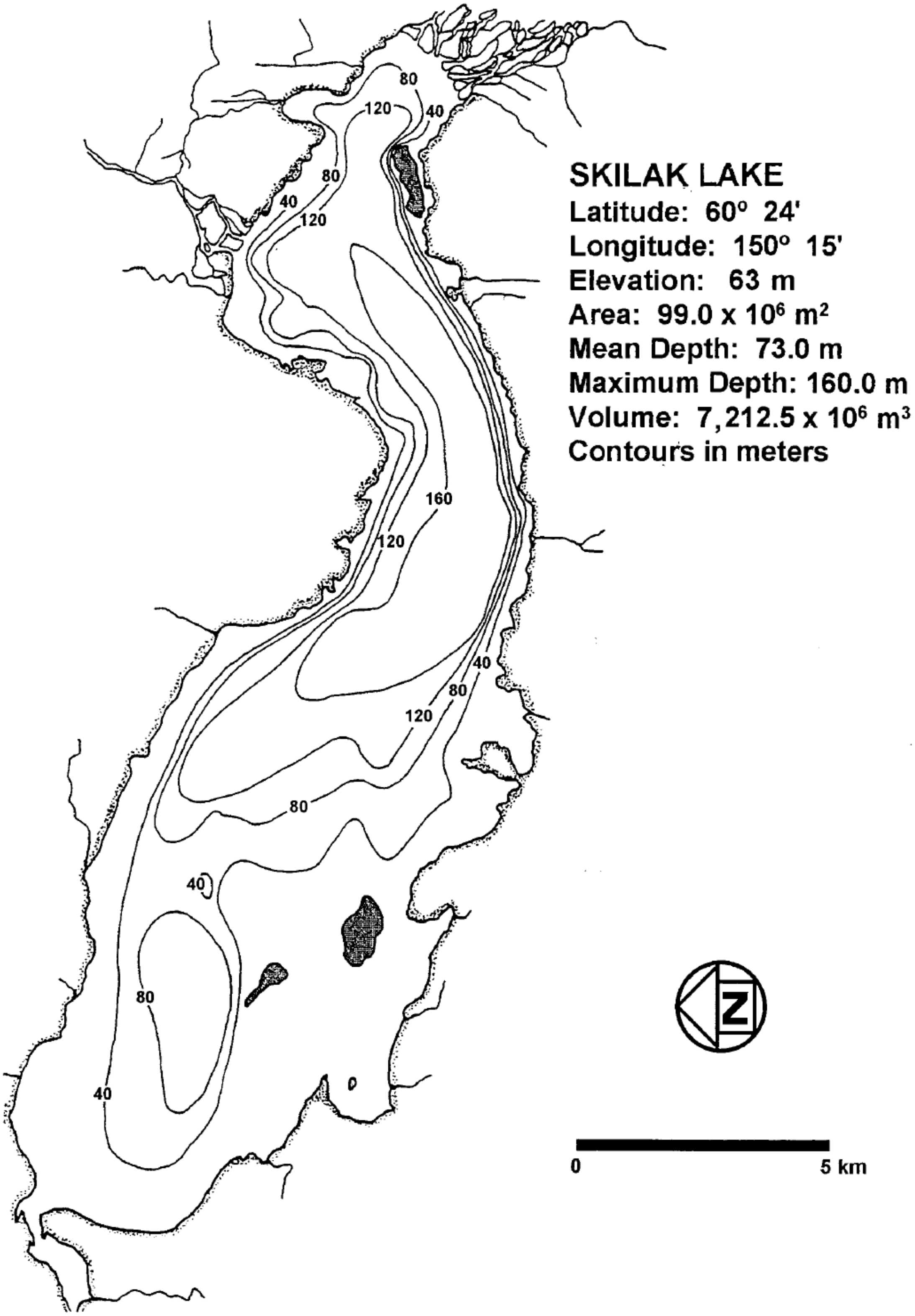


Figure B.2 Skilak Lake Bathymetry (Spafard & Edmundson, 2000)

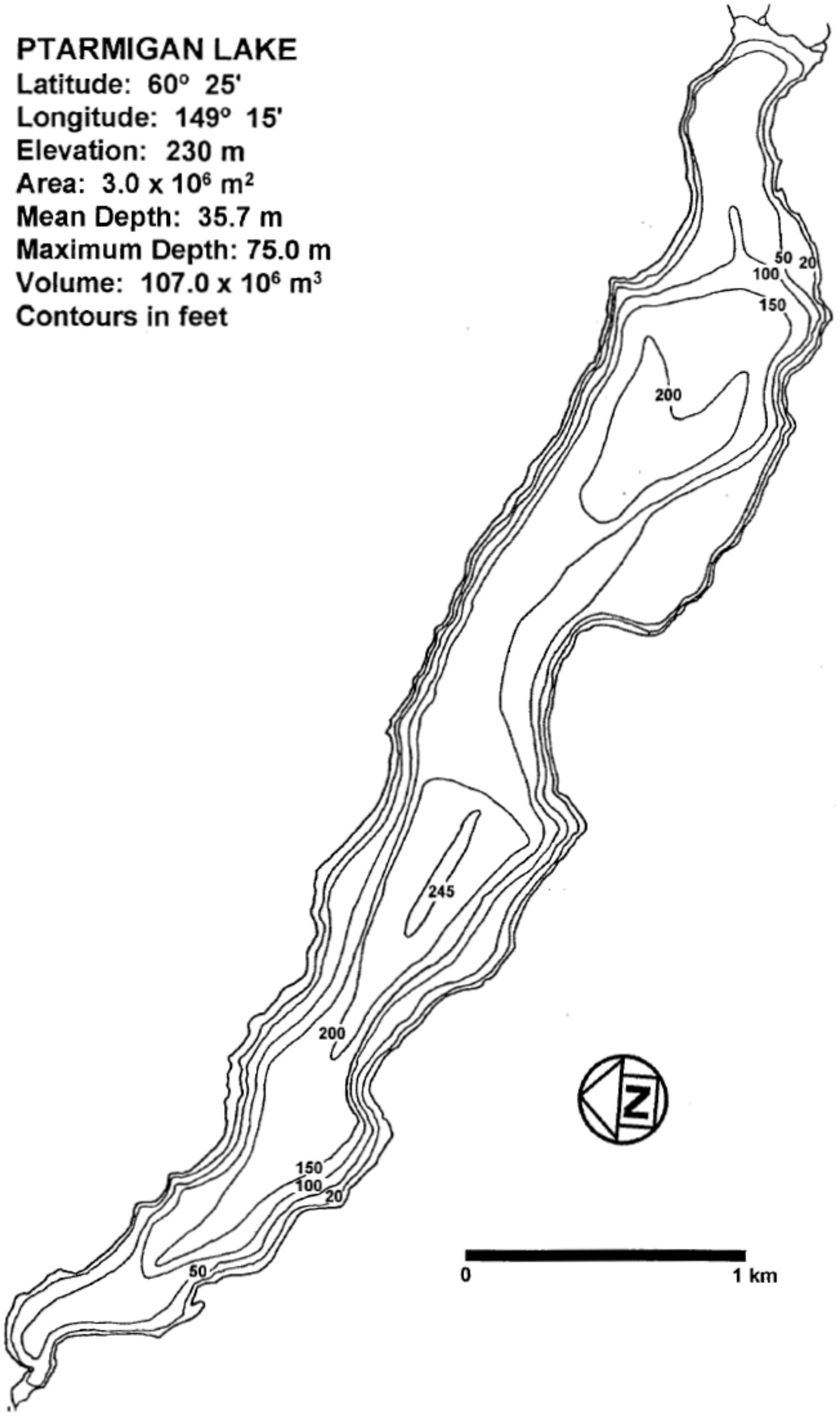


Figure B.3 Ptarmigan Lake Bathymetry (Spafard & Edmundson, 2000)

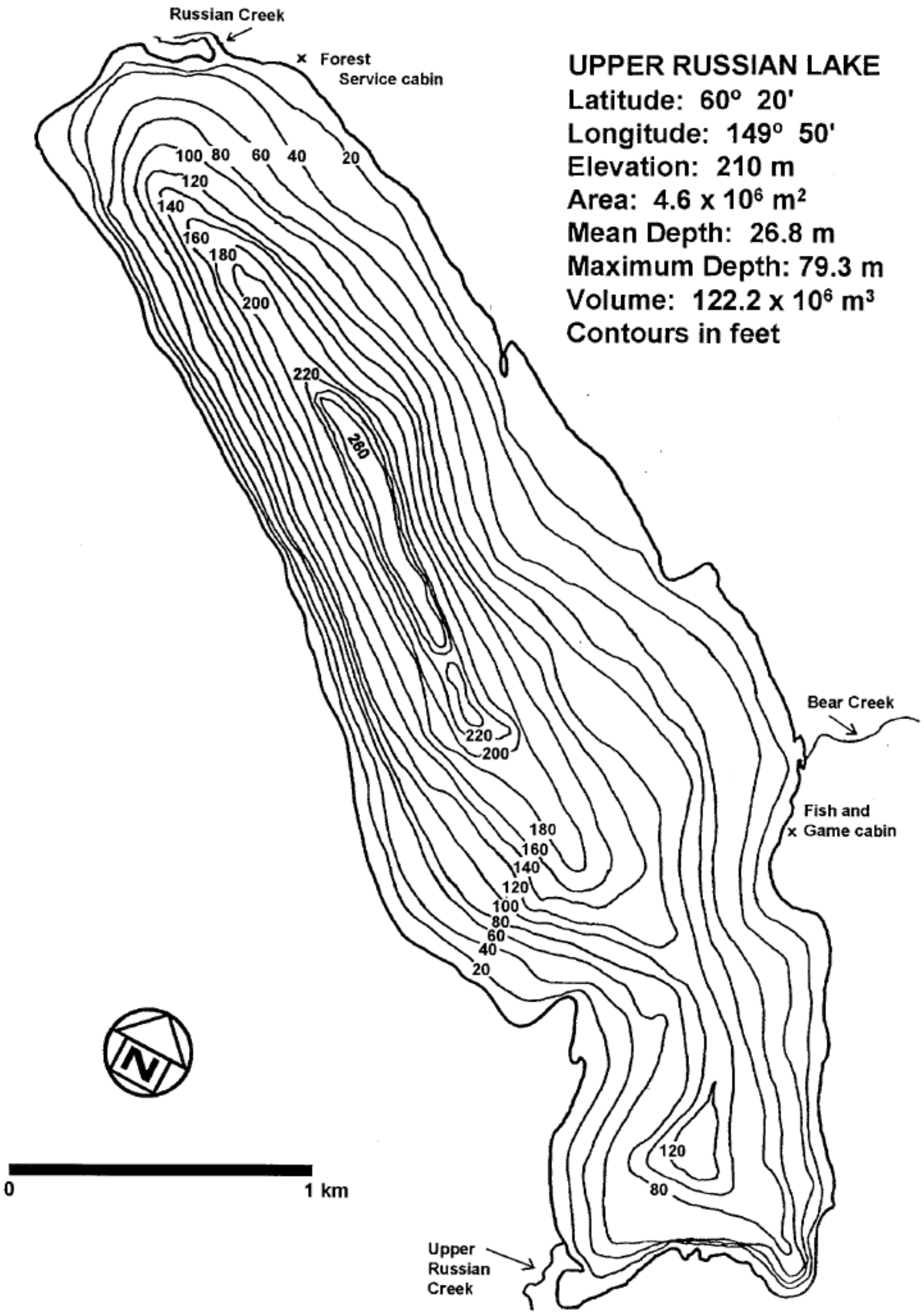


Figure B.4 Upper Russian Lake Bathymetry (Spafard & Edmundson, 2000)

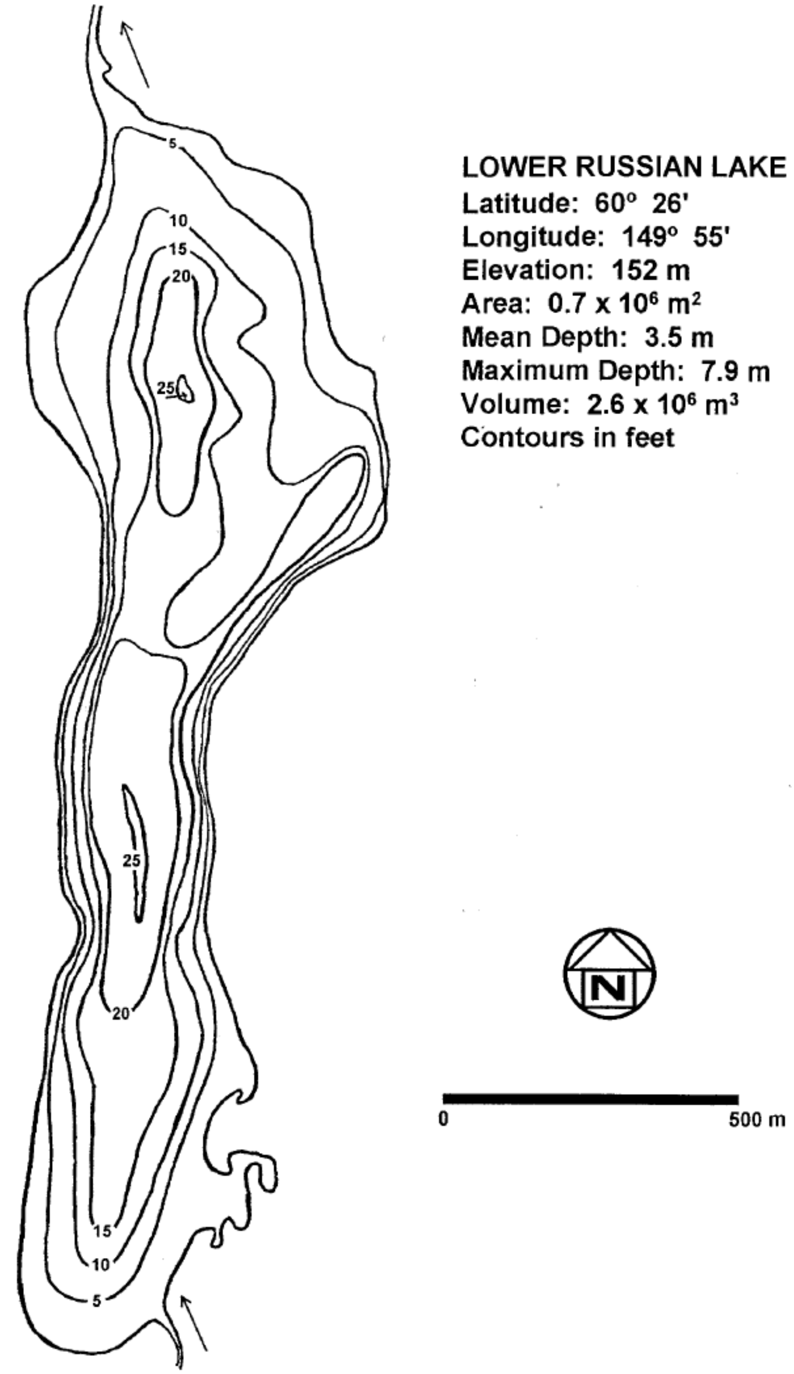


Figure B.5 Lower Russian Lake Bathymetry (Spafard & Edmundson, 2000)

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Appendix C: Lake Relationship Regression Equations

- Ptarmigan Lake Elevation-Storage Equation
    - $y=1.9643x^{2}-2148.5x+587873$
        - $R^{2}=0.99862$
- Kenai Lake Storage-Discharge Equation
    - $y=-0.000000000000000000019244801004x^{6}+0.00000000000000144992396519682x^{5}-0.00000000004300020436036x^{4}+0.000000640234568339404x^{3}-0.00509899024206947x^{2}+25.2225715757517x+4540366.94255103$
        - $R^{2}=0.986445054330265$
- Skilak Lake Storage Discharge Equation
    - $y=0.00000000000000001470x^{5}-0.0000000000134369337x^{4}+0.00000004755592460895x^{3}-0.000855197821966282x^{2}+11.8475097873867x+4796462.89674523$
        - $R^{2}=0.994065988710589$

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Appendix D: Tabled Model Parameters

Table D.1 Beaver Creek Spring Parameters

Beaver Creek Spring Parameters				
Sub-basin	Parameter		Value	Units
Timberlost	Area		19.91	sq. miles
	Simple Canopy	Initial Storage	20	%
		Maximum Storage	1	inch
	Simple Surface	Initial Storage	90	%
		Maximum Storage	2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	2	%
	SCS Unit Hydrograph Transform	Lag Time	700	Min
Ootka	Area		10.39	sq. miles
	Simple Canopy	Initial Storage	60	%
		Maximum Storage	1	inch
	Simple Surface	Initial Storage	25	%
		Maximum Storage	1	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	2	%
	SCS Unit Hydrograph Transform	Lag Time	600	Min
Beaver	Area		11.42	sq. miles
	Simple Canopy	Initial Storage	10	%
		Maximum Storage	0.3	inch
	Simple Surface	Initial Storage	40	%
		Maximum Storage	1	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%
	SCS Unit Hydrograph Transform	Lag Time	400	Min
Beaver Creek	Area		26.44	sq. miles
	Simple Canopy	Initial Storage	10	%
		Maximum Storage	0.3	inch
	Simple Surface	Initial Storage	60	%
		Maximum Storage	0.5	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	12	%

	SCS Unit Hydrograph Transform	Lag Time	3500	Min
Basin Reaches				
Reach Name	Length (ft)	Slope	Manning's n	Rectangular Channel Width (ft)
Reach 1	9342	0.003	0.08	11.23
Reach 2	47028	0.0003	0.08	15.7
Reach 3	2804	0.003	0.08	6.58
Reach 4	12091	0.003	0.08	5.53
Reach 5	4545	0.0041	0.076	11.06

Table D.2 Beaver Creek Summer Parameters

Beaver Creek Summer Parameters				
Sub-basin	Parameter		Value	Units
Timberlost	Area		19.91	sq. miles
	Simple Canopy	Initial Storage	20	%
		Maximum Storage	0.2	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%
	SCS Unit Hydrograph Transform	Lag Time	2444	Min
Ootka	Area		10.39	sq. miles
	Simple Canopy	Initial Storage	20	%
		Maximum Storage	0.2	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%
	SCS Unit Hydrograph Transform	Lag Time	2200	Min
Beaver	Area		11.42	sq. miles
	Simple Canopy	Initial Storage	29	%
		Maximum Storage	0.2	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	7	%
	SCS Unit Hydrograph Transform	Lag Time	1400	Min
Beaver Creek	Area		26.44	sq. miles
	Simple Canopy	Initial Storage	29	%
		Maximum Storage	0.4	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.47	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%

	SCS Unit Hydrograph Transform	Lag Time	1200	Min
Basin Reaches				
Reach Name	Length (ft)	Slope	Manning's n	Rectangular Channel Width (ft)
Reach 1	9342	0.003	0.08	11.23
Reach 2	47028	0.0003	0.08	15.7
Reach 3	2804	0.003	0.08	6.58
Reach 4	12091	0.003	0.08	5.53
Reach 5	4545	0.0041	0.076	11.06

Table D.3 Beaver Creek Fall Parameters

Beaver Creek Fall Parameters				
Sub-basin	Parameter		Value	Units
Timberlost	Area		19.91	sq. miles
	Simple Canopy	Initial Storage	20	%
		Maximum Storage	0.2	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%
	SCS Unit Hydrograph Transform	Lag Time	2444	Min
Ootka	Area		10.39	sq. miles
	Simple Canopy	Initial Storage	20	%
		Maximum Storage	0.2	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%
	SCS Unit Hydrograph Transform	Lag Time	2200	Min
Beaver	Area		11.42	sq. miles
	Simple Canopy	Initial Storage	29	%
		Maximum Storage	0.2	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.2	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	7	%
	SCS Unit Hydrograph Transform	Lag Time	1400	Min
Beaver Creek	Area		26.44	sq. miles
	Simple Canopy	Initial Storage	29	%
		Maximum Storage	0.4	inch
	Simple Surface	Initial Storage	7	%
		Maximum Storage	0.47	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	5	%
	SCS Unit Hydrograph Transform	Lag Time	1200	Min

Basin Reaches

Reach Name	Length (ft)	Slope	Manning's n	Rectangular Channel Width (ft)
Reach 1	9342	0.003	0.08	11.23
Reach 2	47028	0.0003	0.08	15.7
Reach 3	2804	0.003	0.08	6.58
Reach 4	12091	0.003	0.08	5.53
Reach 5	4545	0.0041	0.076	11.06

Table D.4 Russian River Parameters

Russian River Parameters				
Sub-basin	Parameter		Value	Units
Upper Russian	Area		192.96	sq. miles
	Simple Canopy	Initial Storage	17	%
		Maximum Storage	0.8	inch
	Simple Surface	Initial Storage	20	%
		Maximum Storage	0.9	inch
	SCS Loss Method	SCS Curve #	70-72	
		Impervious %	1	%
	SCS Unit Hydrograph Transform	Lag Time	1700	Min
Lower Russian	Area		64.32	sq. miles
	Simple Canopy	Initial Storage	1	%
		Maximum Storage	0.39	inch
	Simple Surface	Initial Storage	20	%
		Maximum Storage	0.6	inch
	SCS Loss Method	SCS Curve #	70	
		Impervious %	1.5	%
	SCS Unit Hydrograph Transform	Lag Time	1630	Min
Basin Reaches				
Reach Name	Length (ft)	Slope	Manning’s n	Rectangular Channel Width (ft)
Upper Russian	44880	0.004	0.025	45

Table D.5 Ptarmigan Creek Parameters

Ptarmigan Creek				
Sub-basin	Parameter		Value	Units
Upper Ptarmigan Creek	Area		101.21	sq. miles
	Simple Canopy	Initial Storage	80	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	90	%
		Maximum Storage	0.3	inch
	SCS Loss Method	SCS Curve #	69	
		Impervious %	5.5	%
	SCS Unit Hydrograph Transform	Lag Time	1080	Min
Lower Ptarmigan Creek	Area		33.74	sq. miles
	Simple Canopy	Initial Storage	70	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	40	%
		Maximum Storage	0.4	inch
	SCS Loss Method	SCS Curve #	72	
		Impervious %	2	%
	SCS Unit Hydrograph Transform	Lag Time	290	Min

Table D.6 Kenai River Watershed Parameters

Kenai River Watershed				
Sub-basin	Parameter		Value	Units
Snow River	Area		660.41	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.5	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	1.2	inch
	SCS Loss Method	SCS Curve #	70	
		Impervious %	29.41	%
	SCS Unit Hydrograph Transform	Lag Time	1700	Min
Upper Ptarmigan Creek	Area		101.21	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.3	inch
	SCS Loss Method	SCS Curve #	69	
		Impervious %	5.58	%
	SCS Unit Hydrograph Transform	Lag Time	1080	Min
Lower Ptarmigan Creek	Area		33.74	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.4	inch
	SCS Loss Method	SCS Curve #	72	
		Impervious %	0.5	%
	SCS Unit Hydrograph Transform	Lag Time	290	Min
Trail river	Area		813.67	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.05	inch
	SCS Loss Method	SCS Curve #	70	

		Impervious %	3.82	%
	SCS Unit Hydrograph Transform	Lag Time	3600	Min
Quartz Creek	Area		455.19	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.5	inch
	SCS Loss Method	SCS Curve #	2	
		Impervious %	1.19	%
	SCS Unit Hydrograph Transform	Lag Time	1200	Min
Upper Kenai River	Area		587.93	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.5	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.5	inch
	SCS Loss Method	SCS Curve #	70	
		Impervious %	7.14	%
	SCS Unit Hydrograph Transform	Lag Time	3600	Min
Upper Russian River	Area		192.96	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.8	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.9	inch
	SCS Loss Method	SCS Curve #	70	
		Impervious %	1.8	%
	SCS Unit Hydrograph Transform	Lag Time	1700	Min
Lower Russian River	Area		62.32	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.39	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.6	inch
	SCS Loss Method	SCS Curve #	70	

		Impervious %	1.8	%
	SCS Unit Hydrograph Transform	Lag Time	1630	Min
Skilak River	Area		897.51	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.14	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.1	inch
	SCS Loss Method	SCS Curve #	72	
		Impervious %	24.23	%
	SCS Unit Hydrograph Transform	Lag Time	3600	Min
Middle Kenai River	Area		1244.37	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.3	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.5	inch
	SCS Loss Method	SCS Curve #	72	
		Impervious %	6.2	%
	SCS Unit Hydrograph Transform	Lag Time	1600	Min
Moose River	Area		1061.19	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.3	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.5	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	2.26	%
	SCS Unit Hydrograph Transform	Lag Time	2000	Min
Killey River	Area		908.92	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.1	inch
	SCS Loss Method	SCS Curve #	72	

		Impervious %	15.45	%
	SCS Unit Hydrograph Transform	Lag Time	3600	Min
Funny River	Area		566.97	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.1	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	0.3	%
	SCS Unit Hydrograph Transform	Lag Time	2600	Min
Beaver Creek	Area		250.69	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.4	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.8	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	2.5	%
	SCS Unit Hydrograph Transform	Lag Time	1600	Min
Lower Kenai River	Area		952.23	sq. miles
	Simple Canopy	Initial Storage	100	%
		Maximum Storage	0.1	inch
	Simple Surface	Initial Storage	100	%
		Maximum Storage	0.8	inch
	SCS Loss Method	SCS Curve #	65	
		Impervious %	4.34	%
	SCS Unit Hydrograph Transform	Lag Time	4000	Min

Basin Reaches				
Reach Name	Length (ft)	Slope	Manning's n	Rectangular Channel Width (ft)
Snow River Reach	26188	0.0094	0.03	223
Ptarmigan Creek Reach	3785	0.033	0.03	70
Trail River Reach	4951	0.0096	0.03	82
Quartz Creek Reach	1653	0.0143	0.03	72
Upper Russian River Reach	44880	0.004	0.025	45
Russian River Reach	1097	0.0112	0.025	105
Skilak River Reach	19387	0.0046	0.03	162
Funny River Reach	248	0.0091	0.03	42
Beaver Creek Reach	292	0.001	0.035	55
Reach 6	43560	0.002	0.025	159
Reach 5	45901	0.003	0.025	109
Reach 4	35390	0.00001	0.025	309
Reach 3	40235	0.0014	0.025	309
Reach 2	27945	0.001	0.025	265
Reach 1	101377	0.001	0.03	424
Beaver to Cook Inlet	50583	0.00002	0.03	840

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