Analyzing the relationship between latitudinal position & stream discharge in glacial-fed river systems

Kevin Strybos

December 2017

Term Project Paper

Introduction

In recent years, glacial recession and climate change have entered the common political environment as warming temperatures, drought, and rising sea levels have become more apparent. While glacial recession may lead to rising sea levels and glacial lake outbursts, it also may lead to decreasing water supply for rivers, drinking water, and agriculture in regions where people rely heavily on glacial runoff during the dry season. In my study, I examine river basins that are both fed by glacial runoff, the Santa River Basin in Ancash, Peru and the Taku River Basin in Juneau, Alaska.

My interest in the Santa River Basin stems from a hiking trip I did this past summer in the Huascaran National Park, which the river runs through. This region is particularly interesting because it's dominated by the world's highest tropical mountain range (The Andes) and the largest glaciated area in the tropics. During the dry season when precipitation is low to zero, over 1.4 million people are left to rely on the glacial runoff from the glaciers in the Santa Basin. As glaciers continue to melt rapidly, those populations are at risk as water resources decrease and demand increases.

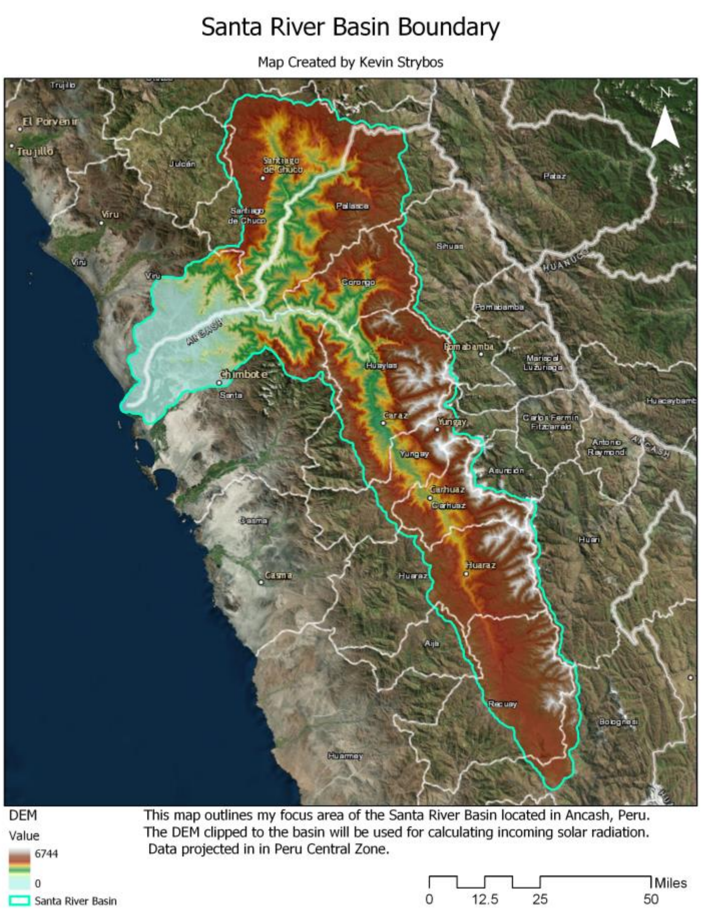
The Taku River Basin feeds into Alaska's capital, Juneau, home to about 32,800 people who live and rely on the river's resources. The Taku Basin runs along the Juneau Icefield where many glaciers are located and provide glacial runoff. During the warmer months when the area surrounding Juneau receives over 18 hours of daylight per day, glaciers provide around 35% of Alaska's total runoff. This runoff is halted during the winter months when there is little sunlight and almost no any melt occurring.

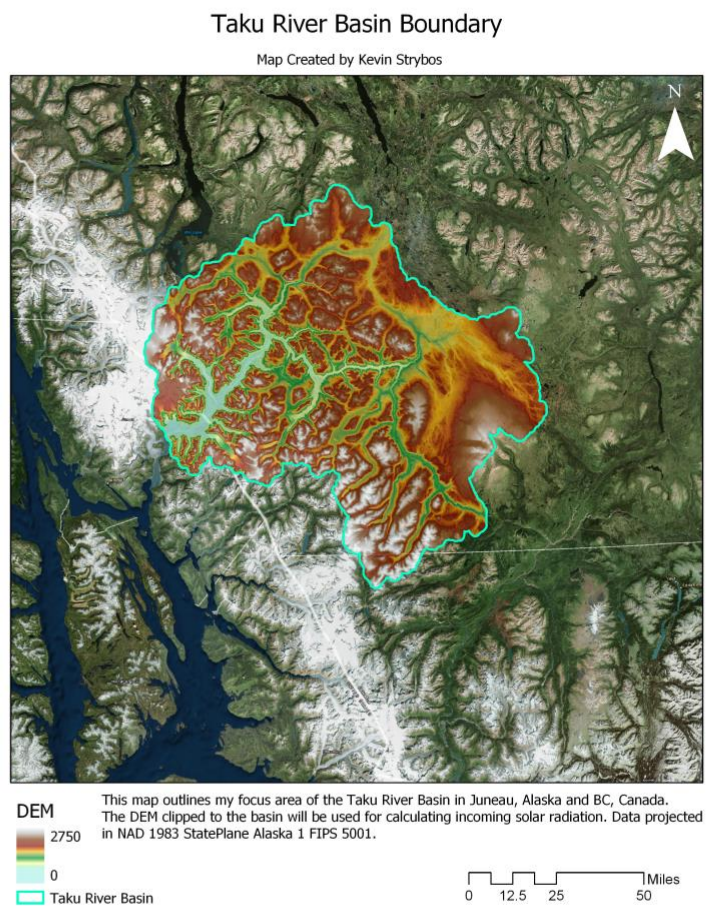
Although I didn't know about the Taku River Basin before beginning this project, I found it interesting not only because of its similarity to the Santa Basin as a glacial fed system, but also because of its differences. While the Santa Basin is in a low latitude, high altitude region, the Taku River Basin is in a high latitude, low altitude region. Latitude and altitude both have implications on the seasonality of weather patterns for a region. For this reason, my study's objective was to perform a comparative analysis of the two basin's monthly average incoming solar radiation and its relationship to monthly average stream flow during the years of 1995, 2000, and 2005.

Methods

Study Area

The study area chosen for this project was a glaciated area within each basin. First, a point feature was placed at the outlets of the Santa and Taku Rivers in order to delineate the watershed boundaries and streams in each basin. After creating the boundaries, I imported shapefiles of the glaciers. In order to narrow down the focus area even more, a section of the glaciers was digitized in each basin. These areas were used as the focus areas in order to measure the incoming solar radiation hitting each of these glaciated areas during every month of the year. Stream flow data was collected from stream gauges at or near the outlet of each





Data Sources

<u>NASA's ASTER GDEM V2 (Digital Elevation Models)</u>

NASA's ASTER GDEM V2 product provides global digital elevation models with 30m resolution. This product was chosen in order to maintain consistency between data by being able to download DEMs for Peru and Alaska via the same product. These DEMs were downloaded directly from the USGS Earth Explorer page.

<u>USGS National Water Information (Stream Flow Data for Alaska)</u>

USGS provides stream flow data for rivers throughout the United States where stream gauges exist and are active. Data can be downloaded in a few formats. I exported the data for monthly averages for each year (1995, 2000, 2005) in a tabular format.

<u>Dr. Baraer of University of Quebec (Stream Flow Data for Peru)</u>

For the Santa River, I used monthly average stream flow data provided to me by Dr. Michel Baraer from the University of Quebec, who has done extensive research in the region for years. Finding data for the region proved to be difficult or spotty, so I was lucky to have acquired Dr. Baraer's data, which matched my focus years.

<u>GLIMS: Global Land Ice Measurements from Space (Glacier Shapefiles)</u>

GLIMS provides current data on the shape and total area of glaciers around the world. Shapefiles were downloaded from their site for the Alaska and Peru regions. These shapefiles were used as the specific focus areas for my project, as I was most focused on the incoming solar radiation hitting the glaciated area within the river basins.

Spatial Reference

Ancash, Peru: Peru Central Zone

Juneau, Alaska : NAD 1983 State Plane Alaska 1 FIPS 5001

Geoprocessing

This project used both ArcGIS Pro and ArcDesktop to complete various stages of geoprocessing. The beginning stages of my project focused on delineating watershed boundaries and streams to create a visual representation of the hydrologic systems in my focus areas. Aside from the use of the clipping tool to remove glaciers outside of the focus area, the purpose of delineated boundaries served only as a visual component of my project rather than for analysis purposes. In my maps, stream flow data were visualized by editing the width of the river features to represent the fluctuation in month to month stream flow averages.

The Area Solar Radiation and Zonal Statistics tools served as the primary geoprocessing tools for my analysis of the two basins. Thus, I will focus on describing their application for the purposes of this report.

Area Solar Radiation

The Area Solar Radiation tool is part of the Solar Radiation toolset, which is accessible with a Spatial Analyst license for ArcMap. The ASR tool provides an output raster where each cell has a value equal to the watts of solar radiation received per hour. This tool has a variety of parameters based on the location and time interval the user wants to analyze. For each river basin, a monthly time interval was set, which then provides an output raster for each month of the year. Due to the geoprocessing time of this tool, incoming solar radiation was only calculated for the glaciated areas rather for the entire basin. In order to use this as the input DEM for the ASR tool, I first had to use the Extract by Mask tool to create a DEM file for just the glaciated areas.

Parameters:

in_surface_raster: The input surface raster is the DEM of your area of focus. For this analysis, the DEM was clipped to only the glaciers within the basin.

Latitude: The latitude parameter is automatically calculated when the DEM is input so long as the raster has a spatial reference. This parameter helps determine the angle at which the region is receiving solar radiation.

time_configuration: Time configuration establishes the overall length of time being analyzed. “TimeWholeYear” was set for this parameter, although other options include “TimeWithinDay,” “TimeMultiDays,” and “TimeSpecialDays.”

each_interval: This parameter defines the amount of outputs created by the ASR tool. By choosing “INTERVAL” vs “NOINTERVAL,” an output is created for each interval set by the “*time_configuration”* parameter. “INTERVAL” was chosen for this parameter to create 12 output rasters—one raster for each month of the year.

All other parameters were left at their default values. Three optional outputs can be created with the ASR tool, “*out_direct_radiation_raster*,” “*out_diffuse_radiation_raster*,” and “*out_direct_duration_raster*.” None of these outputs were created because the tool’s main output “*out_global_radiation_raster*” provides the output needed for this analysis. The output global radiation raster provides a raster grid where cell values represent average solar radiation in watt hours per meter squared.

Zonal Statistics

The Zonal Statistics tool is also accessible with a Spatial Analyst license and is used to calculate the statistics of a value within a defined area. A portion of the glaciated areas was digitized and then the Zonal Statistics tool was used on that area to find the average solar radiation hitting that location each month. This step had to be repeated 12 times for each basin in order to find the average incoming solar radiation for each month. Therefore, the end result of this part of the analysis would provide 12 averages for each basin.

Parameters:

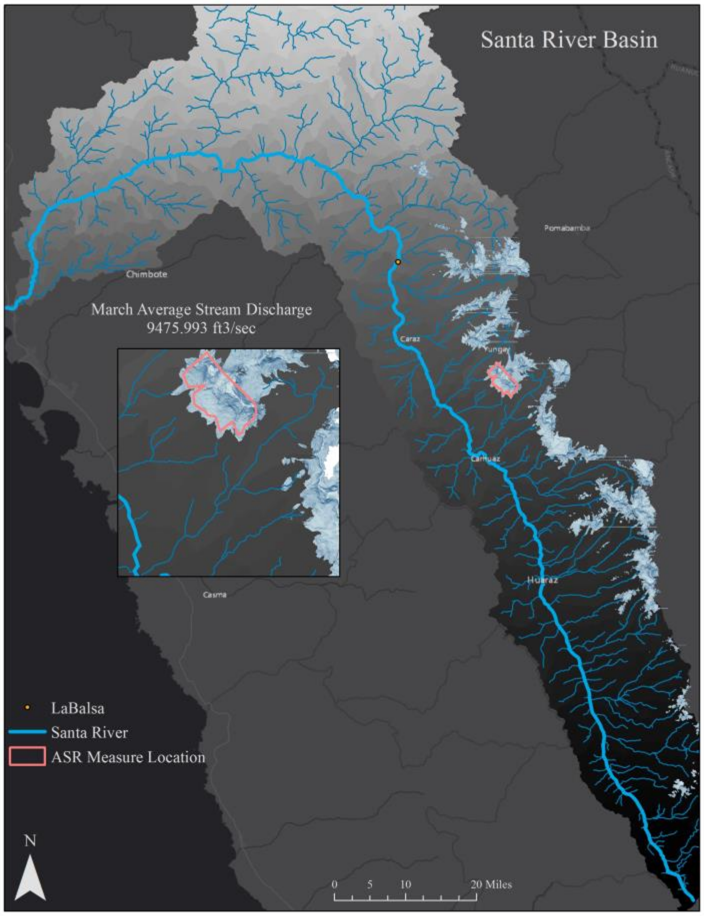
in_zone_data: This parameter is used to define the area that the tool is being ran on. The input could either be a raster or a feature layer. For this parameter, I digitized an area of glacier in each basin that would be used for this input. This area/polygon can be seen in pink in the maps below.

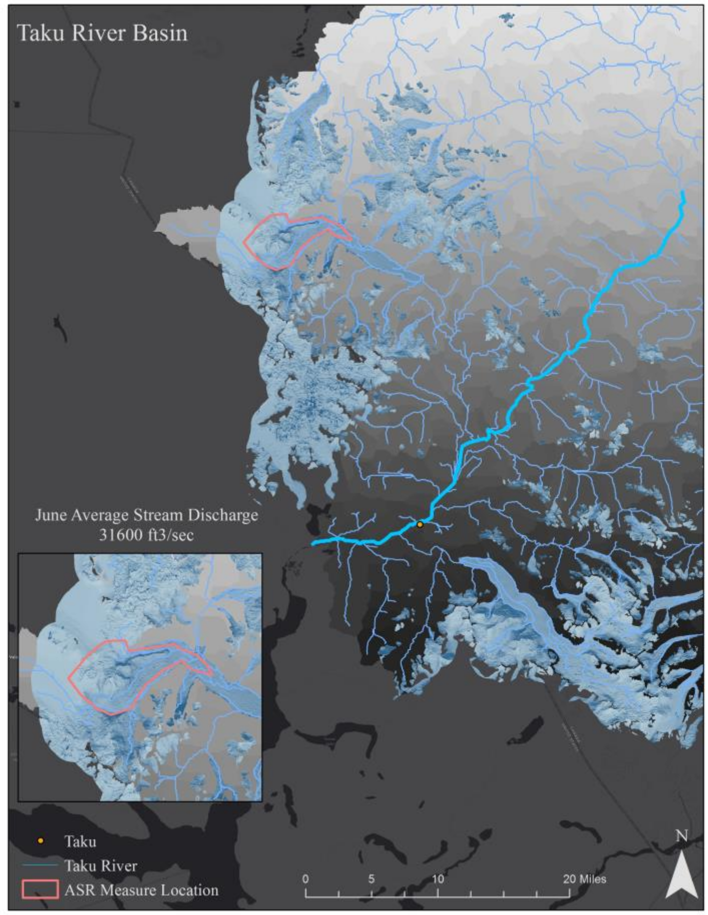
zone_field: Zone field is the field that defines each unique zone. For this analysis, only one zone was created for each basin. Object ID was used for this parameter.

in_value_raster: The in-value raster is the raster that needs to have statistics gathered on it. The ASR output file, out_global_radiation_raster, was used as the input since we want to gather the average incoming solar radiation for each month.

statistics_type: Various types of summary statistics can be chosen in this parameter. “MEAN” was selected for the statistic.

ignore_nodata: This parameter allows the user to decide if NoData values influence the output statistics. I selected “DATA,” which tells the tool not to allow NoData values to influence the output value.

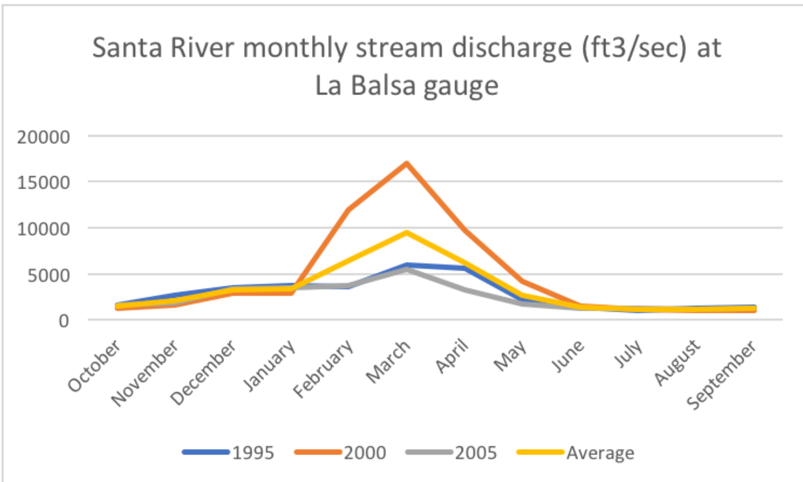


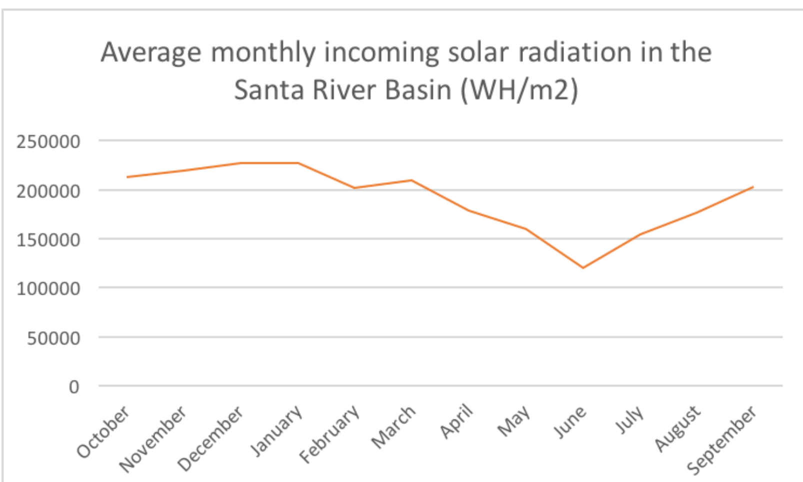


Results and Discussion

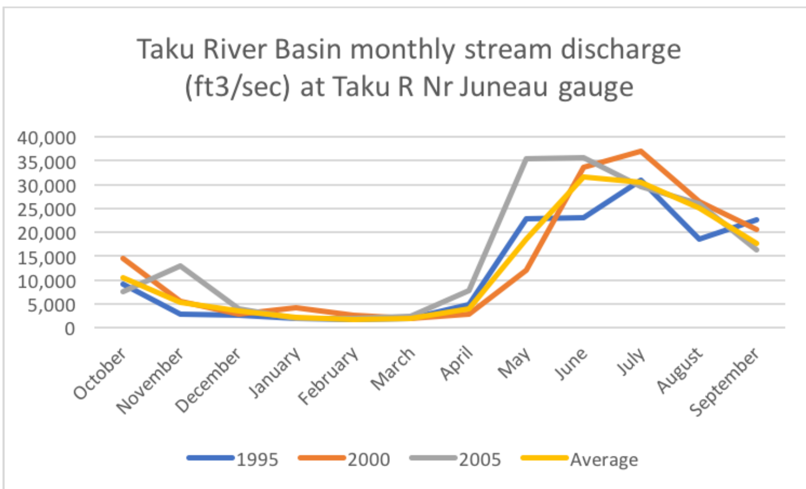
Although the results of this project were not shocking, they were enlightening and thought provoking. My findings highlight the positive correlation between incoming solar radiation and average monthly stream flow. As regions enter the winter seasons and the glaciers receive less incoming solar radiation, there is a decrease in stream flow since glaciers aren't providing melt water to the rivers. In contrast, as incoming solar radiation increases during the summer months there is also an increase in stream flow.

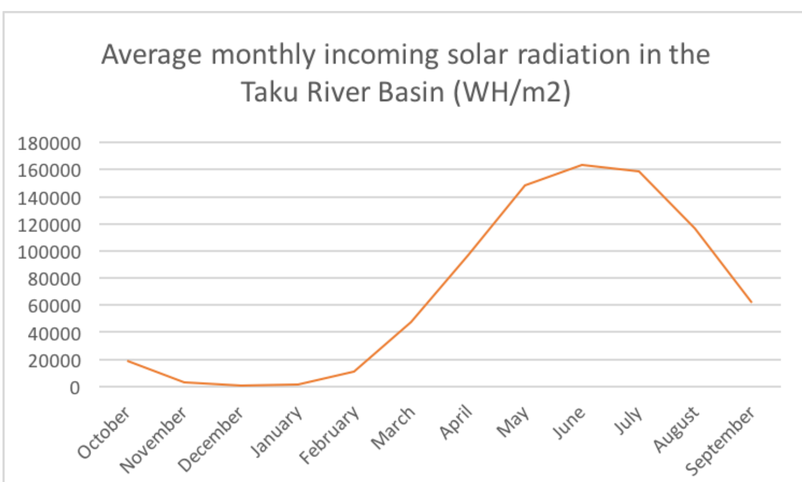
In the Santa River Basin, peak incoming solar radiation occurs during the months of December and January. It's worth noting that even though there is seasonality in solar radiation within Ancash, because the region is located in the tropics it receives greater and steadier amounts of incoming solar radiation than regions further from the equator. This is due to the direct angle at which the solar radiation hits the equator throughout the year, providing as much as about 2.5 times the amount of annual solar energy received at the poles. Santa River stream gauge data for 1995, 2000, and 2005 shows that peak stream discharge typically occurs between the months of February` to April with an average peak stream discharge of approximately 10,000 ft^3/sec occurring in March. Because glacial melt runoff takes time to move from the top of the mountains down to the river outlet, it's not surprising that peak stream flow occurs a month or so after the region has received its peak incoming solar radiation.





In the Taku River Basin, peak incoming solar radiation occurs during the months of June and July when the region receives daylight for around 18 hours a day. During these warmer months, glacial melt runoff provides over 35% of Alaska's total runoff. As a result, peak stream flow occurs during the same months in which the average peak stream flow for 1995, 2000, and 2005 is 33,000 ft^3/sec in June. During the winter months of November through February when the region receives less than approximately 6 hours of sunlight each day, the Taku River receives little to no stream flow. The extreme seasonality of incoming solar radiation, due to the high latitudinal position of Juneau, Alaska, causes dramatic decreases in temperature during the winter months. These low temperatures freeze most precipitation and streams during these months, and as a result the Taku River has little to no stream discharge.





Future Work

Future analysis should incorporate precipitation data to help better determine the contributing ratio of glacial runoff to precipitation when measuring stream discharge. While glacial runoff is a major contributing factor, peak stream discharge occurs during the rainy season in Ancash, Peru and therefore precipitation should be accounted for. For a deeper analysis, the addition of groundwater data would also be essential for a more accurate analysis.

In the future, I'd also like to better understand how to calculate the lag time of glacial melting to the time the runoff flows downslope into to a specific destination. This would allow for better assumptions to be made about the contribution of glacial melt to a specific month's stream discharge.

Lastly, future projects should also use field data on incoming solar radiation rather than ArcGIS geoprocessing tools alone. While the ESRI Area Solar Radiation tool takes into account many parameters, the tool doesn't account for extremes (increases or decreases in solar radiation) that may occur in a particular year. While the default values of the ASR tool are adequate for this project, future analysis should also research and apply more specific regional and seasonal based values to parameters set as default where necessary.

Conclusion

This project has performed a geospatial analysis through the use of ArcGIS to model monthly stream discharge within a glacial fed river basin and the monthly incoming solar radiation at the glacier site. As incoming solar radiation increases in glacial fed river systems so does the stream discharge of the rivers fed by glacial runoff. The results highlight the effect latitudinal position has on the seasonality of incoming solar radiation, where seasonality increases the further a region is from the equator. Although the results proved valuable for understanding the correlation between solar radiation and stream discharge, further studies should incorporate the use of precipitation, groundwater, and field data on incoming solar radiation.

References

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