A Geospatial Analysis of the California Drought: Hetch Hetchy Reservoir, Trinity Lake and Shasta Lake

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Abstract:

The state of California is currently in a drought and has been since 2011. With less precipitation falling and temperatures rising farmers have had to use an increasing amount of water to keep their crops sufficiently hydrated which in turn has contributed to a drop in water levels (Richman 2015). This research project looks at three different reservoirs that are all important for supplying water for either agricultural, industrial or domestic usages throughout the state. Hetch Hetchy Reservoir supplies water for the city and county of San Francisco while Shasta Lake and Lake Trinity both are the major water supplies for the Central Valley Project. The Central Valley Project helps supply water and power for the entire state and is the main irrigation water provider for agriculture in the Central Valley (U.S. Bureau of Reclamation, 2013).

Landsat satellite imagery has been geospatially manipulated to determine how the three reservoirs surface areas have changed throughout a 20 year period; 1995 – 2015. The general results concluded that the water level have been steadily dropping and that since the drought started the water levels have dropped significantly. Hetch Hetchy's result were interesting as its surface area has not dropped nearly as much as the other two reservoirs. Prediction were then calculated and if current drought conditions continue these reservoirs could run dry in only a few years. It is unlikely that the reservoirs will fully dry up but it does put pressure on California to change and adapt to it new future climate. Whether this will be through genetically modifying crops to become drought resistant or having an increase in desalination plants to harvest water from its coast, if something does not change California is in for a shaky and dry future.

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1.1 Introduction:

California's drought has been ongoing since 2011 and although over the 2015 - 2016 winter there has been a rise in precipitation due to the El Nino weather pattern, forecasts are still predicting the drought to continue (Wang, 2013). Signs of the drought are present throughout the state and citizens have been impacted on a daily basis (Richman, 2015). The weather patterns that have been hitting the state over the last few years have been some of the driest since records begun. The three year winter average from 2011 to 2014 shows that these years have had the least precipitation ever recorded for the state (Seager, 2015).

Winter precipitation is very important for the state's water resources. Historically during the winter months the snow pack in the Sierra Nevada Mountains accumulates. During the warmer months of the year the snow pack melts off and the water flows off the mountains into lakes and reservoirs that are scattered around the state (Seager, 2015). The reservoirs are used to store water so that it can be later used as irrigation water for the Central Valley and for general human water usages (shower, drinking, etc.). Map 1 shows the major hydrology for California including the major rivers, lakes, reservoirs and canals. When there is limited precipitation the numerous water bodies do not fully fill up and in some cases run dry. The

Map 1: California hydrology map (Henderson, 2016)

constantly changing water levels make the reservoirs an increasingly unreliable water source. Figure 1 shows a pre drought (July 2011) and during (Aug 2014) drought picture of Lake Oroville in Northern California. Lake Oroville is often seen as the poster child for California's drought, for a period of weeks the lake's water level was dropping at the rate of a foot a day. Causing the lake to reach its second lowest elevation ever recorded of 649 feet, the lowest recorded amount was during the drought in the 1970's when the elevation level was at 645 feet (Tam, 2014).

Figure 1: Lake Oroville 2011 and 2014 images (Govere, 2014)

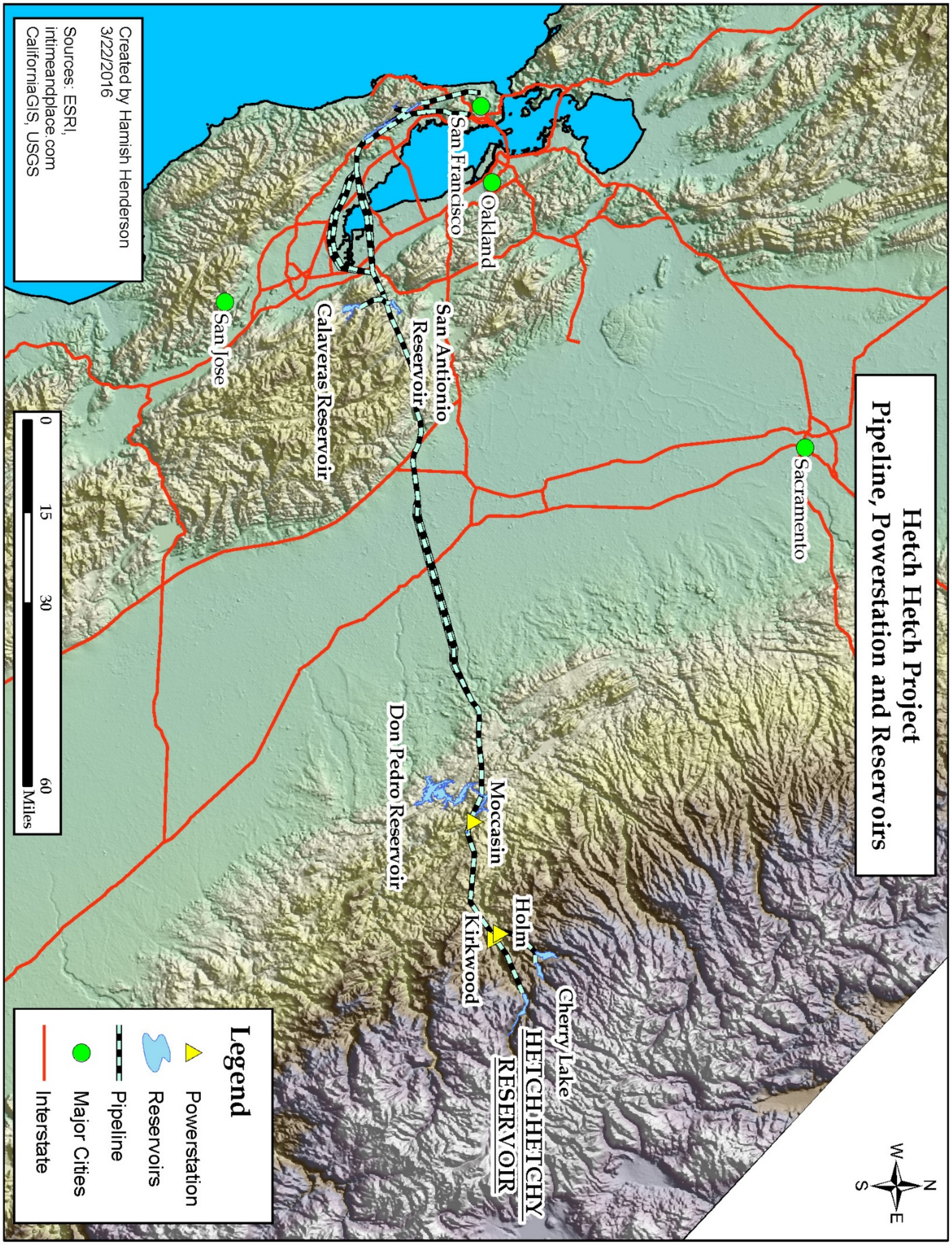
There are multiple different ways to study and record the effects of drought. One of the most accurate ways to determine how the water bodies are changing is through on-site samples. The problem with on-site samples is that they are expensive and take a lot of time to obtain. An easier and quicker way to quantitatively determine how water bodies area changing is through a geospatial analysis and the use of aerial imagery. In 2008 a drought monitoring project was performed in the Tamil Nadu region of India. The project consisted of using remote sensing techniques to determine where drought would most likely affect crop land. They used satellite imagery combined with rainfall amounts to quantify and locate what areas of crop land are most at risk during of drought (Muthumanick, et.al, 2011). Another project that used GIS to analyze drought occurred at the University of Bagdad in Iraq. This projected consisted of using rainfall quantities to determine the frequency of drought over a 30 year period, 1980 to 2010 (Al-Timimi, Al- Joboori, 2013). Both of these examples area good demonstrators of how powerful a tool a GIS analysis can be with regards to drought mitigation, monitoring and future predictions.

1.2 Study Sites:

For this study three different reservoirs have been chosen for a geospatial analysis. The following have been chosen due to their importance for irrigating agricultural fields in the Central Valley and supplying water for major population hubs: Hetch Hetchy Reservoir, Trinity Lake and Shasta Lake. Map 2 gives a spatial location of the three different reservoirs.

The Hetch Hetchy Reservoir is located in the Sierra Nevada Mountains and within the United States third established National Park boundary, Yosemite (Dean, 2010). The reservoir is the main water provider for the city and county of San Francisco, which is about 167 miles to the east (Wood, 2008). San Francisco City and County gets its water from the Hetch Hetchy Program, 80% of its water comes from Hetch Hetchy Reservoir (Randolph, 2002). There are a few other reservoirs that also contribute to the project; these can be seen in Map 3. Although the reservoir lies within Yosemite National Park it is ran and maintained by the San Francisco

Map 2: Study site locator map (Henderson, 2016)



Map 3: Hetch Hetchy Project reference map (Henderson, 2016)

Public Water Utilities Commission. Figure 2 shows Hetch Hetchy Reservoir during the drought period.

The reservoir was created in 1923 after the creation of the O'Shaughnessy Dam. There was a lot of controversy prior to the building of the dam and the flooding of the Hetch Hetchy Valley (Richardson, 1959). After the devastating 1906 San Francisco earthquake and resulting fire the city of San Francisco desperately more reliant water source and in 1908 the Tuolumne River and Hetch Hetchy Valley were approved for development (Hanson, 2013). The Sierra Club and John Muir, a fought hard to prevent the valley from being flooded. Ultimately their efforts were futile in stopping the flooding of the Hetch Hetchy Valley although it did spark a change in water policy throughout the country (Wood, 2008). The Hetch Hetchy Reservoir was one of the first reservoirs that was built and used to move water around the state.

Figure 2: Hetch Hetchy Reservoir during the drought, 2015 (Raymer, 2015)

The Tuolumne River which has its headwaters high in the Sierra Nevada Mountains flows and fills the Hetch Hetchy Reservoir. Water that is used from Hetch Hetchy flows into an aqueduct that travels down from Sierra Nevada's and across the Central Valley towards San Francisco peninsula.

Trinity and Shasta Lake are both located in northern portion of the state, just north of the town of Redding. Although both of these water bodies are called lakes they are both man-made reservoirs and therefore have dams (Sharp, 2012). Both of these water bodies are part of the Central Valley Water Project.

The Central Valley Project is one of the United States largest water conversation developments it covers two of California's major watersheds: the Sacramento River and the San Joaquin River. This covers a geographical area from the Cascade Mountains in the north and the Kern River in the south, a distance of about 400 miles (U.S. Bureau of Reclamation, 2013). The purpose of the Central Valley Project is to protect the Central Valley, a productive area for agriculture from water shortages and to control floods. There are many goals of the Central Valley Project such as supplying industrial, agricultural and domestic water, produce hydroelectric power, provide opportunity for recreation and increase water quality (U.S. Bureau of Reclamation, 2013). The entire system consists of 20 different dams and reservoirs, 11 power plants and around 500 miles of canals, all of the infrastructure allows for 9 million acre-feet of water to be effectively managed and used throughout a large portion of California (U.S. Bureau of Reclamation, 2013). Map 4 shows the area that the Central Valley Project covers and the locations of reservoirs, hydroelectric power stations and canals.

Trinity Lake, located northwest of Redding, was originally called Engle Lake after Clair Engle who was in instrumental in the creation of the Trinity Dam which consequently created

Map 4: Central Valley Project reference map (USBR, 2013)

the lake (Trinity Lake Resort and Marinas, 2012). The dam was constructed in 1961 by United States Bureau of Reclamation. The reservoir is fed by the Trinity River which flows south from the Scott Mountains, after passing through the reservoir the Trinity River flows into the Klamath River before finally discharging into the Pacific Ocean, off the coast of California. In 1997 the lake was renamed by the United States Forest Service to Trinity Lake, due to its proximity with the Trinity River (Trinity Lake Resort and Marinas, 2012). An aerial image of Trinity Lake and the Trinity Dam from 2013 can be seen in Figure 3.

Figure 3: Trinity Lake and Dam from the air. (Blake, 2013)

Trinity Lake is fairly large with around 145 miles of shoreline and it has a max capacity of 2,447,650 acre feet (Sharp, 2012). The lake is a popular tourist attraction, with people coming to enjoy water sports such as; water skiing and wake boarding. In addition to water sports members of the public are also able to enjoy their time on a houseboat. The shoreline consists of rugged and steep terrain making it an ideal place to take a hike and admire the lake views (Trinity Lake Resort and Marinas, 2012).

Shasta Lake is also a reservoir and therefore has a dam keeping all the water in, the dam was completed in 1945. The dam was built over the Sacramento River and when the area was flooded it also rose to a level which filled out some of the Sacramento River's tributaries such as the; Pit River, McCloud River and the Squaw Creek (Cassano, 2016). The Sacramento River is also a tributary of the Klamath River. Like Trinity Lake, Shasta is also managed by the U.S. Forest Service and in particular it is within the Shasta – Trinity National Forest (Department of Water Resources, 2009). Figure 4 is an image from 2014, its shows how much the water level has dropped at Shasta Lake.

Figure 4: Shasta Lake water level drop. August 30th, 2014 (Taylor, 2014)

California largest reservoir and third largest water body is Shasta Lake, it has a total capacity of 4,552,000 acre feet. Only Lake Tahoe and the Sultan Sea are larger than Shasta Lake (Cassano, 2016). Shasta Lake is another popular tourist destination with people coming to enjoys it water and shores for water skiing, camping, boating and fishing. It has around 360 miles of shoreline, many of which are steep, mountainous and covered in Manzanita (Cassano, 2016).

2.1 Methods:

The reservoirs were selected after doing online literature reviews through the Fort Lewis College library Ebsco database. After reading multiple scholarly articles it was concluded that Lake Shasta and Trinity Lake would be analyzed due to their key role that they plan in irrigating cropland in California's Central Valley (Sharp, 2012). Hetch Hetchy Reservoir was chosen as it is the main water provider for the city and county of San Francisco (Wood, 2008).

The main method that I have used during this project was a GIS analysis. I downloaded multiple Landsat satellite images from the USGS (United States Geological Society) GLOVIS (Global Visualization Viewer) website. I have downloaded images every 3 years starting from 1995; in addition I also downloaded images for each year since the current drought has started in 2011. All of the images were taken in the late summer months and had fewer than 10% of the total image covered by clouds. Landsat images are taken using different bands on the electromagnetic spectrum. For Landsat 5 (1995-2011) band 4 showed the best boundary between water and land. For Landsat 8 (2013-2015) band 5 showed the clearest distinction between shoreline and water and was therefore used. Unfortunately I was not able to analytically use any data from 2012 as the satellite (Landsat 7) that was running at this time had a sensor malfunction (USGS, 2013).

In ArcMap I performed hydrological and raster modeling which created raster grids of the water body's different surface areas. Rather than doing this manually for every single image I made a ModelBuilder program that systematically created the different surface area raster's. These raster grids were then manipulated so they would only show water and non-water values. This split all the pixels into one of two categories, water or land. Since a pixel is 30 x 30 meters the number of water pixels was multiplied by 900 to determine its area in square meters. This resulted in the total square meters of water on the surface of each lake. These numbers were then all converted into acres.

By layering all the different years surface area boundaries on top of each other; I was able to create a visual representation of the amount of change over the 20 year period. The data was recorded and graphs were made for all three water bodies. Final maps were made so that the data could be cartographically displayable.

3.1 Results:

The purpose of this research was to quantitatively analyze how much the surface area on the three selected reservoirs had changed over the 20 year period (1995 – 2015). In particular the below results will show how much surface area amounts have dropped during California's current drought.

Hetch Hetchy Reservoir

Hetch Hetchy Reservoir is much smaller than the other two lakes examined in this study and it has seen the smallest overall changes. There is around a 300 acre change over the 20 year period. Map 5 is a geospatial map showing the surface areas change from 1995 to 2015. The inset map shows the location of biggest change in surface area between the two years. The highest recorded amount was from 1995 when the lake had a surface area of 2,000 acres. Unlike the other two lakes the lowest recorded amount was in 2014 when the reservoir hit a low point of 1,724 acres. The reservoirs surface area then proceeded to rise to 1,843 acres in the summer of 2015. There was a rise in acreage in 2011 before it proceeded to drop until 2014. A graphical representation of this data can be seen in Figure 5. The numerical data is available in the table below, Table 1.

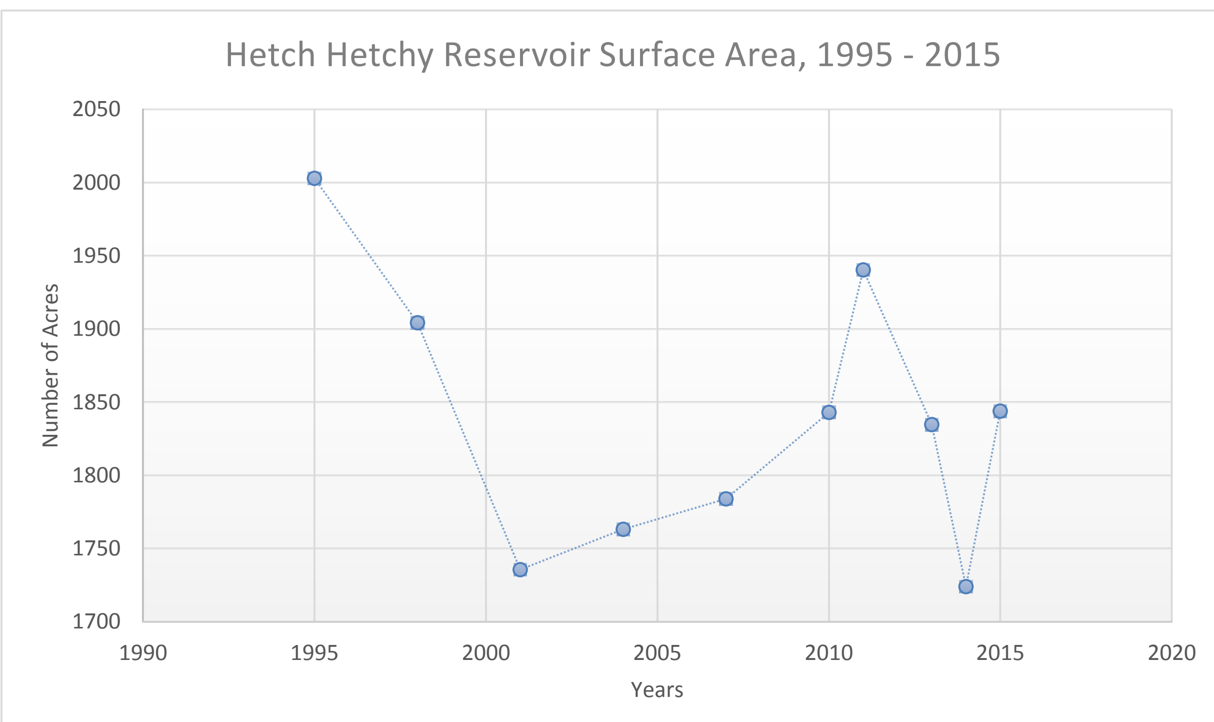
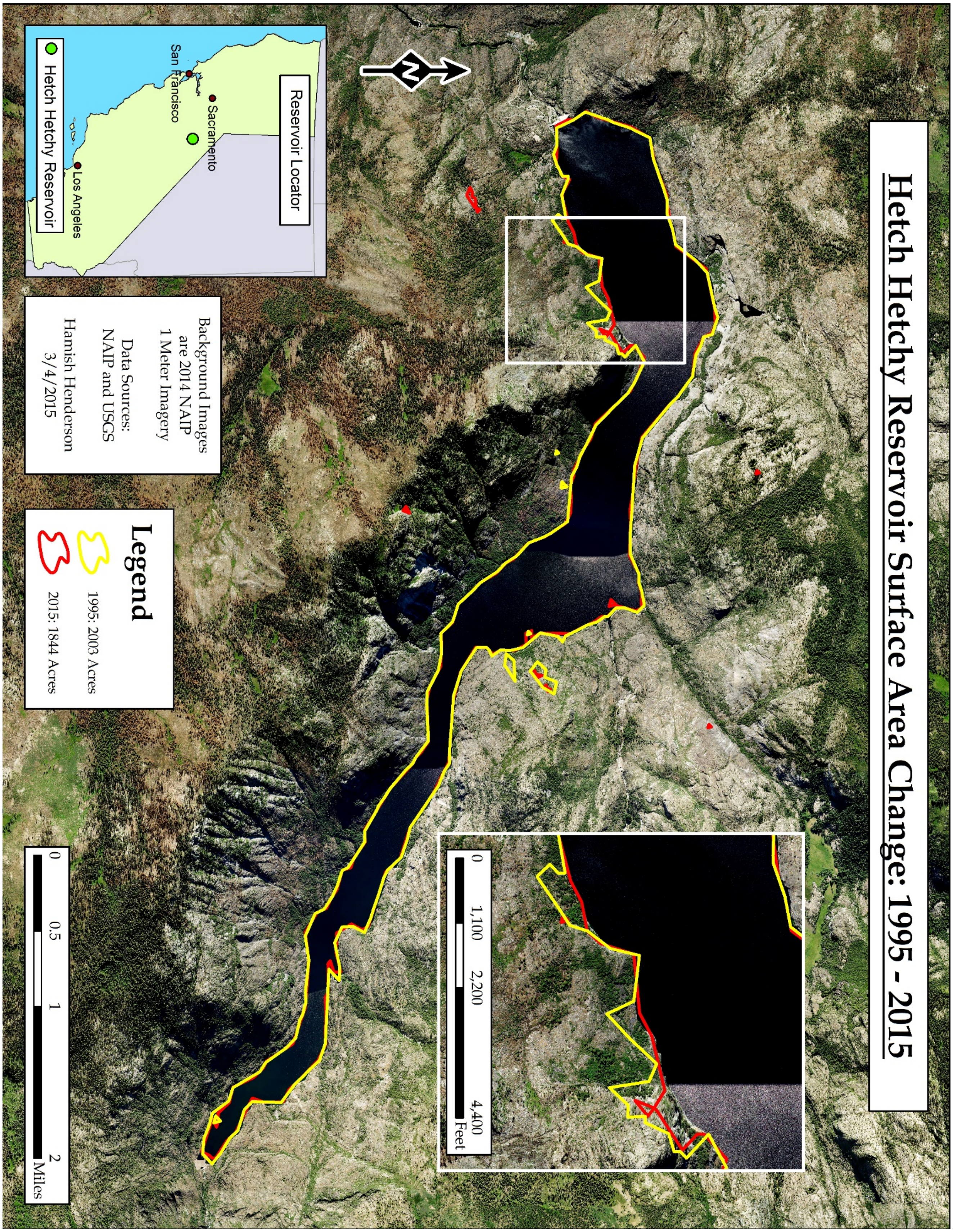


Figure 5: Hetch Hetchy Reservoir surface area change from 1995 to 2015



Map 5: Hetch Hetchy Reservoir surface area change 1995 to 2015 (Henderson, 2016)

Shasta Lake

Shasta Lake was the biggest lake that was analyzed during this study. The lake and all of its tributaries have an estimated max surface area of around 30,000 acres. Interestingly the highest recorded amount during this study was just over 20,000 acres in 2010, which is around 2/3 thirds of its max capacity. The lowest surface area that was geospatially recorded was 11,426 acres in 2015. Map 6 shows the different surface area max extents during the 20 year period. There were two different areas that showed a large recession in surface area, these areas are shown in the inset maps in map 6. This is what was expected being that 2015 was during the current drought. During the 20 year period there was also another dip in surface area in 2001, the lake was just less than 16,000 acres filled at this point. A linear representation of the change in surface area for Lake Shasta is represented in Figure 6. The full results for all the lakes, including Lake Shasta can be seen in Table 1.

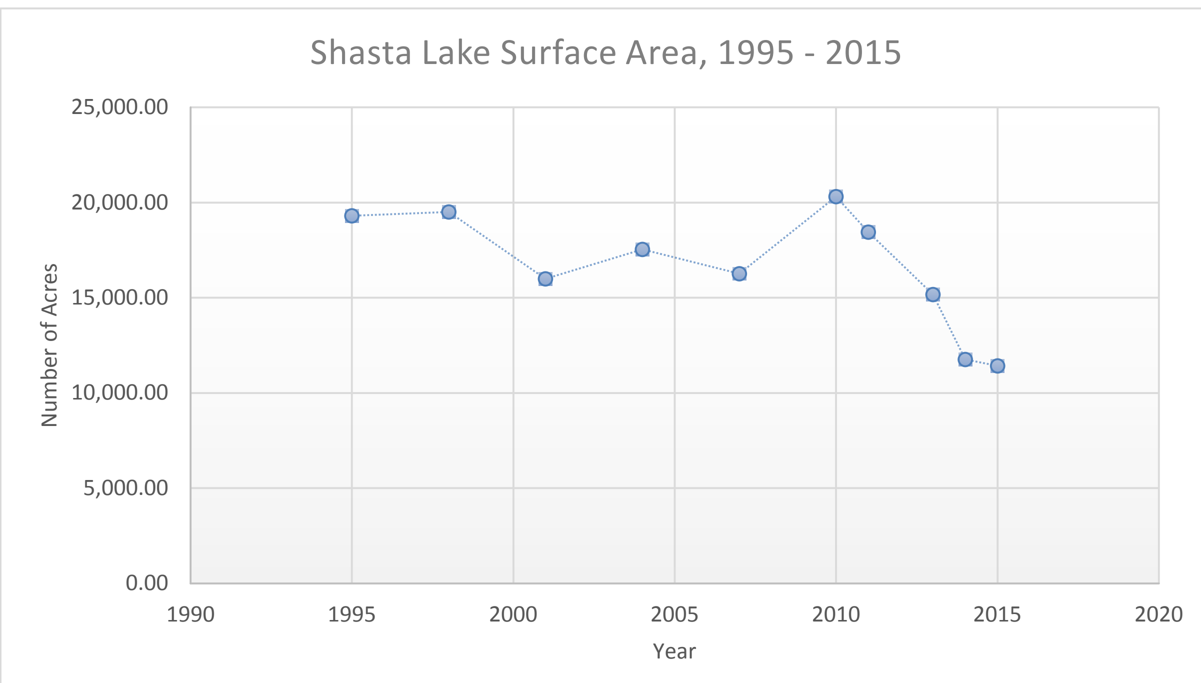
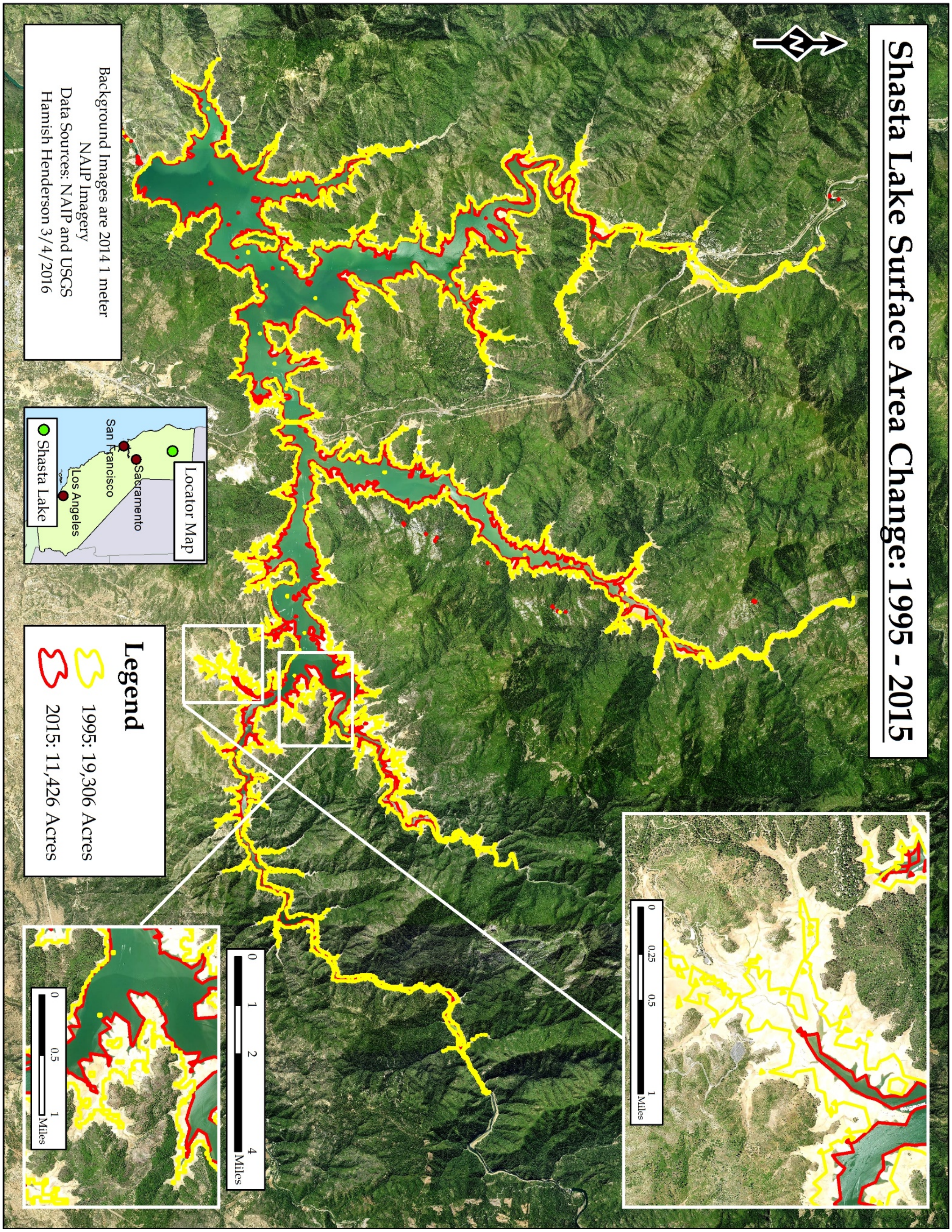


Figure 6: Lake Shasta surface area change from 1995 to 2015



Map 6: Shasta Lake surface area change 1995 to 2015

Trinity Lake

Although being geographically close to Lake Shasta, Trinity Lake has had a larger percentage change in its surface area change. The max surface area that was recorded during the 20 year period was just less than 16,000 acres, in 2011 which is the same year that the drought started. Once again 2015 was the lowest recorded amount with only 5,900 acres of the lake being filled, a change of more than 10,000 acres in only 4 years. Map 7 shows the different max surface extents during the 20 year period. The inset maps show how drastic the change has been in some areas of the reservoir. This was a significantly bigger drop than was experienced in Lake Shasta. The full trajectory of the Trinity Lake's surface area change can be seen in Figure 7, a spatial representation of the data can be seen in Figure 7.

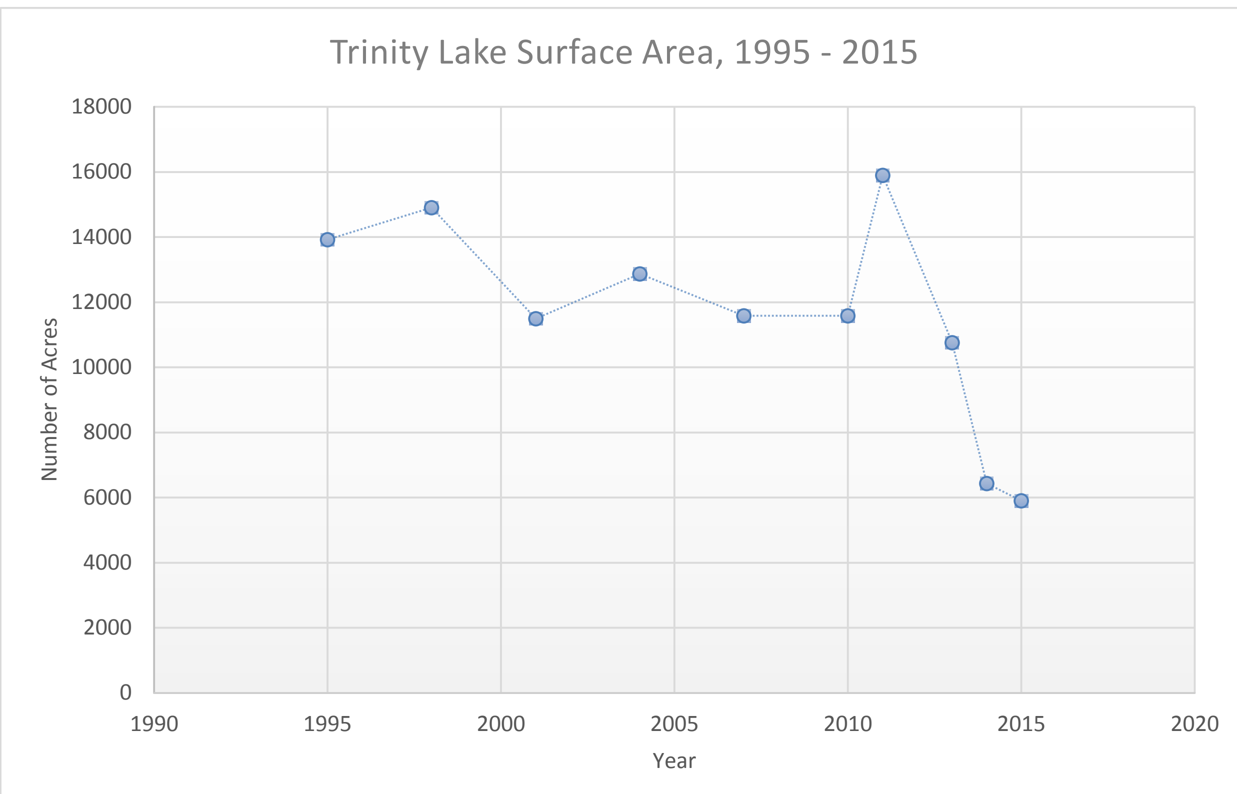
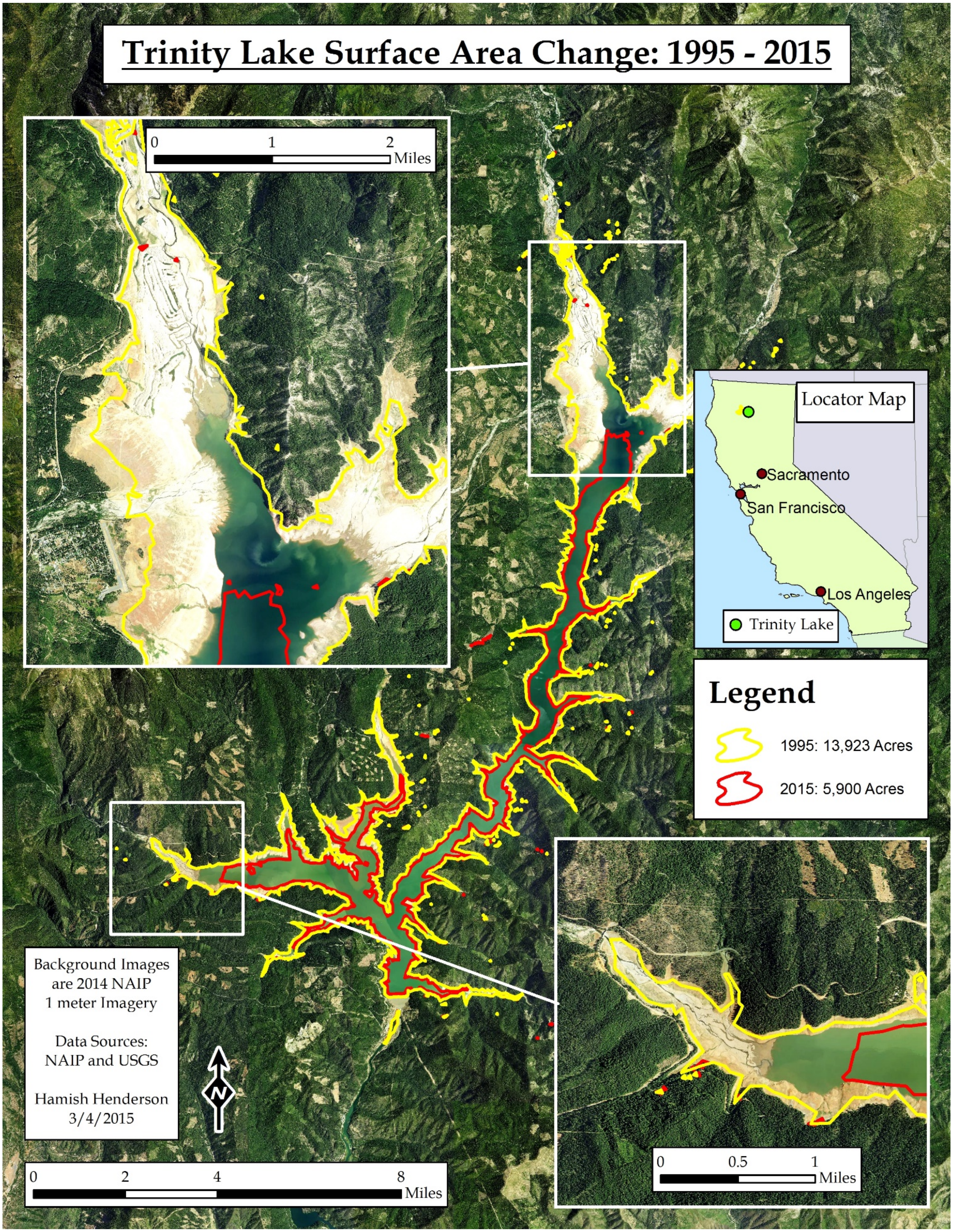


Figure 7: Trinity Lake surface area change from 1995 to 2015



Map 7: Trinity Lake surface area change 1995 to 2015 (Henderson, 2016)

Table 1: Table 1: Numerical surface area data for Shasta Lake, Trinity Lake, and Hetch Hetchy Reservoir 1995 to 2015. Green highlights are the highest recorded amounts and purple indicated the lowest surface area recorded

Year	Shasta Lake	Trinity Lake	Hetch Hetchy Reservoir
1995	19,306.32	13,923.70	2,003.11
1998	19,505.36	14,912.69	1,904.37
2001	15,999.53	11,493.81	1,735.57
2004	17,539.39	12,870.21	1,763.15
2007	16,271.74	11,587.88	1,784.05
2010	20,314.88	11,589.00	1,842.99
2011	18,442.98	15,897.67	1,940.40
2013	15,169.33	10,757.46	1,834.76
2014	11,753.57	6,435.22	1,724.00
2015	11,426.65	5,900.58	1,843.88

4.1 Discussion:

Hetch Hetchy Reservoir appeared to not have dropped as much as expected during the drought years. During the 20 year period that was analyzed the surface area only changed by 279 acres from its max possible surface area, this equates to a 13.9 % drop. 1995 was the highest recorded amount for the reservoir peaking at just over 2000 acres. Interestingly the reservoir surface dropped to its second lowest amount during 2001, a period when California was not in such a severe drought. The reservoirs area did proceeded to increase back up by almost 8% by 2011. Another interesting observation that was discovered was that the reservoir actually increased in surface area from 2014 to 2015. This is a notable occurrence because it would be expected that 2015 would have been the lowest amount recorded. Most likely this means that in 2014 there was more water needed in San Francisco. The rise of surface area levels in 2015 could also be tied to people realizing that California is in a severe drought and that water should be used more frugally.

Trinity Lake's results were far more consistent although freighting compared with previous expected projections when compared to Hetch Hetchy. The reservoir stayed at around the same level for the majority of the time up until 2010. During 2011 the reservoirs surface area increased to its highest amount during the 20 year period. Then as soon as the drought began the surface area amount dropped continually until 2015. The lowest amount that was recorded was 5900 acres which is almost 10,000 acres less than it was in 2011. This is a drop of almost 63%, a huge change in just a short four year period.

The results that were generated from the Shasta Lake results were similar, although not as dramatic as Trinity Lake. Shasta Lake experienced a small drop in surface area in the early 2000 but it then bounced back up and in 2010 when it was at its peak for the 20 year period. When the drought hit the surface area amounts did start to drop. By 2014 the amount had dropped by 42% it then started to decrease less and by 2015 it had only dropped another few hundred acres. In 2015 Shasta Lake was at about 38% of its max possible surface area.

Therefore it appears that Hetch Hetchy has been the reservoir that has been affected the least from the three reservoirs that were studied in this project. Geographically Hetch Hetchy is the highest of the reservoirs and the water also has the least amount of distance to travel before flowing into the reservoir that could play a role in why its surface area was not as impacted. As it is the highest it probably is consistently colder than the other two lakes. The lower and warmer reservoirs could suffer from more water being evaporated from the surface of the two reservoirs. Also both Shasta and Trinity are fed by much bigger rivers than Hetch Hetchy Reservoir and therefore the water has more opportunity to evaporate and to be taken also unnaturally out of the rivers.

4.2 Calculated surface area compared with actual water elevation levels:

In addition to measuring how surface area on the reservoirs have changed another important factor with seeing how reservoirs have been affected is how the water level itself has fallen or risen. In some scenarios surface area may not change very much but the water level in the reservoir could still significantly drop. This is due to the geographical topography of the area, if the reservoir has steep banks then the water levels can fluctuate greatly with limited change in surface area. California's Department of Water Resources (DWR) has an extremely informative website called the California Data Exchange Center (CDEC). Within the website there is portal that contains information for many of the major reservoirs that are scattered around the state. Information is updated on a daily basis and includes items such as current water storage, outflow, inflow and what storage was this time last year (CDEC, 2016). One of the most useful measurements that are record are the elevation of the water. In addition to showing these results on a daily basis there are records that in most cases cover most if not the entire life span of the reservoir.

According the results that were calculated during this study the surface area of Hetch Hetchy Reservoir did not change a huge amount, as it only fluctuated a few hundred acres from its peak to low point. If only looking at the surface area data you would not expect the water levels in Hetch Hetchy to change a huge amount. However Hetch Hetchy is surrounding by steep banks on the majority of its shoreline and in images (Figure 2) that have been taken during the drought a clear line of past water extents is clearly visible. This means that the reservoir water storage capacity has actually changed more than the surface area calculations suggest. Unfortunately the elevation instrument that the CDEC use at Hetch Hetchy doesn't appear to be working correctly and therefore reliable data cannot be analyzed from it. The reservoir storage calculator does seem to be working however which can still give a good idea as to how the reservoir has changed and will provide a good reference to the data calculated through the GIS analysis. The graph below labeled as Figure 8 depicts how the storage of the reservoir has changed from January 2011 through to the end of December 2015, or the drought period. As expected there are highs and lows each year, with late spring traditionally having the highest capacity due to snow melt runoff. According to the graph the lowest storage amount that was recorded was in 2014 and this is what the surface area resulted also suggested. The

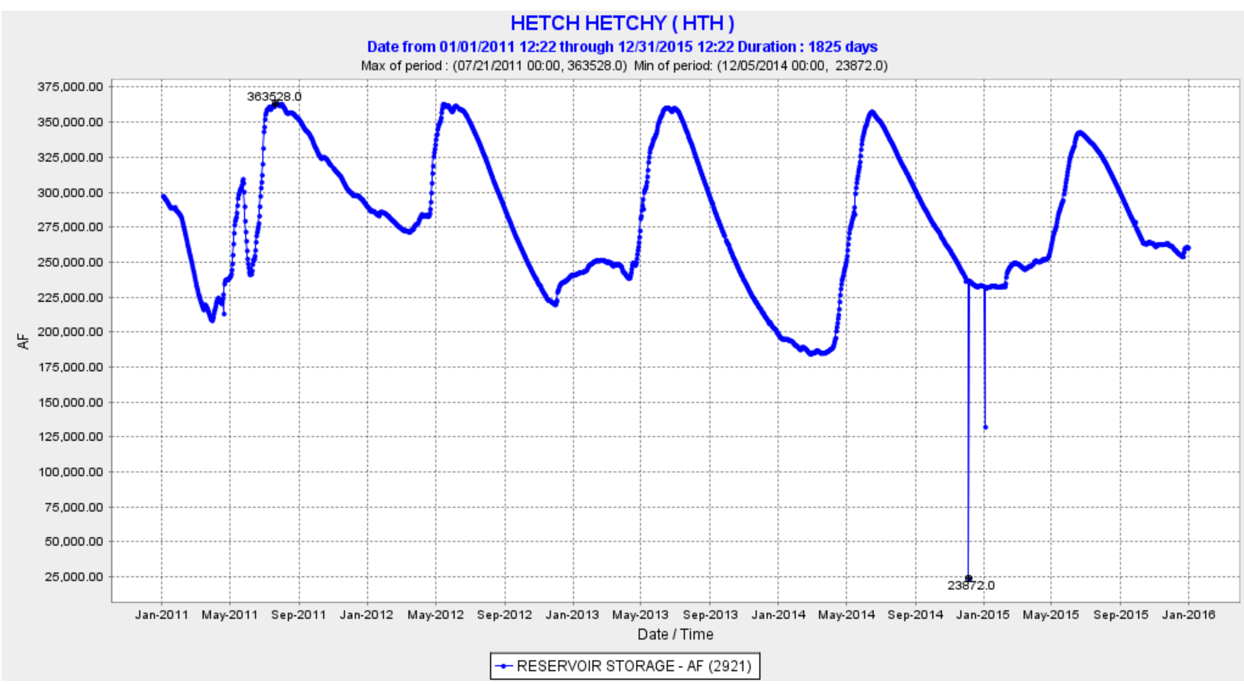


Figure 8: Hetch Hetchy Reservoir Storage from 2011 to 2015 (CDEC, 2016)

reservoir storage amount then proceeded to rise back up in 2015 and leveled out at roughly the same level as 2013's low point. The surface are amount that was recorded for 2013 was 1835 acres and in 2015 it was 1845 acres, a difference of only 10 acres. From these results it shows that the GIS analysis performed on Hetch Hetchy Reservoir was accurate. If the data for elevations levels were also present it would make for a more accurate analysis, luckily for both Shasta and Trinity this data was available for the entire 20 year study period.

Shasta Lake's surface area change amounts were much more significant than the changes that occurred in the Hetch Hetchy Reservoir. The results that were calculated had 2010 as being the year in which the surface area was greatest, with an amount just over 20,000 acres. 2015 was the lowest recorded with an amount just under 11,500 acres. From this data we would expected that a elevation profile of the reservoir over the twenty year period would have the elevation staying fairly high from 1995 to its peak in 2010 and then a noticeable decrease from 2010 until 2015. The sensor at Shasta Lake has recorded data since the dam was created and therefore it is an excellent resources to compare results with. A period from 1995 through to 2015 was selected and Figure 9 is the changes in reservoir elevations. The graph displays that there has been two significant drops in elevation levels in the twenty year period. One of the drops and also the lowest recorded amount of 889ft was in late 2014/early 2015 this was consistent with the surface area results. Interestingly the other dropped occurred from 2008 to 2010, with its lowest dip in that period occurring during late 2008. This was a period in which the surface area resulted had the reservoir at its fullest. According to the graph there was a large rise in elevation in 2010, over 100ft, but it would have been expected that the 2010 would be the year in which the highest elevation would be recorded. The reservoir reached its

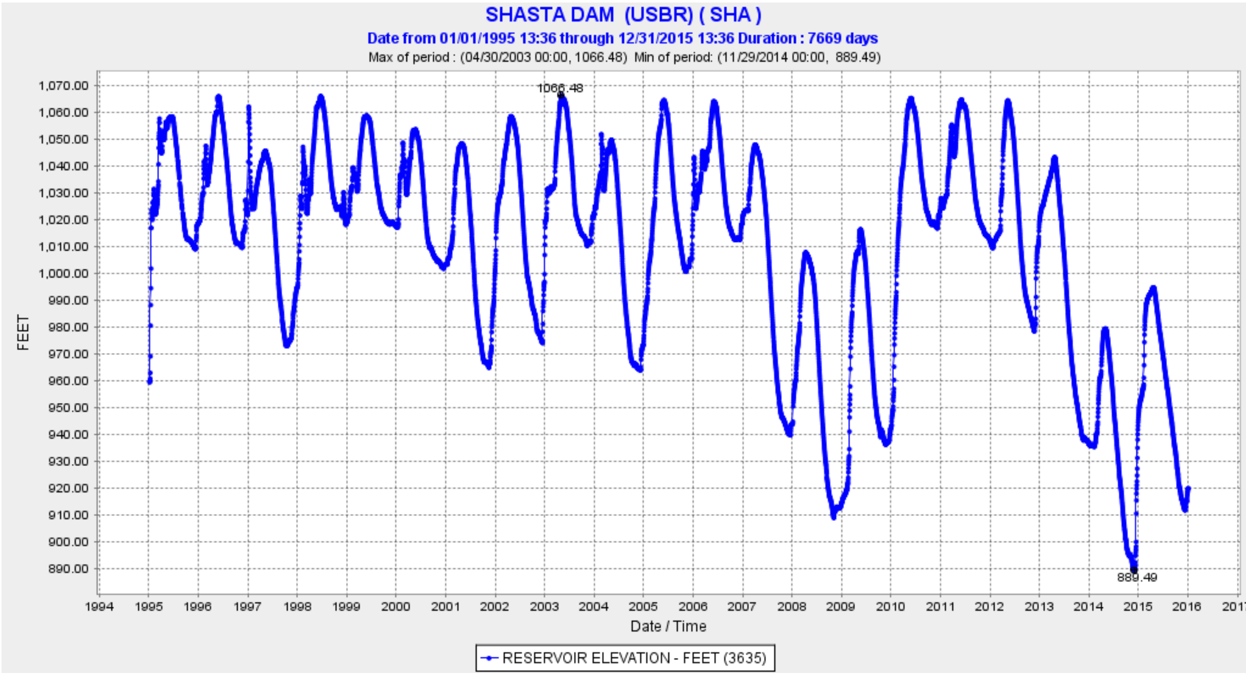


Figure 9: Shasta Lake change in elevation from 1995 to 2015 (CDEC, 2016)

peak in 2003 when elevation levels of 1066ft were recorded. Therefore the elevation of the water dropped 177ft from 2003 to 2015. Although there was no recorded surface area amount for 2003 a rough prediction can be calculated from the 2001 and 2004 data. From 2001 to 2004 the reservoirs surface area increased by 1540 but in 2004 the surface area amount was still 2,500 acres lower than the reservoirs highest in 2010. It is possible that the reservoir did have a spike in 2003 and then dropped back down in 2004. Without actually having a surface area amount for 2003 it is difficult to determine the accuracy for that year. The overall pattern for the elevation changed is consistent with the surface area data.

Just like Shasta Lake there has been data recorded for Trinity Lake since it became a reservoir. Therefore an accurate check can be performed on the surface area results. The results from the surface area calculations had the reservoir hitting its highest peak in 2011 at just under 16,000 acres, the lowest recorded surface area amount was in 2015 at 5900 acres.

From these results it would be expected that the elevation levels are going to stay fairly consistent until 2011 and then there would be a significant drop all the way until 2015. Just like with Shasta Lake the entire 20 year period was selected and the elevation change results can be viewed in Figure 10. The overall trend that the graph depicts is that elevation levels stayed at a fairly high amount for the first 10 years and then there was a dip from 2008 to 2010. Elevation levels once rose in 2011 and then progressively the level dropped until 2015. The drop from 2008 to 2010 is consistent with the surface area change that occurred during the time, there was a difference of about 4000 acres from 2010 until 2011, which would equate to the 130ft elevation change that happened. According to this graph the highest recorded point was in 1998, at an elevation of 2370 ft., the surface area result for 1998 had the reservoir at just under 15,000 acres. It was expected that the graph would have 2011 as being the highest elevation recorded, and although it is not the highest amount it is within a foot of the 1998 value. Therefore the surface area amounts in 1998 and 2011 should be very similar. However there is almost a 1000 acre difference between the two years, with 1998 being the lower value. This is mostly due to the limitations of the Landsat imagery's low resolution.

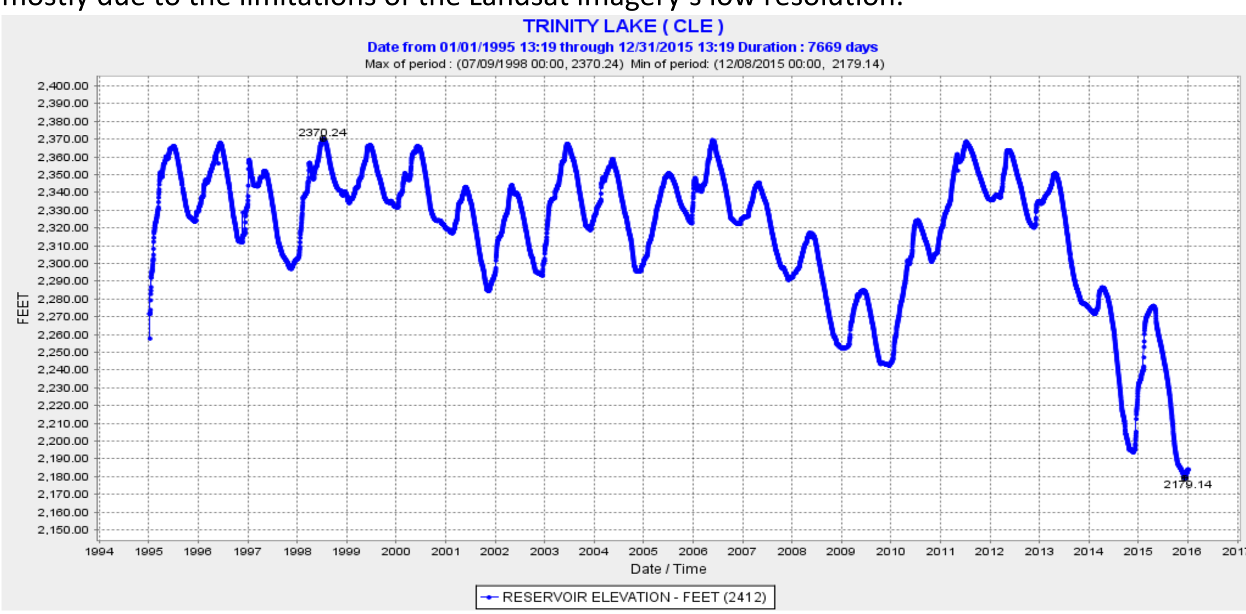


Figure 10: Trinity Lake elevation change 1995 to 2015 (CDEC, 2016)

4.3 What is California's expected future with regards to water?

From the results that were determined during this project a 10 year projection was made as to what the future surface area amounts of each of the three reservoirs could look like. For each reservoir two different projections were made; one used data from the entire twenty year period while the other only used the data from the current drought (2011-2015).

The graph labeled Figure 11 shows the two different projections for Hetch Hetchy Reservoir. The blue line indicates the projection using all 20 years of data and although the water surface amounts do appear to drop it is not a large amount. By 2025 it is projected that water surface area will still be lower than the current amount but marginally higher than the 2014 results. The orange line is the projection only using drought year data. This projection indicates that if current drought patterns continue water surface area amounts could drop to as low 1500 acres by only 2023, this would be around a 25% drop from max possible surface area. However Hetch Hetchy's outlook looks more promising than either Shasta or Trinity Lake.

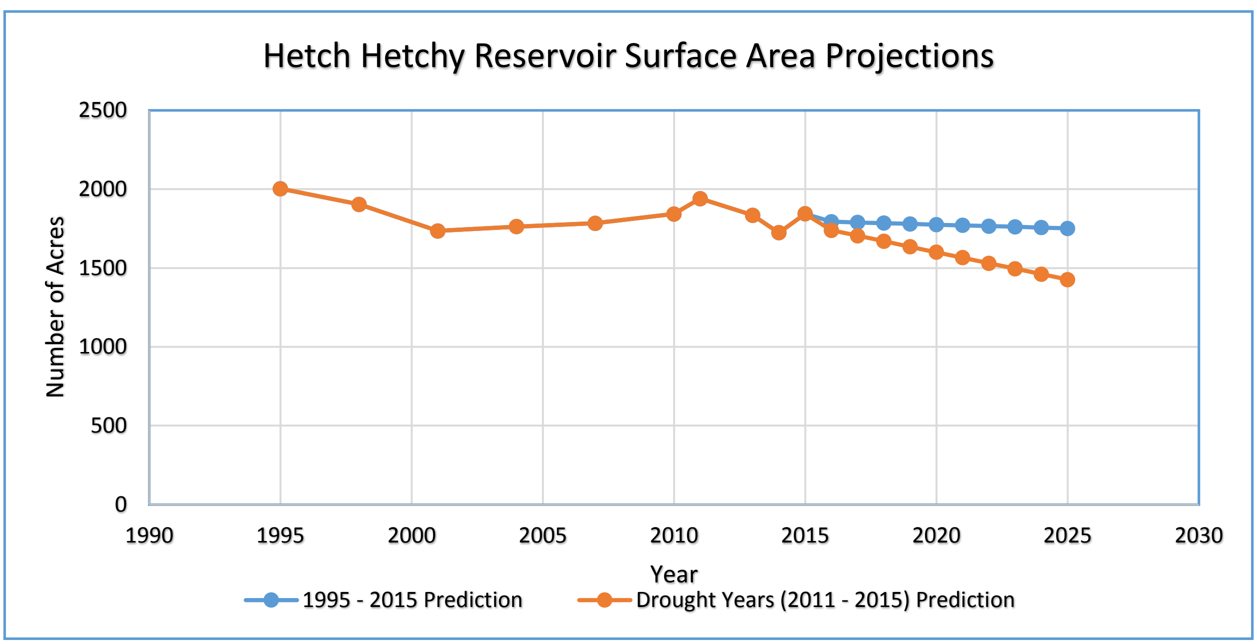


Figure 11: Hetch Hetchy Reservoir surface area future projections

Shasta Lake's projections also have the reservoir continuing to lose surface area, a graph of this data can be seen in Figure 12. Once again the blue line represents the projection based of the data from the 20 year period. This expected trend notes that water levels will rise initially and then continue to drop and that by 2025 that Shasta Lake's surface area amounts will have dropped to around 11,500 acres which is around 60% of total max surface area capacity for the reservoir. The projection produced from the drought period data are not as promising however. In the same graph the orange line is the drought projection and it marked to continue dropping. The projections have predicted that the surface area amount will drop by 1900 acres a year and that if current climate and drought patterns continue the reservoir will fully dry up by 2021.

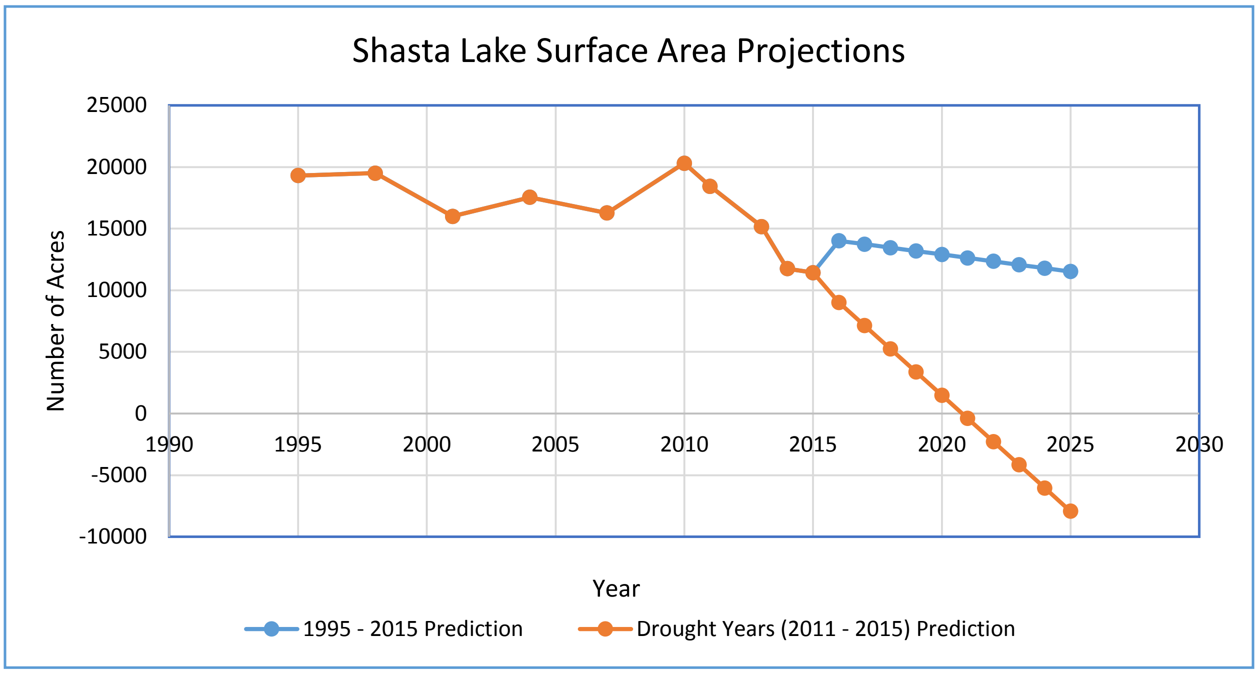


Figure 12: Shasta Lake surface area future projections

Although neither Hetch Hetchy nor Shasta's future projections looked promising they both look favorable compared to Trinity Lake. Figure 13 shows Trinity Lake's shaky future. As in the previous graphs the blue line represents the 20 year period of data. The 20 year projection has the surface area amounts dropping and at higher rate than the other two reservoirs. By 2025 the expected surface area amount is just over 6000 acres. The really scary projection is the orange line or the drought year period projection. However this projection indicates that the reservoir will lose 2900 acres a year, this is about 1000 acres more than Shasta Lake and Shasta Lake is around a third larger in size than Trinity Lake. With such a significant drop each year it will only take until 2017 for the reservoir to run dry.

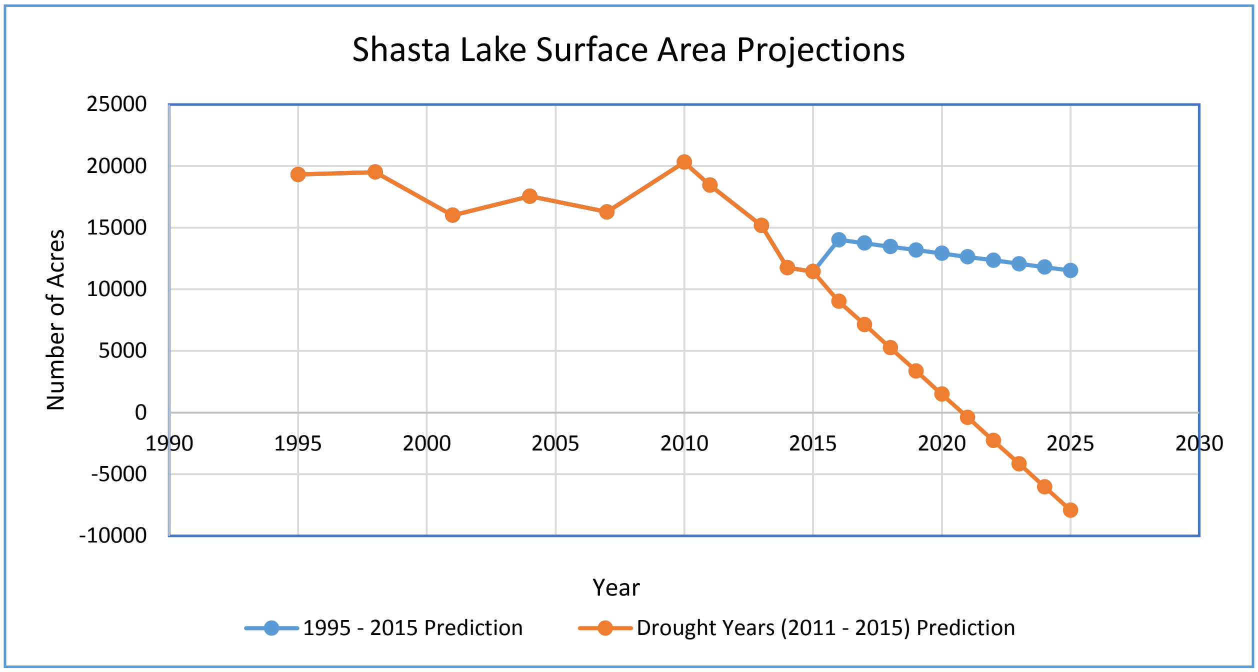


Figure 13: Trinity Lake surface area future projections

These projections have to be taken with a grain of salt as these are a worst case scenario, especially with Trinity Lake. Although these projections can give an immediate reaction has to what could happen in only a few short years. With water levels dropping throughout the state water conservation is a big topic of discussion. Many portions of the state have limited water usage by having only certain days that domestic irrigation sprinklers can be used (Zimmerman, 2015). This could be why Hetch Hetchy didn't not see as big a drop compared with the other two reservoirs. These measures will help conserve water although they are not going to solve all of California's water problems. It is clear that over the last 20 years water levels in California have only dropped and with a warmer outlook anticipated that level is only going to drop more.

Irrigation for agriculture is the biggest user of water in the state and this is where California needs to tackle its water problems. As the stop of crop growing is not really an option as lives depend on the food that comes out of the Central Valley, the way the crops are grown needs to be altered. One option is to change the crops that are growing there to plants that do not require as much water in the first places.

A way to not change the crops to still use less water is genetically modify the plants by adding a gene strain that corresponds to drought resistant or tolerant. This altering of genes has been done in other locations around that world that are having water issues and it could be implemented in California's Central Valley (Hu, Xiong, 2014). The third option would be to obtain water from somewhere else. The most logical place would be to extract water from the coastal waters. Obviously this water is salty and has to go through a desalination process before it could be used for irrigation but it could still be more cost effective than building water transportations systems to gather water from other areas around the country.

5 Limitations and Future Research:

Like with any research project not everything went as expected and there is always room for future improvement. The largest limitation with this project was resolution of the Landsat satellite images. All the images that were used had a resolution of 30 meters by 30 meter pixels. This is a large area and when the raster separation was performed through the GIS program it can only assign one variable per pixel. Therefore the edges of the reservoirs could change going to have a tolerance of up to 30 meters one way or the other. To solve this problem access to higher resolution multispectral imagery would be needed. There are other satellite that are both private and public that can take higher resolution image, unfortunately these are expensive and have not been around for the entire time period that this project took place over. Multispectral images can also be taken from plane based imagery and this could be an easier way get current data. For example once a month someone could fly a plane over each reservoir and then a higher resolution image could be produced. Another possible way to have access to higher resolution photograph would be to fly a drone over each location. A drone cost significantly less than a hiring a pilot and plane to fly a flight path. However a drone is not able cover as much area as quickly as a plane, so for a large reservoir such as Shasta Lake flying a drone might not be feasible. On the other side if you had a small reservoir such as Hetch Hetchy you would be able to fly a drone over it rather quickly and have access to the data in a timely manner. If there was access to higher resolution multispectral imagery the accuracy of the data would be significantly higher and therefore a true representation of surface area change could be calculated.

Another suggestion for future research would be to calculate a surface area for each year, rather than in three year increments. This would give the results more credibility and in particular an easier comparison between the elevation levels and surface area amounts would be possible. The problem with doing a surface area amount for each year is that it would be a longer time commitment. It would take longer as more Landsat images would have to be downloaded and then the GIS manipulation of the data would have to be performed 20 times per reservoir as opposed to the 10 times per reservoir that was completed for this project. In addition to having data for each year it would also be interesting and useful to have multiple surface area extents for each year. For example having one during late spring when snow melt runoff is highest and another towards the end of summer or fall when the water levels are at their lowest. Just like with having samples every year this would take much longer to obtain the data but it could also be written as a script so that it could automatically perform the GIS analysis once the Landsat images were downloaded.

6 Conclusion:

The purpose of this project was to geospatially determine surface area during the recent California drought. Three reservoirs of key agricultural and domestic importance were selected and analyzed over a 20 year period; Hetch Hetchy Reservoir, Shasta Lake and Trinity Lake. The overall trend in the three reservoirs indicated that that had been negatively impacted during the drought period. Trinity Lake was the worst affected out of the three, with its lowest amount at around about a 1/3 of its max capacity. The results were then compared with elevation levels and projections of future surface area amounts were predicted. The results indicated that if current conditions do not change then California is going to keep having a drop in water levels and in some cases the reservoirs could dry up. Therefore it is critically important that the state changes how it manages it water. Multiple ideas were suggested ranging from desalination projects, water conversation and genetically modifying crops to be drought resistant and have a low water tolerance. If California is able to change and adapt to a future with limited water resources then it will continue to strive, if not it is in for a dry and turbulent future.

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