THERE AND BACK AGAIN: AN ANALYSIS OF WATER AREA AND CLIMATE OF 3 EPHEMERAL LAKES IN THE OREGON CASCADES

by

Riley Chambers

A THESIS

Presented to the Department of Earth Science
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Science

November 2023

An Abstract of the Thesis of

Riley Chambers for the degree of Bachelor of Science
in the Department of Earth Science to be taken December 2023

Title: There and Back Again: An Analysis of Water Surface Area and Climate of 3 Ephemeral Lakes in the Oregon Cascade Range

Approved: *Sarah Cooley Ph.D.*
Primary Thesis Advisor

The Willamette River is the main provider of water to the Willamette Valley. It flows northward through the valley, where 70% of Oregon's residents reside, eventually connecting to the Columbia River on the border of Oregon and Washington. The headwaters of the Willamette River originate in the Oregon Cascades, specifically in the High Cascades. The large amount of precipitation that falls on the Cascades allows seasonal cycles of water release from the melting of snowpack throughout the dry season. The Oregon Cascade Range, because of its geologic composition, has unique relationships between geology and climate that contribute to the water access to the people and landscape of the Willamette Valley.

The Cascades are generally divided into two provinces: the older, eroded, less basaltic, more impervious Western Cascades, which extend from the eastern base of the Willamette Valley to about the Santiam Junction; and the High Cascades, which are much younger geologically (about 4 Ma), more basaltic, and contain vast swaths of porous bedrock. Most of the water flow in the Western Cascades is surface flow, whereas groundwater flow from precipitation penetration into the porous bedrock is the main form of water transportation in the High Cascades.

3 seasonal lakes that reside along the border of the Western and High Cascades highlight the interrelationships between the climate and the geology. Fish Lake, Lava Lake, and Lost Lake are similar in the way they fill and drain each year from precipitation and geology. The rates at which they drain and if these rates are dependent on SWE (snow water equivalent), air temperature, and precipitation levels can help to better understand how the geology is impacted by the climate and how this might affect water access downslope in the Willamette Valley.

Acknowledgements

I would like to thank Sarah Cooley, who helped me throughout this entire process and was an amazing advisor. I could not have done it without her, and I am proud to be her first honors thesis advisee! Thank you for everything. I would like to thank Michael Moffitt for helping me cross the finish line and always being there for anything. I would like to thank Marla Trox, who is just a wonderful person, and for being so helpful. Thank you to Miriam Alexis Castellón Jordan for helping me stay on track. Thank you to the Earth Science department, the Geography department, and the Robert D. Clark Honors College. I would like to thank my family for supporting me in every facet of life, especially in my education, and helping me grow into the person I want to be. Thank you to Rigel Wakil, Derek Graham, Sydney Greene, Elle Russell, and all of my other friends for supporting me, inspiring me, and being amazing people. Thank you to Metallica, the Grateful Dead, Vince Guaraldi, Nickel Creek, and all of the other musicians I listen to that help me stay focused and inspired.

I would also like to acknowledge that the land studied in this research and the land the University of Oregon resides upon is the homeland of the Kalapuya-Ilihi and Molalla people. Recognizing this is essential in order to respect the history that is a part of this area and ensure we interact with this land responsibly in the future.

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Introduction

The Willamette Valley is a highly fertile land that provides a home to about 70% of residents in Oregon (Robbins, 2023). Much of the fertile sediment was deposited in the valley from the Missoula and Benneville floods, in which, about 20-14 thousand years ago, Lake Missoula in Washington State flooded due to glacial melting (USGS, 2020). The Willamette River, which cuts right through the valley northward to the Columbia River, provides water to hundreds of thousands of residents. It is integral in the production of wine by the more than 700 wineries (Willamette Valley Visitors Association, 2023) and by agriculture production, including seed and grass (Robbins, 2023). The Willamette River's headwaters are situated in the Oregon Cascade Mountain Range. The weather systems that are blocked by the high topography allow precipitation to fall on the west side in the form of both snow and rain. The high amount of precipitation combined with the distinctive geology allow for consistent seasonal releases of water that benefit all of the residents of Willamette Valley in the form of a trustworthy water supply.

The Oregon Cascades mountain range is home to some of the most unique hydrologic features in the United States. Several tributaries to the Willamette River start in the High Cascades, a region of relatively young, and still volcanically active, mafic rock. The high permeability of the basaltic lava flows from recent volcanic activity (Tague et al. 2007) contributes to a large amount of groundwater storage that re-surfaces on the Western Cascades. Ephemeral lakes, such as Fish Lake, Lava Lake, and Lost Lake, that exist on the border of the active High Cascades and eroded Western Cascades showcase the unique relationships between geology and climate. These lakes drain and fill each year in a seasonal cycle. Instead of from man-made processes, such as dams, that release water throughout the year in seasonal cycles, these lakes fill and drain because of influences by the water cycle and the geology. The seasonal cycle of snowpack and snowmelt, along with the highly permeable bedrock, contributes to a natural cycle of filling and draining. However, little is known about these ephemeral lakes. Shedding new light on some of the interactions between the recent geologic history and climatic variables in these ephemeral lakes, such as drainage rate and temperature, precipitation, and SWE (or snow water equivalent) can help us better understand the relationships between the climate, hydrologic cycle, and the geology of the Oregon Cascades, especially in consideration of the broader implications of how these relationships will change with the changing climate.

This paper aims to begin to understand these principles with the study of the 3 ephemeral lakes aforementioned by using satellite imagery data to create time series of drainage rates, represented by changes in surface water area, over a 6-year period between 2017 and 2022. These rates are compared to precipitation, air temperature, and SWE data and analyzed to show potential correlations.

Study Area

Geologic and Geographic Setting

The Oregon Cascades contain young provinces of rock. The Cascades are generally divided into two physiographic subsections: the older, more silicic, Western Cascades and the younger, more mafic, High Cascades. The Western Cascades are the most eroded section of rocks that underly some of the High Cascade formations and extend to the eastern border of the Willamette Valley (Sherrod, 2023). The Western Cascades were formed 4 million to 40 million years ago as part of a volcanic arc due to the subduction of the Juna de Fuca plate under the North American plate. The rocks here, mostly calc-alkaline and andesite (Taylor, 1990), are from the Late Eocene to Miocene in the Tertiary age (Smith, Snee, and Taylor, 1987). The products of the volcanism that formed these structures, such as local andesitic volcanoes and eruptions of silicic pyroclastic rock (Priest, 1990), have been subjected to many forms of erosion, alteration, and deformation, mainly due to their composition and uplift (Priest, 1990). This distinguishes them from the younger, less eroded formations of the High Cascades.

The basaltic and andesitic voluminous lava flows from the High Cascades that characterize much of the High Cascade section today began erupting about 8-10 Ma and about 4 Ma. (Taylor, 1990). This volcanism is bounded by the uplift of the Western Cascades. The active volcanic arc margin consists of cinder cones, lava domes, and larger volcanoes, such as the Three Sisters and Mount Jefferson (Sherrod, 2023). The consistent eruptions within this 10-million-year time period have left the landscape broader and flatter (Harris, 1988), due to the effusive mafic eruptions, gently sloping eastward towards Bend away from the Western Cascades. The recent volcanic activity provides the landscape less of an opportunity to form deep river channels and eroded basins, while the mafic composition of the lava flows gives the area certain characteristics, such as highly porous rock that allows higher infiltration rates than that of more silicic magma (Jefferson et al., 2009) and networks of lava tubes, formed by the cooling of the outer layers of basaltic lava flows (Geggel, 2015).

The young lava flows of the High Cascades have high permeabilities (Saar and Manga, 2004). This allows much of the precipitation here, which is quite high because of the high elevation blocking large air masses and atmospheric rivers coming in from the Pacific Ocean, to infiltrate and recharge groundwater flow. The water then emerges downgradient of the upper elevations as, "large-volume, spring-fed streams with higher summer flows and lower temperatures than the shallow subsurface flow-fed steam draining the…older, less permeable Western Cascades terrain." (Jefferson, Grant, and Rose, 2006) The water then travels from the High Cascades as groundwater to the Western Cascades, where it coalesces into lakes and rivers. Lakes existing among higher elevations can drain into groundwater storages, resurface in other lakes and streams, and eventually coalesce into major tributaries of the Willamette, such as the McKenzie, Middle Fork Willamette, and Santiam rivers.

In the High Cascades, about 75% precipitation falls as snow (Tague et. al, 2006). The temperate climate allows for this precipitation to be stored in the winter as snowpack and melted as water in the summer, so a consistent water supply from the headwaters is supplied to Western Oregon during the dry season. About 70% of this precipitation falls between March and November, snowpack forming above 1200 m in elevation and primarily as falling as rain below 1200m (A. Jefferson et. al, 2010).

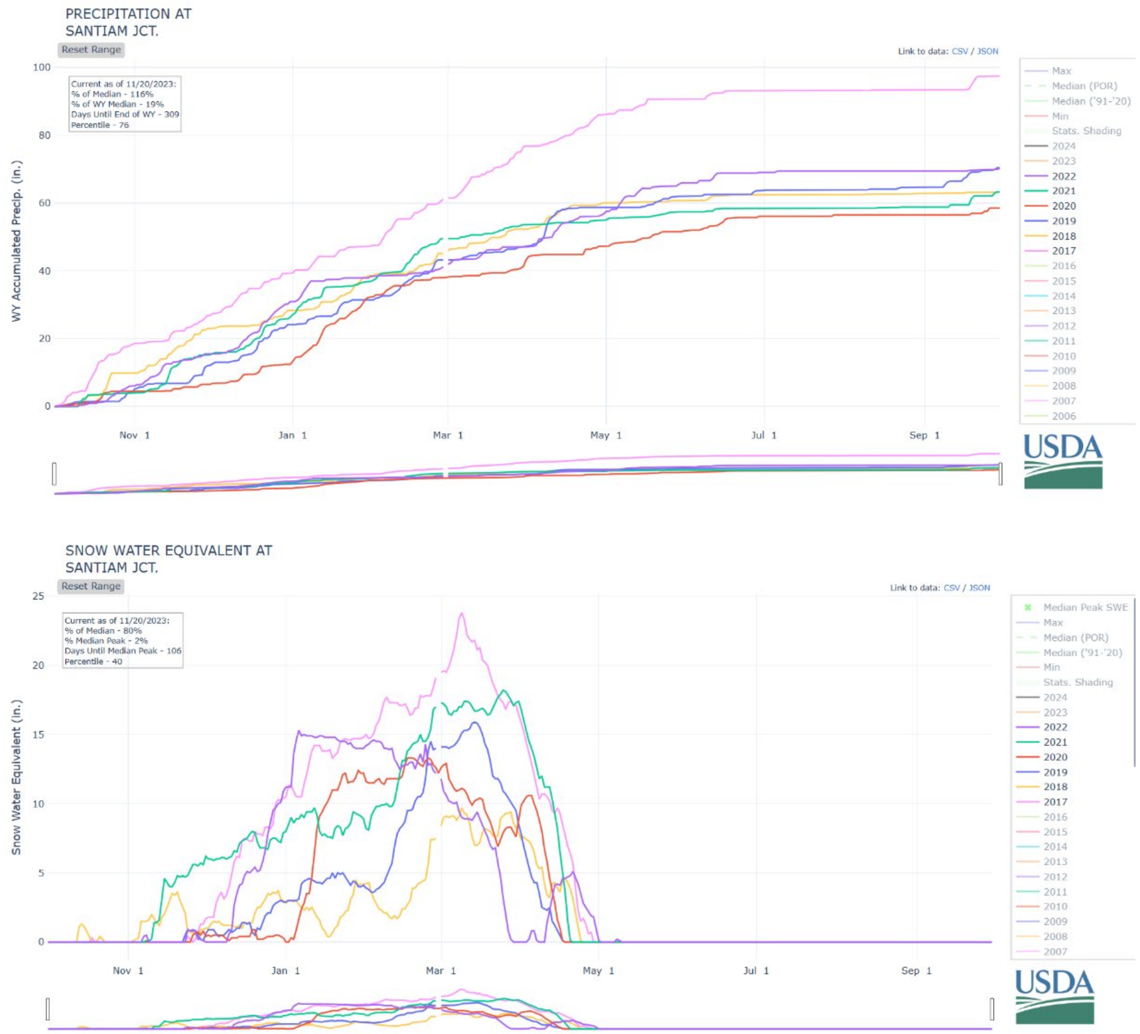


Figure 1: Precipitation and SWE at Santiam Junction Site 733. There is a lot of variability within these 6 years, but 2017 clearly was a much wetter year than the others.

Lakes

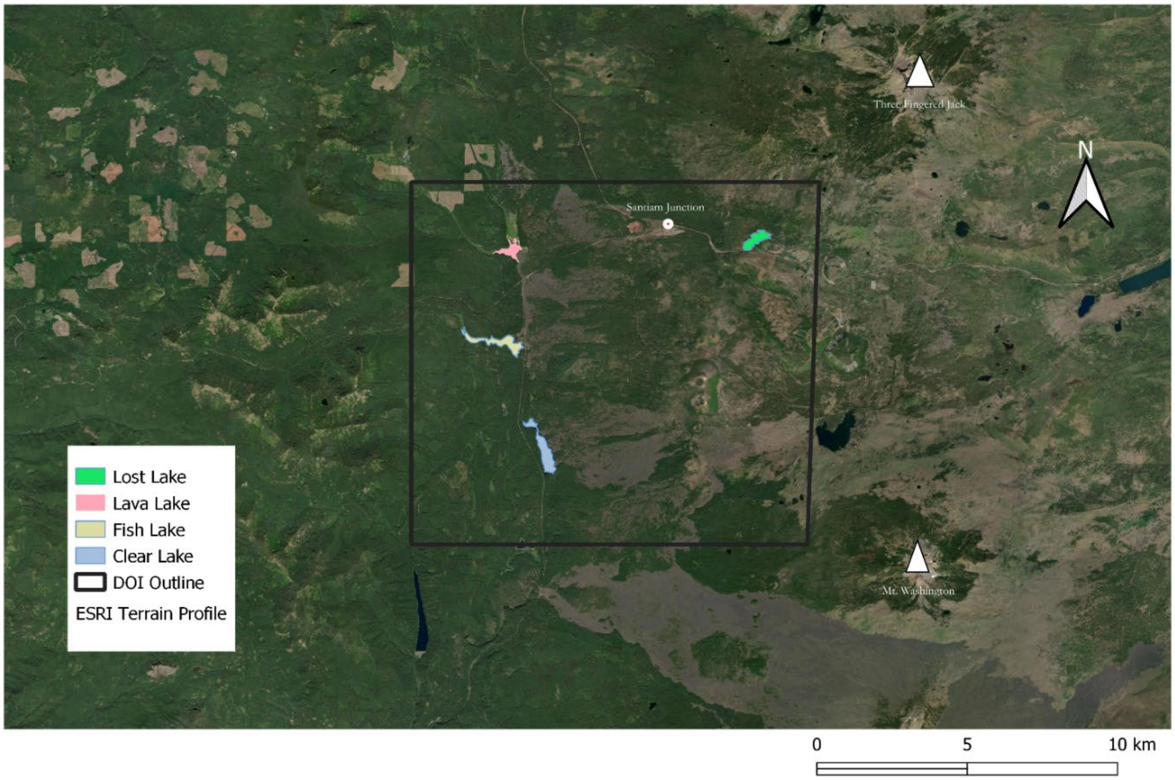


Figure 2: Subject Area DOI. The DOI is a square of approximately 170 km^2 within the High Cascades, about 4 km west of Mt. Washington and the Santiam Pass. The Santiam Junction is where OR 126 and OR 46 converge to continue on as OR 126.

The 4 lakes within the study area all lie within a 10 km radius of one another. This suggests that the climate they interact with is very similar. For the purpose of this study, the variations between air temperature, precipitation, and SWE between each lake are negligible.

The DOI is a square of approximately 170 km^2 within the High Cascades, about 4 km west of Mt. Washington and the Santiam Pass. Figure 1 shows the geographic positions of the lakes within the DOI in proximity to Highway 126 and Highway 22, the Santiam Junction.

Clear Lake is the control. It is on the southernmost lake in the study region. It maintains consistent water levels year-round, as it is influenced by both groundwater recharge and precipitation. It contributes much of its drainage to the McKenzie River, the river that flows directly through the central High and Western Cascades down to the Willamette.

Fish Lake is an ephemeral lake that lies just west of OR 126 highway west of the Santiam Jct. It is about 3.2 km north of Clear Lake and just south of Lava Lake (Figure 2). It was created by the damming of Hackleman Creek about 4,000 years ago by the eruption of Sand Mountain (Friends of Fish Lake, 2023). It has a small outlet channel that feeds into Fish Lake Creek, which makes its way, mostly through groundwater flow, to Clear Lake and on to the McKenzie River.

Lava Lake lies north of Fish Lake on Cascade Lakes Highway OR 46. It was formed by the damming of its eastern shore by lava flows. It is primarily fed by subsurface springs, as there are no permanent surface flows that supply water. The outlet is in the southeast corner of the lake, so it feeds into groundwater or surface water that makes its way to Clear Lake and the McKenzie. (USDA Forest Service, 2023).

Lost Lake is the most known and studied of the 3 ephemeral lakes. It is directly on the north edge of OR 126, east of the Santiam Junction. It was most likely formed about 12,000 years ago with the eruptions of several Cascade volcanoes. There are at least 3 drainage holes on the bed of the lake that contribute to drainage, but there is conflicting evidence as to if these holes are lava tubes or just orifices left-over from past geologic activity (Howard, 2015 and Patton, 2015). However, it is not in contention that the water that drains from these holes flows in subsurface paths to reach Clear Lake and the McKenzie River.

Methodology

To first analyze the rate at which the 3 ephemeral lakes were draining, I used satellite imagery from Planet (https://www.planet.com/) and the computer software program QGIS version 3.26 () to represent the lakes visually and to compute the water surface area at specific times during each year between 2017 and 2022.

Planet satellite imagery has been in use since 2013 (Cooley et. al, 2017). It is a commercial company that has deployed more than 200 satellites for use by scholars, companies, and organizations alike (Planet, 2023). There are 3 different types of satellites employed by planet: PlanetScope, which has about a 3.7 m resolution, and surveys over 350 million km^2 per day; RapidEye, which has a 5 m resolution; and SkySat, which has a 50 cm resolution and surveys over 400 thousand km^2 per day. I used PlanetScope data. It has the capacity for 4 bands in the RGB (color) and NIR (near infrared) spectral arrays. The first year of planetary images that were useable for my research was 2017. Planet's use of CubeSat satellites means that it is primarily used for RGB and NIR band sensing, which is useful for detecting NDWI. It balances high spatial and high temporal resolutions by employing a constellation of satellites. The high frequency of image return from these satellites allows for detecting small changes across hydrologic features. This was useful for my research, because there is a small window during the year of water occupation by these 3 ephemeral lakes, between snow cover and drainage, so the breadth of images captured by the satellites allowed me to choose enough images to gather sufficient water area data.

Between 9 and 13 images were chosen between the months of March and September for each year. Before March, the lakes are covered in snow, and after September, the lakes have all drained. These images were chosen because of clarity and testability. Most images captured, especially during the early stages of Planet's use, such as in 2017, are unusable for this type of analysis because of inhibiting factors, such as cloud cover or missing part of the study area.

The images chosen for each year were then uploaded to QGIS for analysis. Because Planet has certain sweep lines and swath widths for each day, depending on the orbit of the satellites, the images had to be merged into one file. Each image was then clipped to the study area.

Figure 3: Merged Image June 12, 2019. The different swaths from the CubeSat satellite can be clearly seen, but this image is merged into one to be able to analyze the features.

I created precise outlines of each of the lakes, including Clear Lake, by hand. These outlines were created on an image that showed the lakes at full volume. This is to have an area to test how much the water level had gone down by in each image by testing the number of NIR pixels. See Figure 5 below for visuals of the lake polygons.

Each image was calculated within the NIR band to show only the water area. The calculation used in the Raster Calculator function in QGIS for each image appeared in the raster calculator as follows:

(input layer file) < 1000

NIR is a good indicator of water because of water's high absorption of all wavelengths of light (Ryan, 2022). All other surfaces, such as vegetation cover and bare earth, absorb some level of NIR, so if the NIR band within the image is isolated to certain levels, the image can be analyzed for surface water changes, based on how the NIR level changes. The NIR level was set for each image at 1000, to maximize comparison between each image.

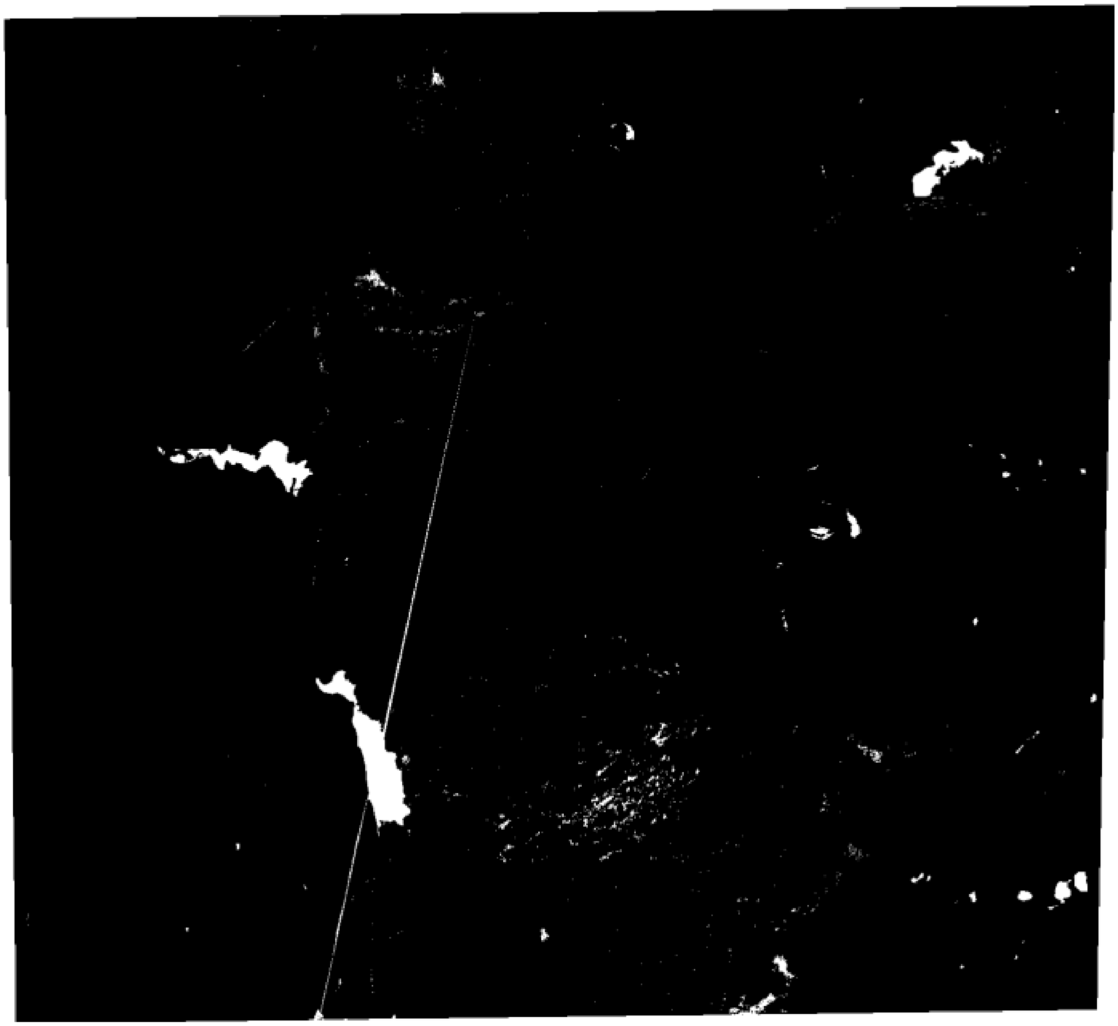


Figure 4: NIR Classification June 12, 2019. The lakes appear in the image as white because they have a lower NIR value. This is because of how much light they absorb.

The lake polygons that I made when the lakes were at full volume were used to count the number of pixels within each polygon that were concurrent with the NIR threshold. Each pixel represents 3.125m by 3.125 m. Also, Planet uses the tool of Zonal Statistics within QGIS was used to compute this within each area of lake polygon.

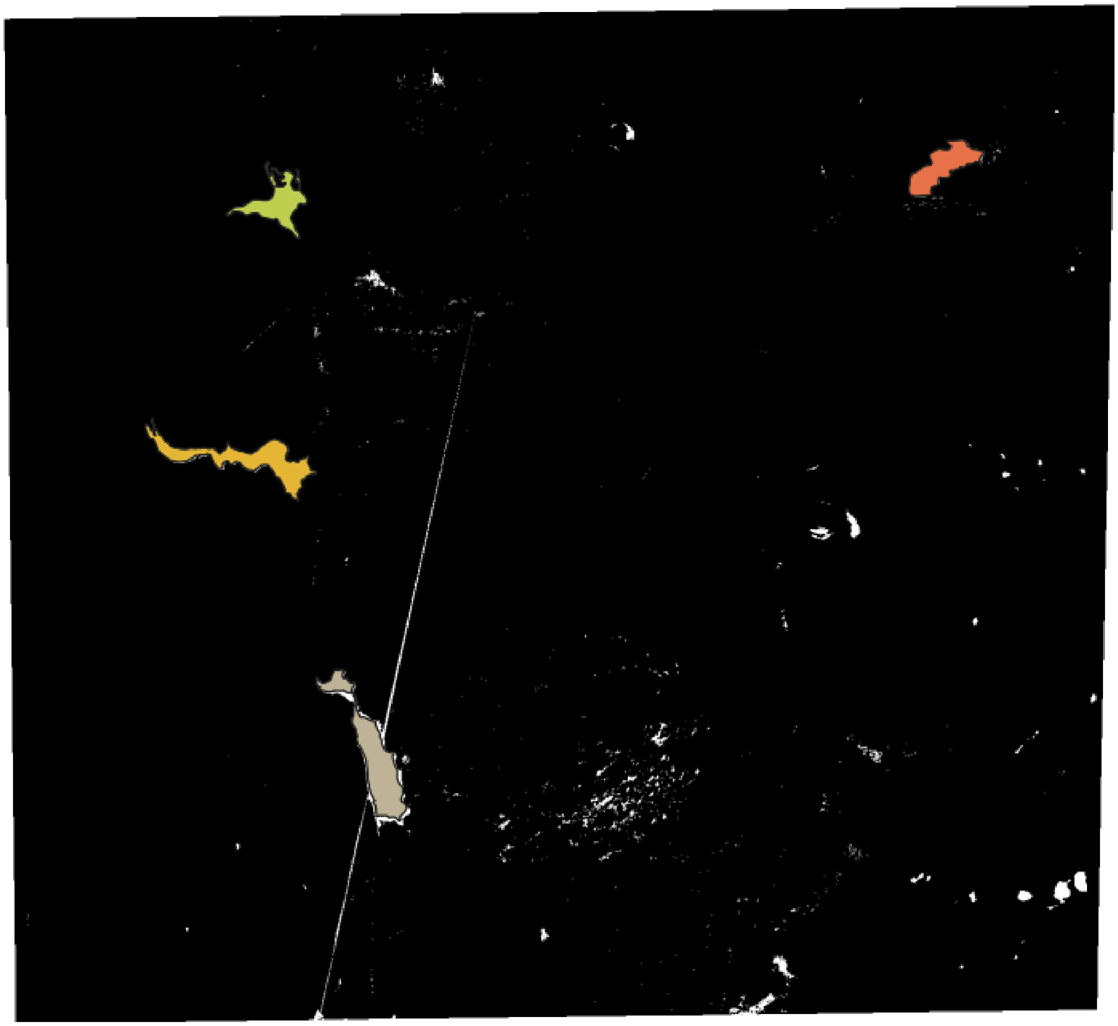
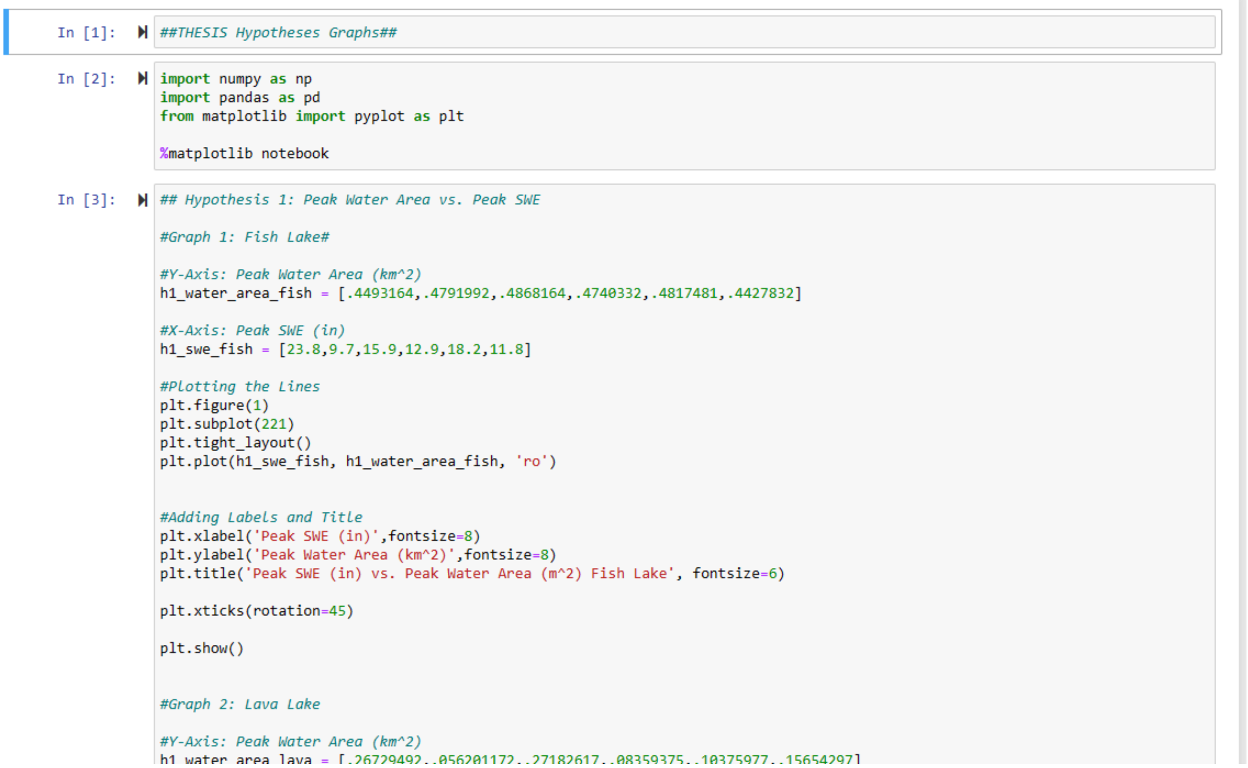


Figure 5: Zonal Statistics June 12, 2019. The Zonal Statistics tool in QGIS allows the number of pixels that fit certain criteria to be counted. In this case, it was pixels that are labeled by the NIR threshold as below 1000. Snow or other features that reflect light very well, such as bare dirt, could potentially skew results.

The data was then compiled in time series for each year for each lake. This data was analyzed in three hypotheses against 3 climatic variables (SWE (snow water equivalent), Precipitation, and Average Air Temperature) data from the SNOTEL Santiam Junction collection site, site 733, provided by the USDA National Conservation Resource Service, as part of the National Water and Climate Center (USDA, 2023). Peak SWE was analyzed against peak water surface area of each lake to understand if the peak SWE does correspond to a greater peak water surface area. Minimum water surface area date, or the date at which the water area was at its least or drained completely for each lake, was analyzed against peak SWE to show if a greater SWE amount will lead to a later date at which the water completely drains from the lakes. Mean air temperature for each year (between April and June) was analyzed against peak water surface area to see if hotter years yield a smaller peak water surface area. Graphs to represent correlations between the SNOTEL data and water surface area data were created with Jupyter Notebook, a free, open-source code-writing software. All code was written in Python for accessibility. Code written for each graph was very similar but changed with data entry. Each date of each image was changed to number of day of the year to preserve continuity between each year.

```
# Geography THESIS graph experiment

import matplotlib.pyplot as plt


### 2018 ###
# Data for the lines
clear_lake2018 = [.5224414063, .5182421875, .5212597656, .5224804688, .5225488281, .5004101563, .5213085938, .5204394531, .52
fish_lake2018 = [.4791992188, .4631445313, .4606542969, .4451171875, .3393359375, .03279296875, .00064453125, 0, 0, 0, 0]
lava_lake2018 = [.05620117188, .1277539063, .0131640625, .002666015625, .001162109375, .00021484375, 0, 0, 0, 0, 0]
lost_lake2018 = [.071875, .2967578125, .2833886719, .2567578125, .1912304688, .07450195313, .00447265625, .00048828125, .0015

# Dates for the x-axis
dates2018 = [112, 122, 134, 148, 156, 166, 175, 188, 195, 209, 217]

# Plotting the lines
plt.plot(dates2018, clear_lake2018, label='Clear Lake')
plt.plot(dates2018, fish_lake2018, label='Fish Lake')
plt.plot(dates2018, lava_lake2018, label='Lava Lake')
plt.plot(dates2018, lost_lake2018, label='Lost Lake')

# Adding labels and title
plt.xlabel('Date (DOY)')
plt.ylabel('Water Surface Area (km^2)')
plt.title('Water Surface Area Over Time 2018')

# Rotating x-axis labels for better readability
plt.xticks(rotation=45)

# Adding legend
plt.legend()

# Displaying the graph
plt.show()
```

Figure 6.1: Time Series Figures Code. An example of code used to plot the time series of the lakes. This example shows data from 2018, but the same code was used for all years to keep results constant.



In [1]:

```
##THESIS Hypotheses Graphs##
```

In [2]:

```
import numpy as np
import pandas as pd
from matplotlib import pyplot as plt

%matplotlib notebook
```

In [3]:

```
## Hypothesis 1: Peak Water Area vs. Peak SWE

#Graph 1: Fish Lake#

#Y-Axis: Peak Water Area (km^2)
h1_water_area_fish = [.4493164,.4791992,.4868164,.4740332,.4817481,.4427832]

#X-Axis: Peak SWE (in)
h1_swe_fish = [23.8,9.7,15.9,12.9,18.2,11.8]

#Plotting the Lines
plt.figure(1)
plt.subplot(221)
plt.tight_layout()
plt.plot(h1_swe_fish, h1_water_area_fish, 'ro')


#Adding Labels and Title
plt.xlabel('Peak SWE (in)',fontsize=8)
plt.ylabel('Peak Water Area (km^2)',fontsize=8)
plt.title('Peak SWE (in) vs. Peak Water Area (m^2) Fish Lake', fontsize=6)

plt.xticks(rotation=45)

plt.show()


#Graph 2: Lava Lake

#Y-Axis: Peak Water Area (km^2)
h1_water_area_lava = [.26729492,.056201172,.27182617,.08359375,.10375977,.15654297]
```

Figure 6.2: Hypotheses Figures Code. An example of the code written to produce a figure of Peak Water Area vs. Peak SWE. The same outline of code was used for each hypothesis but was substituted for the correct variables and data.

Results

Time Series

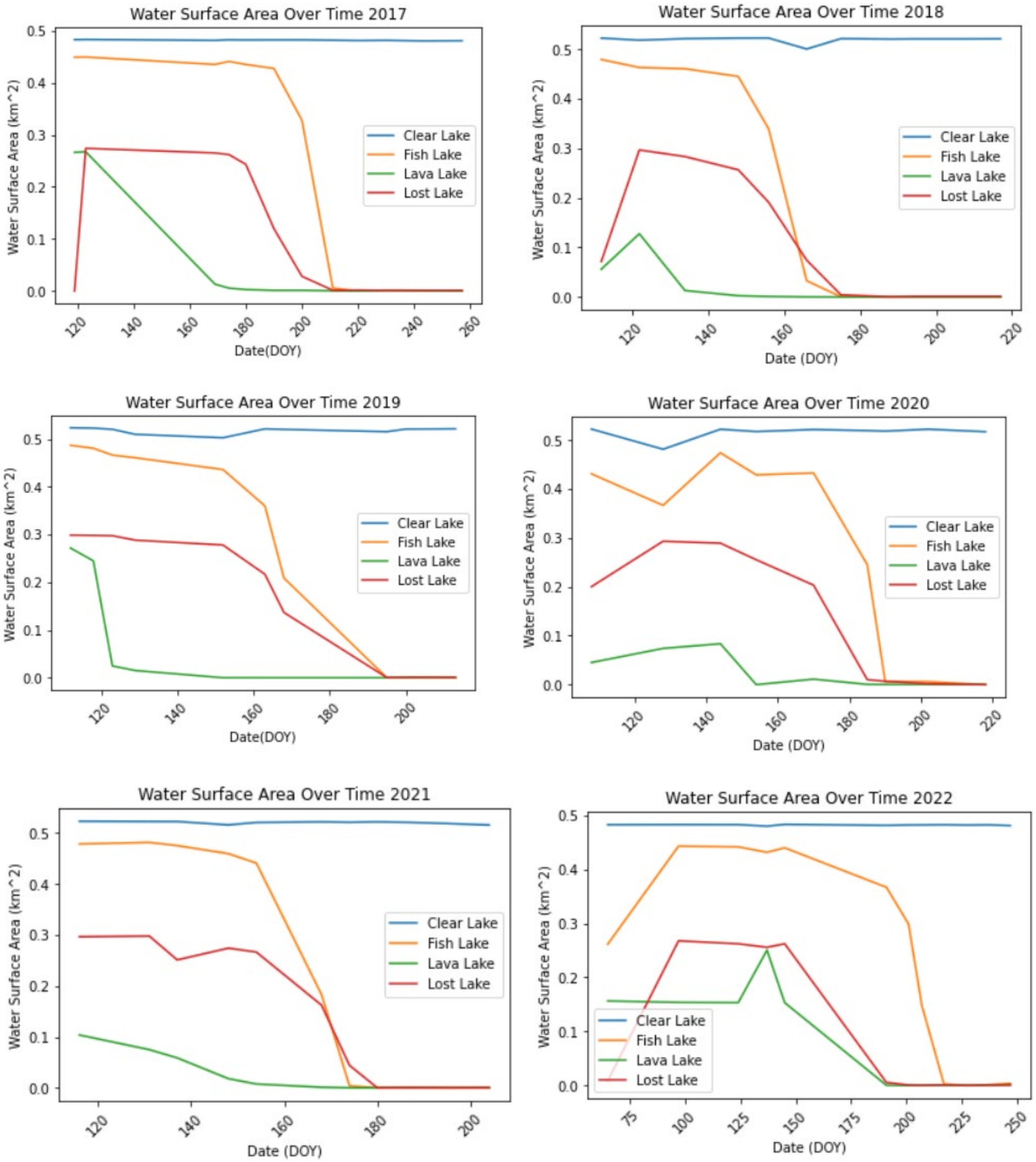


Figure 7: Lake Time Series. The time series of the lakes for each year are displayed by year, with day of year on the x-axis and water surface area in km2 on the y-axis. Clear Lake is the horizontal above all other lakes. All other lakes show some form of fluctuation.

With Clear Lake as a control, there are clear patterns that exist between the three ephemeral lakes. As shown in Figure 6, Fish Lake seems to hold the most amount of water of the three ephemeral lakes prior to drainage, with Lava Lake holding the least amount of water. This is consistent across all years. Also consistent seems to be the drainage rates. While Fish Lake does seem to hold the most amount of water initially per area, it seems to drain the fastest, as in loses the most amount of water in the shortest time period. For example, in 2021, Fish Lake had a water area in km^2 that was most similar to its starting point but lost almost all of its water in about 15 days, between June 9 to about June 24. Lava Lake, similarly, generally has a sharp drainage rate in water levels. For example, in 2019 it lost almost all of its water within about 15 days, from April 28 to May 3. Lost Lake generally has a consistent drainage rate, generally losing its water the most consistently. For example, in 2020, its water level dropped by increments of about .04 km^2 throughout the time series, while Fish Lake's water area was consistent through June 18 and then dropped .2 km^2 in 15 days. Lava Lake tends to drain the earliest in the year, as shown in 2018. It lost most of its water before the end of May, around May 20, while Fish and Lost Lake lost most of their water by about June 14-June 24. The starting levels of water of Clear Lake do not seem to be an indicator of how the ephemeral lakes will start out or change over time. For example, Clear Lake starts out with the least amount of water in 2022 and 2017, but the ephemeral lakes still start out with similar amounts of water and show similar behaviors as in other years. Lava Lake is clearly much more sensitive, though, than the other lakes to outside factors, such as climate and geology.

Peak Water Area vs. Peak SWE

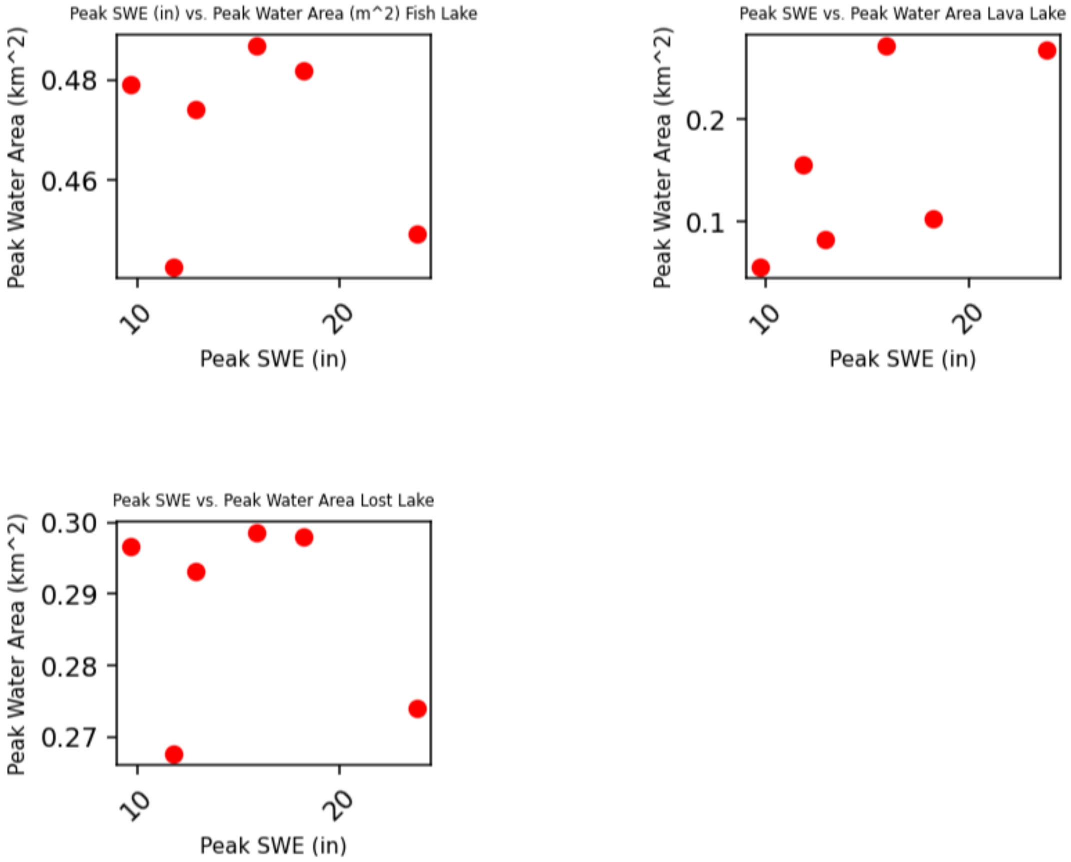


Figure 8: Peak Water Area vs. Peak SWE. Peak SWE in inches versus Peak Water Area in km2 of Fish Lake, Lava Lake, and Lost Lake, respectively.

There does not seem to be any direct correlations between SWE levels and peak water area in any of the 3 ephemeral lakes. Especially in Fish Lake and Lost Lake, it almost seems as if a higher SWE value in the year will give a lower peak water area value. The two lowest values in peak water area for these two lakes correspond to 2017 and 2022. Lost Lake, however, does show slight correlation towards a trend of higher peak water values with higher SWE values.

Min. Water Area vs. Peak SWE

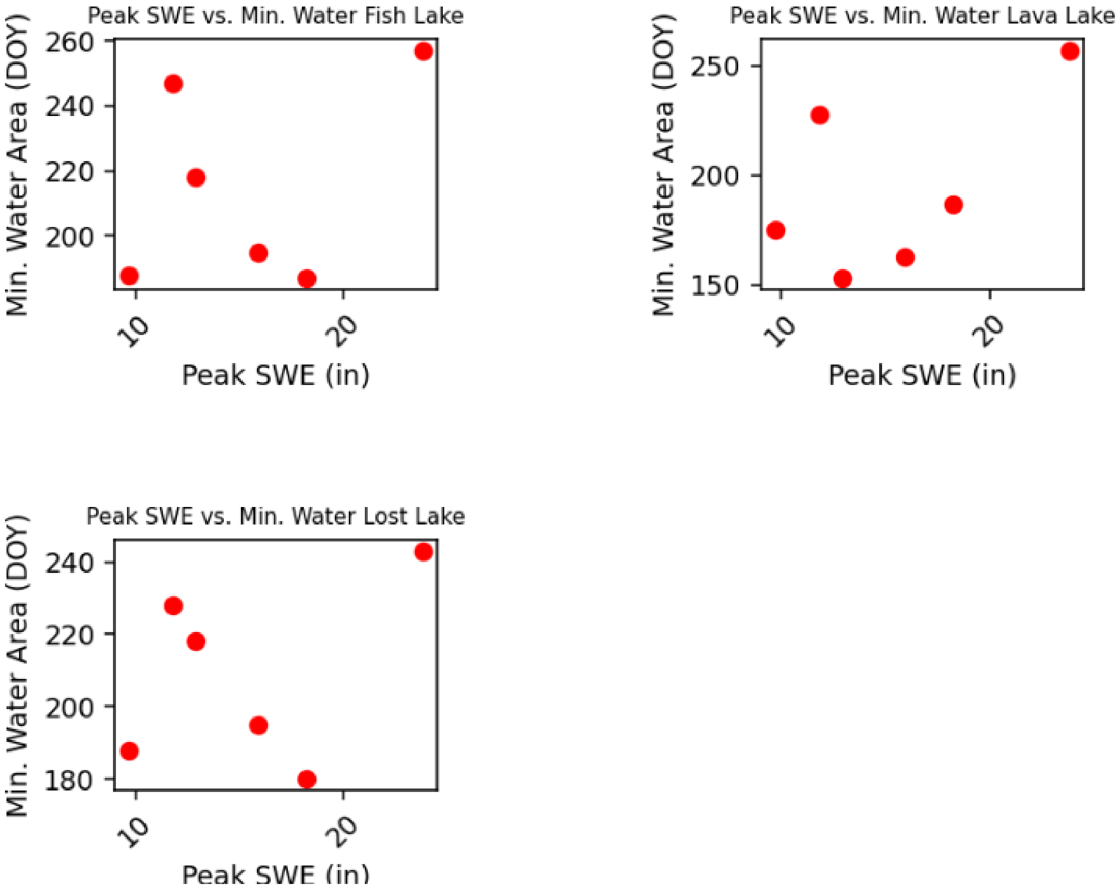
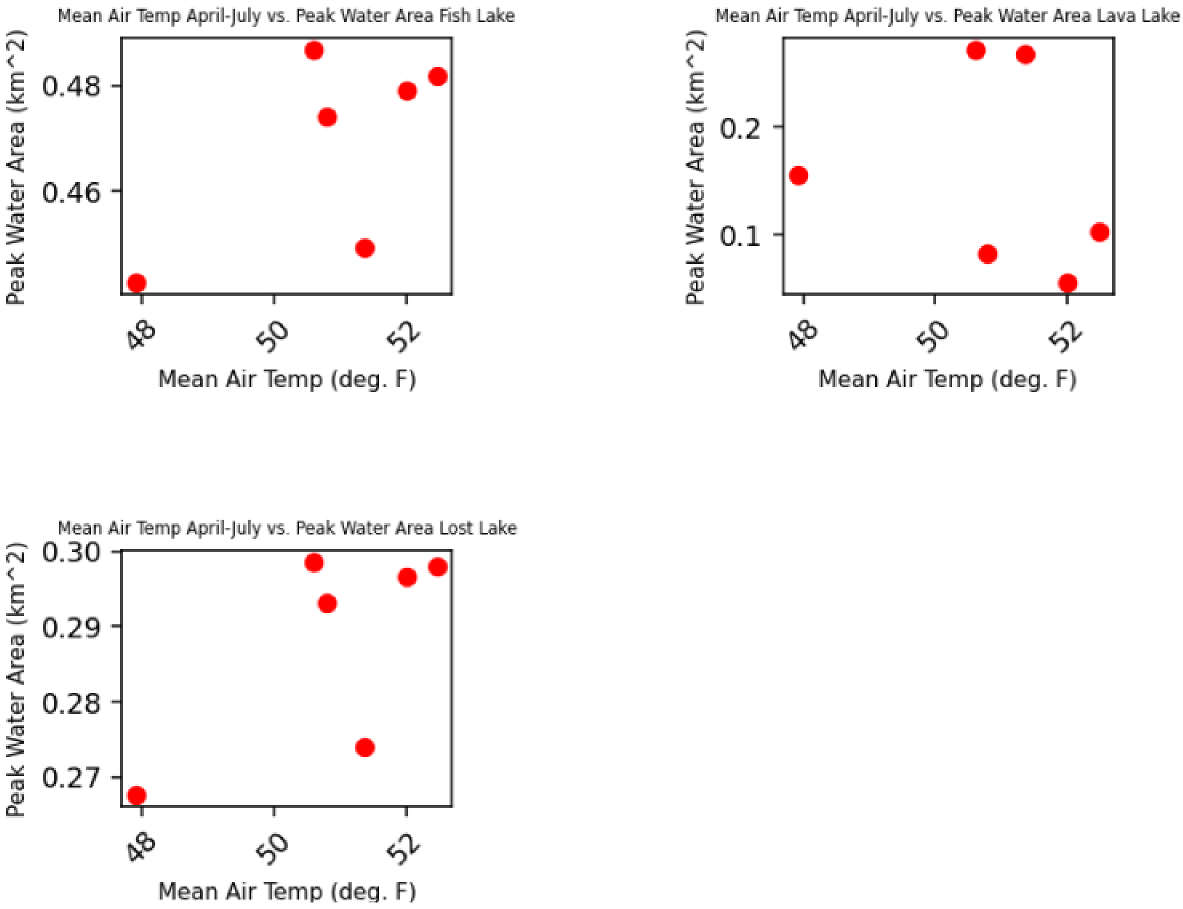


Figure 9: Peak SWE vs. Minimum Water Area Date. Peak SWE in inches versus Minimum Water Area Date in Day of Year. This figure compares the levels of SWE for each year and the date at which the lakes had drained completely.

Similar to peak water area versus peak SWE, there does not seem to be much correlation between minimum water area date (the date at which the water area is 0 or at its lowest) and the peak SWE value. The 2017 value point, with a peak SWE value of 23.8 inches, is an outlier for each of the groups. However, it points towards the expected trend in the Lava Lake figure, which, again, shows a small trend that is different from Lost and Fish Lakes. This trend is the correlation between higher peak SWE values and a late date for minimum water area. In fact, the figures of Lost Lake and Fish Lake almost show an opposite trend, where larger SWE values correspond to faster drainage rates, or earlier dates of minimum water area.

Mean air temperature vs. Peak Water Area


Mean Air Temp April-July vs. Peak Water Area Fish Lake

Mean Air Temp April-July vs. Peak Water Area Lava Lake

Mean Air Temp April-July vs. Peak Water Area Lost Lake

Figure 10: Mean Air Temperature vs. Peak Water Area. Mean Air Temperature in degrees Fahrenheit versus Peak Water Area in km2. The mean air temperature is between the months of April to July, when the levels of lake water are in the process of draining.

It would be expected for the peak water area and mean air temperature to have an inverse relationship. However, the data from Figure 10 does not show this, except for slightly in Lava

Lake. Instead, Lost Lake and Fish Lake seem to have greater peak water areas when the mean air temperature from April through July is higher. This trend is most significant in the Lost Lake figure, but Fish Lake's figure closely resembles it. Lava Lake shows a slight inverse relationship between the two variables. However, a solid conclusion cannot be drawn from this figure, for the data is almost too random to form a trend.

Discussion

There is inconclusive evidence from these analyzations as to whether the climate influences the water levels of the lakes directly. In fact, the evidence, or, rather, lack of evidence, supports the claim that the geology of the area has more to do with the water level fluctuations than the changes in climate. For example, the lack of correlation between peak SWE values and peak water area is a surprising find. It would be expected that the greater the SWE values in a given year, the more water would fill the lake at its peak, which is generally in March. However, this is not shown in the data. This could be due to the fact that the rate at which the snow cover of the lakes, especially Lost Lake, and the drainage rate did not match up, and that the snow cover that inhabited the lakes melted too quickly each year to affect the drainage rates. Furthermore, the snow that melted to water that was observed by the Santiam Jct. 733 hydraulic sensor could have made its way quite quickly into the permeable bedrock to the water table and into aquifers, where the rates of movement are on the scale of years (Jefferson et. al, 2006). In this case, the groundwater influencing the ephemeral lakes would be consistent, with few spikes or changes in hydraulic output or water level.

Lava Lake showed the most correlation between the hypotheses and the data. This could suggest that this lake is the one that is most affected by climate and that the geology of this lake does not necessarily have as much influence on the way it drains. Lost Lake, by contrast, has been observed to have at least 3 lava tubes that act as drains for the lake (Patton, 2015). Physical observation may be needed in these lakes to further determine if there are relationships between physical geology and the drainage rates. The similarities between Lost Lake and Fish Lake suggest similar forms of drainage, but, again, more research needs to be done to physically determine if this is so.

Challenges and Error

While Planet and CubeSat satellite imagery is very useful to determine certain characteristics about a region's hydrology, there are inherent limitations that require in situ observation to understand more thoroughly. For example, many of the images that are clear and able to be used for data collection are inconsistent during a given year. Cloud cover and snow cover made it challenging to have consistent dates used across all years of study. This made it possible to miss certain data points that could give clearer correlations between hypotheses. For example, Lost Lake kept snow cover the longest. This could be due to the slight elevation change between the lakes or its geographic position as closer to Santiam Pass. Also, as mentioned before, most of the precipitation among higher elevations (greater than 1200m) is snow. This influenced the starting water surface area for several years of data for Lost Lake in the figures, compared to the other lakes, because it retained snow much later into the year. Calculating differences in NIR detection by the satellites would be useful to further maximize comparability between the images. Each image has a certain reflectance coefficient that can be used to correct each image. Although the differences between each image are very slight, to be sure each image was totally able to be compared the reflectance coefficient should have been used to ensure comparability. However, despite the challenges of analyzing water area and water volume with CubeSat and Planet, it is quite a useful tool to be able to use images and NIR reflectance and absorption to calculate water area and get generalized trends to draw potential conclusions from. It is amazing that these tools are available to scholars and can be used for so many different types of analyses. In the case of these lakes, it would be helpful to have an in-depth analysis of the geology of this region in particular, because it is so diverse and complicated, that it makes direct relationships between the climate and hydrology more nuanced. As (Jefferson et. al, 2010) mentioned in their article, “the climate appears to play a role in defining [rates], but clear casual linkages and climatic controls are not well established.”

The 2017 water year had an unusually high precipitation total. Specifically, it totaled more than 94 inches of precipitation by the end of September, 20-30 more inches than any other year by that point. As seen in the data, the data points that correspond to 2017 created large outliers in the data sets and figures. Some of these data points, such as for Lava Lake, correspond more closely to expected trend lines, but some of these data points, such as in the Lost and Fish Lake figures, helped to disprove correlation. The 2017 water year helps to show the extremes of the data set and accentuate the conclusions that we are able to draw from them.

The hypotheses themselves could be non-conclusive. Other climatic variables could be more correlated to the changes in water area, such as groundwater recharge and flow, amount of evaporation or evapotranspiration, or other variables within the hydrologic cycle. The hydrologic cycle and its relationship to geology and groundwater is challenging to study as one cohesive variable. The process needs to be broken down into individual parts to be able to be studied, but this can limit the findings of one study to another. Further research needs to be done on these variables with in-situ measurements to get a more complete understanding of this study. Further research needs to be done on the geology of the region, as well, to determine exactly how these lakes are draining and how this affects our water access down in the valley.

Conclusion

In general, there is not conclusive evidence as to whether climate has significant effects on the water area levels of Fish Lake, Lava Lake, and Lost Lake. In fact, this lack of evidence to support these theories suggests that the geology of the area has more to do with the fluctuation of the lake's water levels than the climate. This is an interesting conclusion to be drawn from this study, because climate in a way controls all hydrologic processes. The hydrologic cycle is basically an extension of the climate, so there could not be a way that the water levels in these lakes are not affected somewhat by changes in climate. However, the hydrologic cycle is complicated in this region. Groundwater recharge and aquifer storage have huge effects on the distribution of water to lakes and rivers. The geology of this region has shown that the spring-fed rivers and lakes, such as the McKenzie, are largely dependent on groundwater movement, as well as climate, so there is no doubt that these processes are interconnected. These three ephemeral lakes in the Cascades may still remain partly a mystery until further research can be done.

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