2021 HiMCM Problem B
Team 11621

1 Summary

Climate change is one of the most prevalent global issues of this time period. Temperatures are rising, and landscapes have been altered immensely. Throughout the United States, there are many bodies of water which provide vital resources for a diverse group of animals, humans, and other organisms. As time progresses, various environmental changes impact the levels of water in a plethora of bodies of water, putting entire communities at risk.

One of these water resources most at risk currently, is the largest man-made reservoir, Lake Mead, in Southern Nevada. Throughout this report, we explain these different factors at place in Lake Mead and use mathematical functions to depict these trends over upcoming years, by utilizing past patterns.

We complied a series of many functions, which all added together, would create another function that could accurately model the elevation of the lake at any given moment in time. To do this we studied the patterns in each factor that determined the elevation of the lake, such as outflow into the lake, and evaporation, etc., to create an equation for each of these, and collate them into one equation which would find how much elevation change would be caused by each of the function from a certain starting point to that moment.

Graphing data greatly helped our model and gave us the opportunity to break our data into parts, selectively choosing specific data points to represent our data best. These points were gathered mostly from government climate agencies, that tracked key data sets such as flow rates and temperatures. We then modeled each of these data sets with a function that would model that specific piece of information int he future. For example, we developed an equation that would allow use to calculate the amount of evaporation every month until the lake was dried up.

Computer programs written in Java language gave us the chance to test our equations and calculate the final elevation at a given moment by simulating month by month the elevation changes that would occur. These programs allowed us to test our equations and trouble shoot faster. They also allowed us the possibility of writing a continuous program that would use the elevation at one point to calculate the elevation at the next point, and so on and so on, creating interdependent equations. For example, our equation for evaporation ended up being dependent on elevation that previous month, and by using Java we were able to code a function that would find the previous months elevation, use it to find the elevation change caused by each factor for the next month, thus giving a new elevation point, etc., etc.

When doing our calculations, we discovered that we would need to perform many conversions. Tracking units benefited the credibility of equations and hypothetical data points. We thus transformed some units into others trough numerical conversions.

We also ended up having to convert units such as volume into elevation changes of the lake. This required more complex modeling of the data sets, and through the collection of some outside information, we were able to determine how the volume changes in acre-feet would relate to elevation changes in feet.

We present out model as an equation entered into a Java program. The equation takes only the final time as an input, and runs through every month until that point, and output a final elevation. This information coupled with knowledge of past trends, allows us to compute an efficient and accurate outlook of water elevation all the way into the distant future.

Contents

2 Background

Lake Mead is a large, artificial reservoir located between the Colorado River and the Hoover Dam in Southern Nevada. It is the largest reservoir in the United States by volume and second-largest by surface area at maximum capacity. The water contained by Lake Mead mainly flows in from the Colorado River and out through the Hoover Dam, although other smaller tributaries account for a small fraction of this total. The Hoover Dam was built in 1931 and was the first multi-purpose dam built by the US. It controls flooding, navigation, and generates electrical energy. In turn, the Hoover Dam supports the agricultural growth and municipal growth of large nearby cities like Las Vegas. When the Hoover Dam was built, the excess water not flowing through the dam pooled up behind it, filling canyons and forming Lake Mead.

Since 1935, Lake Mead has been a constant source of electricity through the Hoover Dam and a reliable source of safe water. Over 25 million people rely on Lake Mead for drinking water and water to run thousands of towns. Lake Mead is mainly responsible for the population and cultural boom in the American Southwest. The climate of Southern Nevada is dry and arid. Any moisture from the Pacific Ocean is blocked by the Sierra Nevada Mountain range, making the region historically dry. The flow of water into Lake Mead depends mainly on the Colorado River, but some small tributaries contribute water. One of these tributaries, the Las Vegas

Wash, is mostly recycled water from towns or runoff.

With climate change altering the temperatures in most regions, the West Coast of the United States is getting drier. Wildfires have become commonplace, and droughts are persistent. These effects are ultimately due to the rise in temperatures caused by excess CO2 in the atmosphere. Rising temperatures affect humidity, precipitation and evaporation. This summer (2021), Southern Nevada experienced an intense period of drought. The lack of rain, coupled with high temperatures and the blazing sun, has decreased the elevation of Lake Mead by 64%.

The sudden decrease in water availability has prompted local politicians to reduce the limit of water that can be extracted from the lake. In prior years, cities have been able to extract 300,000 acre-feet of water annually. Starting in 2022, Southern Nevada will be allotted 279,000 acre-feet for consumption. Local leaders are confident that this will not have drastic impacts on humans in the area; however, nearly 90% of all the water used by residents comes directly from Lake Mead.

The Colorado River is composed of melted snow from the Rocky Mountains, originating in Northern Colorado. With rising temperatures, more snow and ice are melting, so the Colorado River's flow is increasing, meaning the effects of the water depletion from Lake Mead won't be noticeable for a certain period. However, once prevalent, they will be detrimental to the population of the area.

A promising solution to this problem lies in water recycling methods. In recent years, water recycling techniques have improved. New technologies can purify water faster and more effectively. A small percentage of the water taken from Lake Mead is currently recycled, but it is not nearly enough to support the sharp decrease in elevation of the lake.

3 Interpretation of the Problem

Our group began by looking at how the elevation of the lake can be modeled, and by agreeing that looking at how elevation changes over time can determine the overall "health" level of the lake. Thus our main goal for this problem was to figure out how we could model the movement of the elevation of the lake.

Something that we decided is that a drought could severely impact the overall health of the lake, and thus the area surrounding it. This meant that we had to decide on what counted as a drought. We decided that when the water level had been falling for three years and did not recover within another five years, this could be considered a drought period.

However, something that we also had to consider is how elevation changes would impact other things, such as how much water could be extracted and the overall health of the economy and how agriculture would be sustained, as Lake Mead is the largest water source in the south-west United States.

Something else that we had to consider is that there are methods for reusing water. We needed to decide on how these methods could be used in order to 'save' the lake, and if these methods would even impact the level of the lake. Something that we found out that we realized that we had to keep in mind is that of the 300,00 allotted acre feet to Lake Mead, more than 70% ends up being recycled already, so there is a significant effort on this front, as the amount of water allotted to Nevada is constant, while the population and water demand is ever growing.

4 Initial Thoughts on Strategy

1. In order to model this situation, we decided that we wanted to create a Java program that would be capable of performing all of the necessary calculations for us.

2. We could create an equation that uses all of the main ways that water can leave or enter the lake in order to calculate the volume change, and then covert this to elevation change.

3. A lot of the elevation changes appear to look like trigonometric functions.

4. It may be possible to use a Fourier transform to generate a complex trig function that may model future movement in the elevation.

5 Assumptions

- The amount of water taken from Lake Mead remains constant at 300,000 acre feet a year. The justification for this is that there was an agreement signed before the beginning of the Hoover Dam construction which allotted a certain amount of water to each state that utilized water from the Colorado River, and Nevada, in which Colorado River fed lake Meade is situated is allotted 300,000 acre feet a year.

- 97% of the total water in Lake Mead comes from the Colorado River. The justification for this is that this was given in the instructions, and this was necessary in order to perform calculations on how much water comes into the river yearly.

- Rainfall can be counted as part of the inflow amount, as the 97% figure seems to likely account for that amount of rainfall. additionally, the amount of rainfall in Nevada is so low that it may be counted as negligible.

Justification: Geographically, the Colorado River feeds directly into Lake Mead, which would mean that all the water, besides a negligible amount that feeds other small lakes, that goes into Lake Meade, can be directly accounted for by the flow from the Colorado River

- Air humidity in the area around Lake Mead is constant at around 40%, as this is the likely humidity in areas around Las Vegas and Boulder City, and this is a stable figure that will be needed for evaporation and dew point calculations later on in this paper.

- Outflow is controlled by humans at the Hoover Dam. The reason for this assumption is so that outflow can be use for calculations, and additionally the outflow at the Hoover Dam is completely regulated by computer programs, simulations, and the Dam workers, and thus they have the final control over the amount of water coming out of Lake Meade at the Hoover Dam, which eventually feed the Colorado River.

- Monthly data is measured on the same day of each month. This is important because it allows for calculations that use monthly data such as monthly elevation at Lake Meade to be used consistently without worrying about varying days of the month on which the data was recorded.

6 Models

6.1 Evaporation Modeling

To start, we used the given data to construct graphs in Excel which would allow us to see patterns [Figure 1]. We noticed an annual rise and fall in elevation as well as specific periods of lower water levels. We began writing a general equation for net change in volume of Lake Mead to accurately represent these changes in water levels. The equation took into account inflow from Colorado River, neighboring tributaries, as well outflow through the Hoover Dam, direct consumption, and loss through evaporation.

$$(c + t) - (e + d + h) = n$$

Where c represents inflow from the Colorado River, t represents inflow from the other tributaries, e represents evaporation, d represents direct consumption, h represents the outflow to the Colorado River through the Hoover Dam, and n represents the change in elevation of the water.

Then we began creating equations using sinusoidal regressions to map out relationships between values such as elevation, volume, and surface area. We graphed volume and area as a function of elevation. The graphs showed that the relationship between the three is irregular, as proven by the natural shape of the Lake Basin. We attempted linear, exponential, quadratic, and sinusoidal regressions.

We ended up noticing that exponential equations worked the best, and as the only equation that we needed was one that converted volume into surface area, we wrote the equation:

$$n = -1170.7061 + 138.9516*\ln[v]$$

Where v is the change in volume, and n is the change in elevation that results form that change in volume. This also allows us to form a similar relationship between elevation and surface area, and logically, the same in reverse for surface area to elevation, etc. However, when the relationship is flipped the expression turns from a logarithmic one to an exponential relationship.

All of this together allows for us to answer the first question, as we now know which factors influence the elevation of the lake most greatly, how they are quantified, and how we can relate elevation, surface area, and volume. There is potential for creating a digital elevation map through an elevation mapping software and then simulating the volume and surface area at different elevations, but this path was not pursued in this paper.

Once we had these relationships, we began studying the inflow and outflow of Lake Mead in order to create out model. We used outflow data that was available from the ClimateDataOnline database and were able to average daily flow values into monthly flow values using a pivot table in Excel. This then allowed us to graph this relation for both the inflow into Lake Mead from the Colorado River to calculate the total inflow per month. Then, data from the Hoover Dam was used to calculate outflow from the lake. The amount of water drained from the lake out of the dam is controlled by humans and changes can be made according to water levels. We read news articles about limits placed on water usage from the lake and calculated the approximate amount of water used by people in neighboring towns, given that the total amount of water that is allowed to be withdrawn from Lake Mead is 300,000 acre feet, of which around 70% is recycled. Our rough estimates showed that with the exception of water loss (evaporation), water levels are relatively stable, with inflow, human use, and outflow balancing each other out fairly well.

So, we concluded that evaporation must be the deciding factor between net increase or decrease of elevation levels, and thus shifted our focus to studying evaporation. We identified that temperature is the independent variable in most evaporation equations, which itself is altered by changes in climate. When evaporation is affected by this change, it in turn affects elevation, surface area, and volume. This conclusion can be proven by our graph of temperature, which shows a consistent increase across sinusoidal progression, which indicates a long term change in evaporation which could be the leading cause of the decreasing elevation of Lake Mead [Figure 4].

This meant that we need to create an equation for evaporation as a function of temperature. We explored multiple options before doing this, including two versions of the Penman formula, an equation using surface area, and deriving our own equation using test values. First, we explored the Penman formula, shown below.

$$E_o = \frac{\left(\frac{\Delta}{\gamma} H + E_a\right)}{\frac{\Delta}{\gamma} + 1}$$

However, this ended up being too complicated for our program and requires certain empirical values whose values were difficult to gather, such as the black body radiation constant for water. So, we found a more simplified version of the Penman formula, which does not take into account radiation. When looking at the first Penman formula we found that radiation had a minimal effect on the evaporation, a since we wanted to derive equations to enter into the Penman formula, we aimed for the more concise option of the simplified Penman formula.

$$E_0 \ = \ \frac{700\,T_m/(100 - A) + 15(T - T_d)}{(80 - T)} (\, mm\, day^{-1}\,)$$

In this formula T stands for average daily temperature, Tm stands T + 0.006h, A stands for the latitude in degrees of the body of water being analyzed, and Td stands for the dew point at that location. All of this combines into a function that evaluates the evaporation in millimeters of elevation per day. Thus, through some simple unit conversion, we were able to convert this into feet per month. This gives us a direct elevation change equation due to evaporation that can be used in our calculations. However, this does not solve the question of the elevation change caused by human use of water form the lake, or from the inflow and outflow.

Another option we tried was deriving an equation for evaporation in terms of surface area, but we found that temperature was not as prominent in this equation. Since we determined earlier that temperature was the changing variable, we needed this value considered.

So, after we had the full equation, we needed some way to model temperature. Using temperature information that we extracted from a nearby weather station, we were able to graph this and realize that this was also a sinusoidal function, with an obvious period of 12 months, as the temperature tends to go on a period of the year. Using the Stats Blue sinusoidal function generator we were able to create the following sinusoidal function:

22.5715*Sin[0.5236 x - 2.1199] + 60

Where x is the time index. However, something that we noticed is that while this function did fairly accurately predict the temperatures from 2005 to 2021, it did not predict how temperatures would change form there. We notices that when we added a linear regression transformation to the equation, we would achieve a much more accurate result [Figure 4].

22.5715*Sin[0.5236 x - 2.1199] + 60 + 0.085x

Where x is the time index. This means that this model is able to accurately follow an increase in temperature over time and simulate a long term shift in temperatures in addition to shorter term shifts in seasonal temperatures. This all together allowed us to accurately model the evaporation over time.

6.2 Inflow, Outflow, and Human Use Equation Modeling

We then decided that it was still necessary to come up with time dependent equations for inflow, outflow, and human use of water from the lake, all in terms of elevation change. This was difficult because we did not have any human use our outflow data, and limited inflow data. Thus, we went to the site ClimateDataOnline, and gathered data from there that allowed use to generate the following equations for both monthly inflow and monthly outflow. The equations were sinusoidal equations that were modeled using the Stats Blue sinusoidal regression modeling tool, and they were each sinusoidal functions. Interestingly however, we found that we achieved the highest accuracy with the inflow results when we modeled a situation that had a bi-yearly period. This is likely due to the fact that the location of where the Colorado River begins receives not only fall rains, but also springtime snow-melt. However, this allowed us to create the following inflow equation:

$$1934.7401*\text{Sin}[1.0472\ x + 0.4445] + 12985.6528$$

Where x is the amount of months after 2005. This equation corresponded fairly closely to our given inflow data, and thus we moved onto the outflow equation [Figure 1]. We ended up going the same route for outflow, but we found that the outflow equation was based on a yearly period, and more closely resembled the expected changes in elevation, which were also based on a likely yearly period:

$$3928.0371*\text{Sin}[0.5236x-1.0888]+12752.828$$

Where once again x is the amount of months after 2005. This equation corresponded even more closely to the given outflow data, and this is likely due to the fact that this is a more calculated flow value, and is controlled by humans. The final step was to figure out how much water we wanted to subtract as a result of human use. This was a tricky value, but we ended up settling on 5800 acre feet a month, as this was a value that could be feasible given the current wastewater recycling percentages. We then use a conversion function to turn out inflow and outflow values from cubic feet a second into acre feet a month, and because this was the same units as the units for the human use, we were able to apply our logarithmic function to turn this into an elevation change amount.

6.3 Program Design

We then moved onto modeling this in a computer program. Our goal was to use Java and to have the user, in this case us, input a date that we wanted to have be the last month for which it would read elevation. In order to do this we compiled the full equation with all of the factors, and set a counter that would be decreased every time that a for loop ran. This would ensure that the simulation would only run as many times as we wanted months to be counted. We then created an elevation counter value that would record elevation at the first of every month, and use this for the calculations of the next month inside of the loop.

Another factor that we had to consider was the initial elevation value. We ended up using a value from January of 2005 because it was a reliable value that we had access to that also provided some information as to where the elevation began from, and we needed an initial elevation for our calculations. Our program ran as such:

1: The user inputs up to which month they want data, by first inputting a month and then a year
2: The program will run through the calculations month by month, printing out the elevation at each month, and setting this as the next months elevation for calculations
3: The counter will have on added to it so that the stopping point may be established based on the entered month and day
4: The results are printed for each month, with the final printed value being the final elevation at the entered month and year

6.4 Results

We then ran the program multiple times, and using the model that used the trends from 2005-2020 we achieved an elevation of **998ft. in 2025, 866ft. in 2030, and 352ft. in 2050.** This means that the elevation of the lake will become critically low during those times, and the current supply chain tubes will no longer be able to adequately supply the water to the cities that depend on Lake Mead's water, such as Las Vegas. This could have disastrous consequences. When we ran the model that used date from the current drought cycle, which we found to be from 2017 and on, we achieved the following elevations: **1027ft. in 2025, 969ft. in 2030, and 609ft. in 2050.** For this model we used the slightly modified inflow and outflow equations which went as follows:

(1934.7401)*Math.sin((1.0472 * timeIndex + 0.4445)) + 12985.6528

(3928.0371) * Math.sin((0.5236 * timeIndex - 1.0888)) + 12752.828

These slightly higher elevations are likely due to the fact that the current cycle seems to have a lower decrease in elevation historically, as can be seen from the data. However, in both scenarios, the elevation dipped to near or actual record lows, and to levels which would be completely unsustainable. This means that in both scenarios, drastic actions would be needed. Or would it?

7 Wastewater Recycling

In order to test whether or not drastic actions would need to be taken, we decided to model what would happen if humans reduced the amount that they use by less than 1%, in fact, we modeled what would happen if they reduced their intake by only 0.01% each year. The results were astounding. When running our third computer model [Figure 9] with a slightly tweaked intake equation, which would be reduced by only 0.01% every year, we discovered that the elevations at the same times as before would be as follows: **1095ft. in 2025, 1113ft. in 2030, and 1086ft. in 2050.** While this shows that the results of the drought would not be completely staves off, the lake would be able to make an almost complete recovery and ruin of the south west could be avoided.

We also decided on actions that could be taken in order to implement this change. Given the already high water recycling efficacy that Nevada posses, it is completely possible that this plan could be put into action. Increasing wastewater recycling by less than 1% a year could completely stave off the current drought in the region. Given that much of the infrastructure is already abundant in Nevada, and that only simple filtration and pump stations are necessary, it is possible that if Nevada were to help out other neighboring Lake Mead water dependent states such as California and Arizona, the problem could be solved quickly and efficiently, especially given that a large amount of water is wasted during agriculture in California, as the main method of water crops is flooding the fields. Local leaders would have to decide to set limits for each of their localities and cities in order that water may best be preserved on the local level. Taxes could be diverted into the most important areas where infrastructure is needed, and this could become part of their campaign plan and promises. Thus the plan would be to implement the system that Nevada already has for wastewater recycling to an even greater level. The impact would obviously be measured by the elevation of Lake Mead, and if it does not return to an elevation of 1095ft. by 2025, then the percentage of water recycled would have to increase again.

8 Conclusion

In conclusion, there is much that can be done in order to fix the Lake Mead situation. Given our models it is likely that without any current changes, the lake will continue to dry up until the region which is feeds begins to dry up as well. This would spell disaster for the economy of not only the South-west, but also the US. Thus, the changes recommended should be implemented, given that such as a nondrastic change can result in such drastic results.

9 Strengths and weaknesses

Below is a chart of our strengths and weaknesses which we found pertinent to the discussion of our model:

Strengths	Weaknesses
1. Takes into consideration non linear patterns	1. Sinusoidal functions may not always be the best fit
2. Factors in multiple different variables	2. Our functions do not accurately predict temperature changes that are non-linearly transposed sinusoidal functions
3. Connects different aspects of Lake Mead as a function of time	3. Our elevation to volume function may not be accurate due to the inconsistent depth map of the lake
4. The model can be used to predict the future	4. Our results show periodic changes greater than what may be expected
5. We end up using trigonometric functions to predict cyclical and periodic functions, but then applying linear transformations in order to achieve more accurate results	5. The fact that our program is dependent on functions makes it difficult to understand where errors may have occurred
6. This model is able to factor in temperature changes as a result of climate change	6. Our volume changes are changed to elevation which may not be accurate
7. The Java script allows for quick and precise calculations to be made	

10 News Article

BREAKING NEWS Friday, 11.12.2021

Nevada News

No. 1542 LAKE MEAD, FRIDAY, NOVEMBER 12.2021 Friday Chronicles

WHAT'S HAPPENING WITH LAKE MEAD?

According to data from recent years, the water levels in Lake Mead have been lowering due to many environmental shifts such as climate change. Lake Mead primarily loses water from evaporation and human consumption. The increase in temperature leads to increased evaporation of the water in Lake Mead, which lowers the water level. Additionally, Lake Mead is a vital source of water for many civilians surrounding the reservoir. Although some water gets recycled back into the lake, most water waste can be accounted for by humans.

What Can YOU Do to Help?

As a citizen of the area that Lake Mead supports, it is important that you are aware of the laws involved with water usage. Experts are recommending that the lake Mead region limits (300,000 acre feet a year for Nevada), excessive water waste as much as possible. Being aware of rules and regulations will help hydrologists maintain as much water as possible in Lake Mead. The lack of water in Lake Mead is an effect of climate change, so we should be conserving energy and making earth-friendly choices when possible.

Recycling waste water is also a possible solution, and it is important that citizens follow future procedures for recycling water, as this is a very effective way to manage the drought. If only 0.01% of water is recycled more than what already is, the findings suggest that the elevation of the lake, and thus the safety of our future, can be increased from a predicted 352ft. by Jan-2050 to a predicted 1086ft! This could save our future, and this is why you should do your part in securing this path!

11 References

1. Harbeck, G. E., Koberg, G. E., Kohler, M. A. (1958). Water-loss investigations: Lake mead studies. Washington: U.S. Govt. Print. Off.

2. Zhao, G., Gao, H., Cai, X. (2020). Estimating lake temperature profile and evaporation losses by leveraging MODIS LST Data. Remote Sensing of Environment, 251, 112104. doi:10.1016/j.rse.2020.112104

3. Sima, S., Ahmadalipour, A., Tajrishy, M. (2013). Mapping surface temperature in a hyper-saline lake and investigating the effect of temperature distribution on the lake evaporation. Remote Sensing of Environment, 136, 374–385. doi:10.1016/j.rse.2013.05.014

4. Evaporation rate (water) calculator. (2021, November 11). Calculator Academy. https://calculator.academy/evaporation-rate-water-calculator/f1p1%7Cf2p0. Accessed 11 November 2021

5. Orlob, G. T., Selna, L. G. (1970). Temperature variations in deep reservoirs. Journal of the Hydraulics Division, 96(2), 391–410. doi:10.1061/jyceaj.0002327

6. National Centers for Environmental Information (NCEI). Climate Data Online. Climate Data Online (CDO) - The National Climatic Data Center's (NCDC) Climate Data Online (CDO) provides free access to NCDC's archive of historical weather and climate data in addition to station history information. — National Climatic Data Center (NCDC). https://www.ncdc.noaa.gov/cdo-web/. Accessed 12 November 2021

7. Bureau of Reclamation, L. C. R. W. T. (n.d.). Lower colorado region. Lower Colorado River Operations — Lower Colorado Region — Bureau of Reclamation. Retrieved November 12, 2021, from https://www.usbr.gov/
lc/region/g4000/hourly/levels.html.

8. Penman Formula E H E - Lunds Tekniska högskola. https://www.tvrl.lth.se/fileadmin/tvrl/files/vvr145/Kompletterandematerialf4.pdf. Accessed 12 November 2021

9. Overview of lake mead. National Parks Service. U.S. Department of the Interior. https://www.nps.gov/lake/learn/nature/overview-of-lake-mead.htm. Accessed 12 November 2021

10. 7 fun facts you didn't know about lake mead: Gray line Las Vegas. Gray Line Tours Las Vegas. https://graylinelasvegas.com/blog/7-fun-facts-you-didnt-know-about-lake-mead/. Accessed 12 November 2021

11. Household water usage utility service center what is average? https://www.rwd3rogers.com/documents/331/HouseholdWaterUsageEstimates.pdf. Accessed 12 November 2021

12. Whitaker, I. (2014, August 24). How our water goes from the toilet to the tap. Las Vegas Sun. https://lasvegassun.com/news/2014/aug/24/how-our-water-goes-toilet-tap/. Accessed 12 November 2021

13. Wolfram Research. (1997). Mathematica. computer software, Champaign (IL).

14. Stats Blue. (n.d.). Sinusoidal regression calculator. Retrieved November 15, 2021, from https://stats.blue/StatsSuite/sinusoidalregressioncalculator.html.

12 Appendix

12.1 Graphs

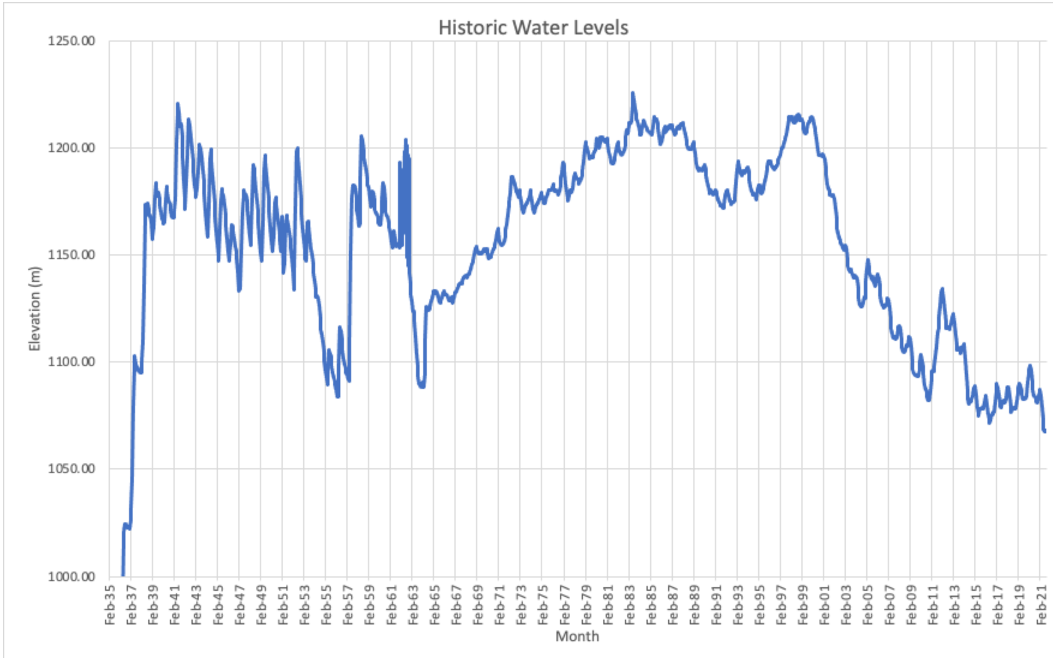

Figure 1. A graph that displays the historical elevation of Lake Mead

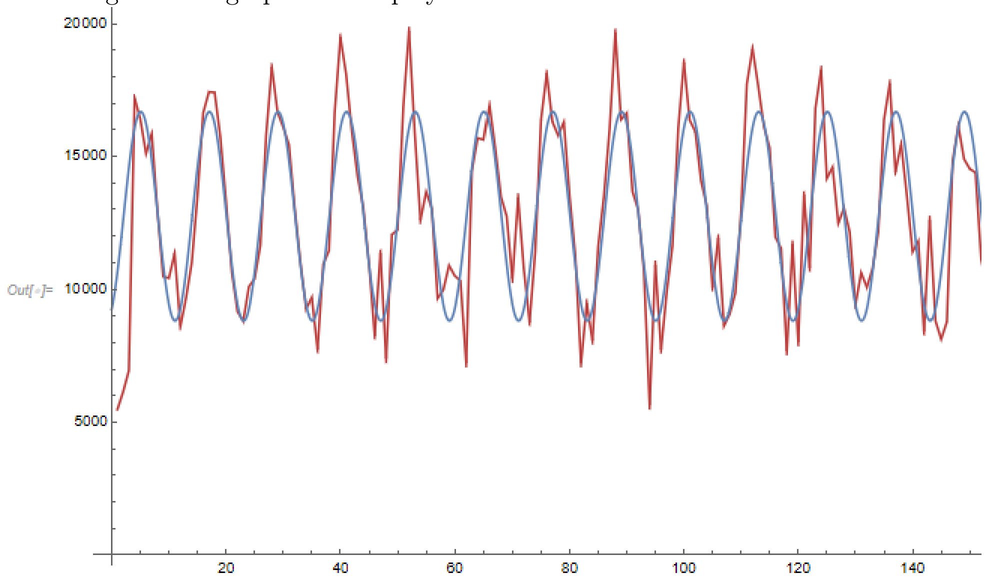

Figure 2. A comparison between the actual data for the outflow vs the equation of best fit for the outflow

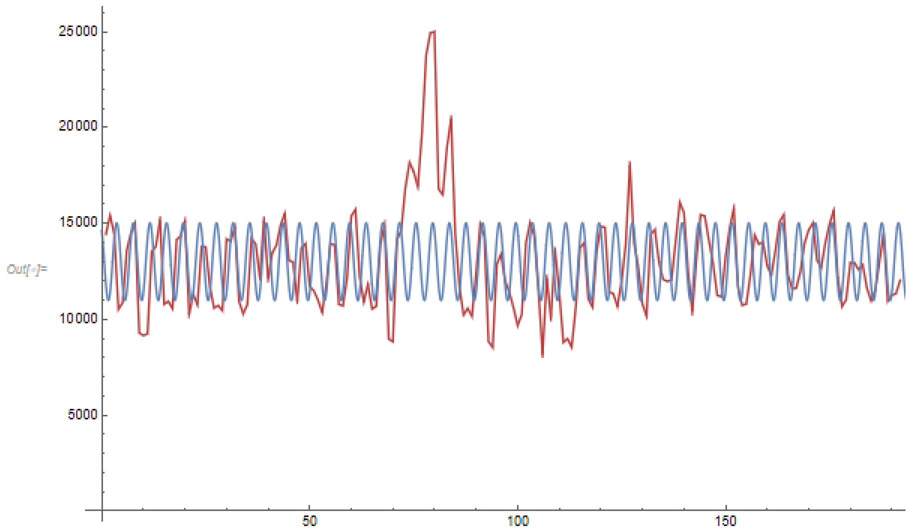

Figure 3. A comparison between the actual data for the inflow vs the equation of best fit for the inflow

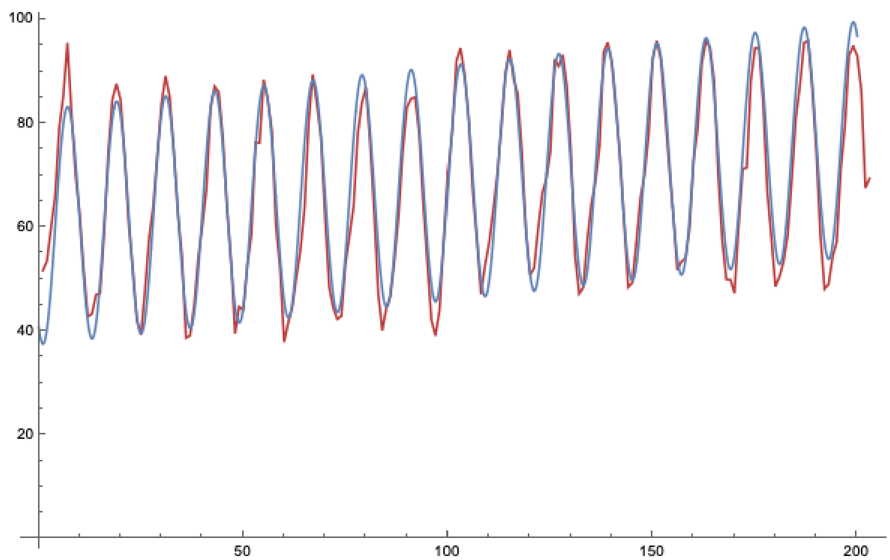

Figure 4. This figure compares predicted temperatures with the actual recorded temperatures

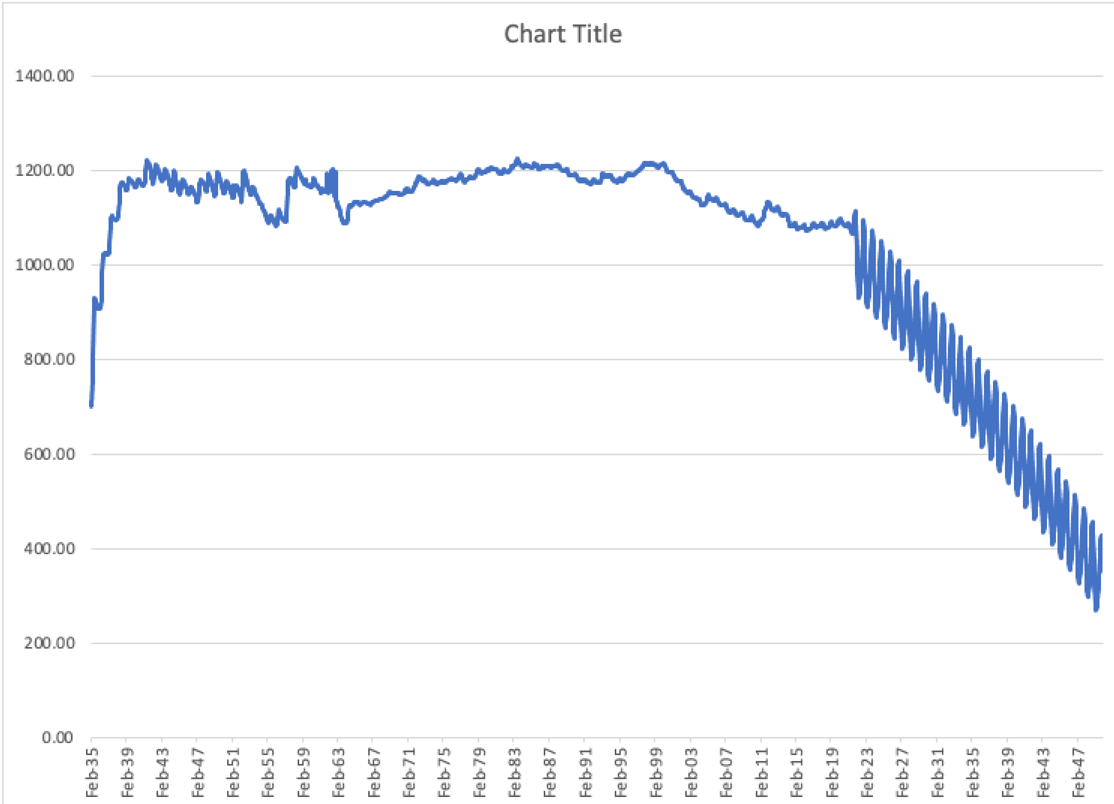

Figure 5. A graph of our resulting values for Model 1

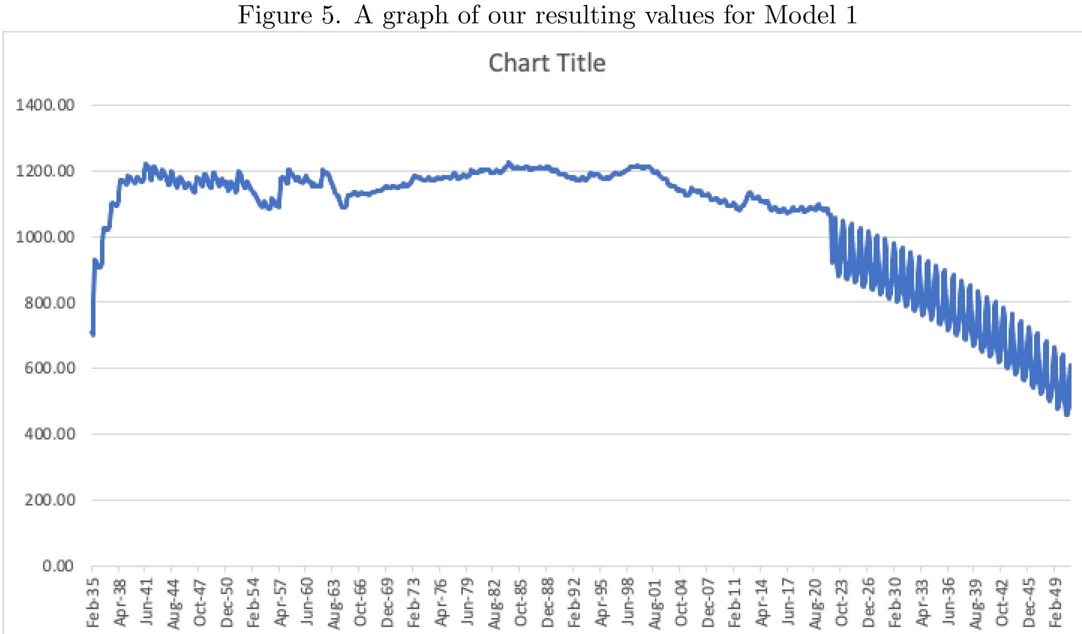

Figure 6. A graph of our resulting values of Model 2

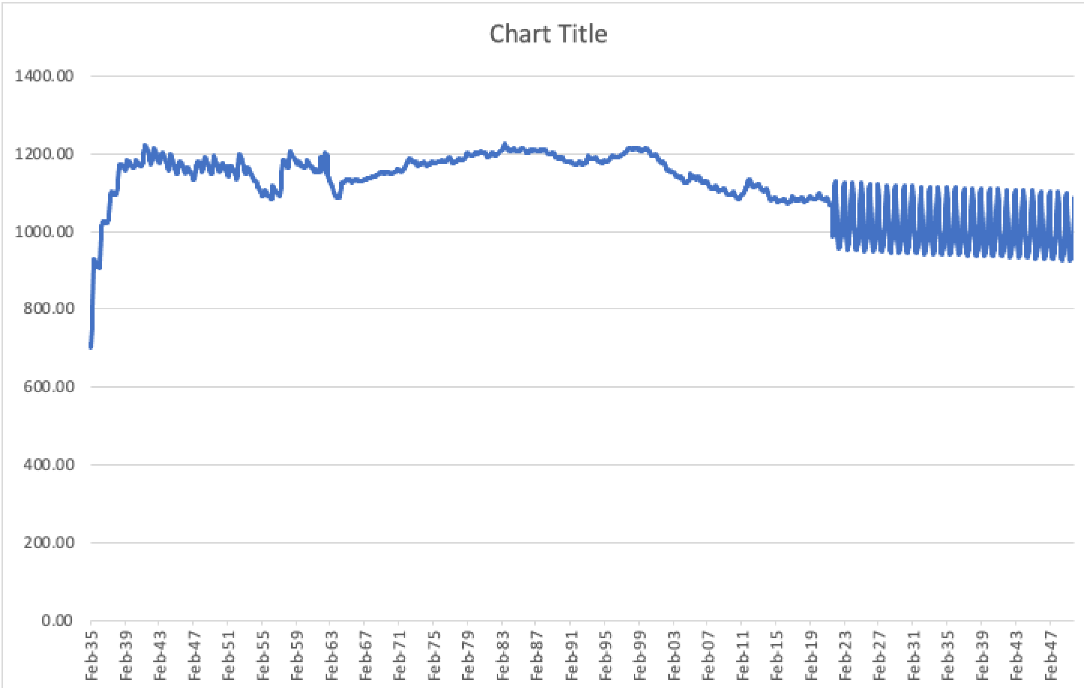

Figure 7. A graph of our resulting values with water recycling

12.2 Data Tables

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	14,440	15,400	14,420	10,520	10,870	13,570	14,470	14,990	9,292	9,154	9,247	13,520
2006	13,780	15,170	10,790	10,940	10,570	14,130	14,340	15,110	10,280	11,300	10,760	13,780
2007	13,750	11,680	10,590	10,720	10,460	14,170	14,050	14,800	10,940	10,290	10,770	14,180
2008	13,910	12,220	15,160	12,120	13,460	13,840	14,900	15,500	13,050	12,960	10,980	13,700
2009	13,920	11,720	11,490	11,000	10,370	11,860	13,930	13,860	10,780	10,710	12,180	15,370
2010	15,710	12,230	10,910	11,820	10,540	10,680	13,870	14,910	8,971	8,833	14,130	14,620
2011	16,850	18,170	17,700	16,910	19,710	23,780	24,940	25,010	16,780	16,490	18,950	20,450
2012	14,420	11,700	10,230	10,570	10,160	12,350	14,940	14,290	8,839	8,534	12,850	13,370
2013	13,640	11,420	10,620	9,680	10,250	13,970	15,030	14,340	11,530	8,172	12,150	10,080
2014	13,560	11,460	8,800	8,984	8,546	10,670	13,720	13,970	11,060	10,650	13,520	14,830
2015	14,780	11,430	11,340	10,680	11,990	13,900	18,040	13,960	12,740	10,810	10,170	14,410
2016	14,660	12,960	12,090	11,980	12,060	14,040	16,080	15,550	12,480	10,390	13,150	15,440
2017	15,370	14,090	12,910	11,250	11,180	13,230	14,750	15,770	11,690	10,730	10,810	12,350
2018	14,380	13,900	14,010	12,800	12,300	13,570	15,070	15,440	12,350	11,600	11,630	12,480
2019	13,940	14,650	15,000	13,060	12,680	13,970	14,940	15,650	12,180	10,680	11,020	12,940
2020	12,920	12,600	12,830	11,630	10,970	11,530	12,970	14,460	10,950	11,250	11,350	12,040
2021	12,730	12,410										

A data table which includes the actual inflow data

	2012	2013	2014	2015	2016	2017
Jan	11600	9899	9850	13540	10770	8130
Feb	13480	11630	12910	10800	12160	8784
Mar	16040	16050	17720	16810	16380	14820
Apr	19660	18540	19060	18270	17740	16150
May	16390	16370	17650	14170	14420	14900
Jun	16630	15930	16120	14590	15460	14530
Jul	13680	14070	15320	12480	13510	14390
Aug	12990	13140	11960	13050	11400	11120
Sep	10680	10060	11530	12150	11800	10080
Oct	5619	11920	7672	9405	8424	
Nov	10930	8629	11680	10610	12620	
Dec	7735	9072	8019	10070	8821	

A data table which includes the actual outflow data

12.3 Code

[Appendix 7]:Model One Code

```
import java.util.Scanner;
import java.lang.Math;

public class HiMCModel1 {

    public static void main(String[] args) {

        Scanner todo = new Scanner(System.in);
        System.out.println("Enter the month you would like to test
            (January is 1, February is 2...)");
        int month = todo.nextInt();
        System.out.println("Enter the year you would like to test
            (from 2005 onwards)");
        int take = todo.nextInt();
        int year = take - 2021;
        double elevation = 1137;
        todo.close();
        int t = 12 * year + month;

        for (int timeIndex = 1; timeIndex <= t; timeIndex++) {
            double inflowCFS =
                1542.9821*Math.sin(1.0472*timeIndex-0.0341)+
                12846.7807;
            double inflow = 1.04*(-1170.7061 + (138.9516 *
                Math.log(inflowCFS*60.37)));
            double outflowCFS = (3928.0371) * Math.sin((0.5236 *
                timeIndex - 1.0888)) + 12752.828;
```

```
                    double outflow = -1170.7061 + 138.9516 *
                        Math.log(outflowCFS*60.37);
                    double humanLoss = -1170.7061 + 138.9516 *
                        Math.log(5800);
                    double tempRadians= ((0.5236 * timeIndex) - 2.1199);
                    double temp = ((22.5715 *
                        Math.sin(tempRadians)+60+(0.085*timeIndex))-32)*5/9;
                    double tempM = 700*(temp + (0.006 *
                        (elevation*0.3048)));
                    double a = 100-36.14;
                    double tempD2 = 15*(temp - (0.8977*temp - 18.338));
                    double evaporationMMD = ((tempM/a)+tempD2) / (80 -
                        temp);
                    double evaporation = 0.1*evaporationMMD;

                    if (elevation<=0)
                            elevation=0;

                    elevation =
                        elevation-evaporation+inflow-outflow-humanLoss;
                    System.out.println(elevation);
            }
    }
}
```

[Appendix 8]:Model Two Code

```
import java.util.Scanner;
import java.lang.Math;

public class HiMCModel2 {

        public static void main(String[] args) {

                Scanner todo = new Scanner(System.in);
                System.out.println("Enter the month you would like to test
                    (January is 1, February is 2...)");
                int month = todo.nextInt();
                System.out.println("Enter the year you would like to test
                    (from 2005 onwards)");
                int take = todo.nextInt();
                int year = take - 2005;
                double elevation = 1137;
                todo.close();
                int t = 12 * year + month;

                for (int timeIndex = 1; timeIndex <= t; timeIndex++) {
                        double inflowCFS = (1934.7401)*Math.sin((1.0472 *
                            timeIndex + 0.4445)) + 12985.6528;
                        double inflow = 1.04*(-1170.7061 + (138.9516 *
                            Math.log(inflowCFS*60.37)));
```

```
                    double outflowCFS = (3928.0371) * Math.sin((0.5236 *
                        timeIndex - 1.0888)) + 12752.828;
                    double outflow = -1170.7061 + 138.9516 *
                        Math.log(outflowCFS*60.37);
                    double humanLoss = -1170.7061 + 138.9516 *
                        Math.log(5800);
                    double tempRadians= ((0.5236 * timeIndex) - 2.1199);
                    double temp = ((22.5715 *
                        Math.sin(tempRadians)+60+(0.085*timeIndex))-32)*5/9;
                    double tempM = 700*(temp + (0.006 *
                        (elevation*0.3048)));
                    double a = 100-36.14;
                    double tempD2 = 15*(temp - (0.8977*temp - 18.338));
                    double evaporationMMD = ((tempM/a)+tempD2) / (80 -
                        temp);
                    double evaporation = 0.1*evaporationMMD;

                    elevation =
                        elevation-evaporation+inflow-outflow-humanLoss;
                    System.out.println(elevation);
            }
    }
}
```

[Appendix 9]:Model With Water Recycling Code

```
import java.util.Scanner;
import java.lang.Math;

public class HiMCModelRecycling {

        public static void main(String[] args) {

                Scanner todo = new Scanner(System.in);
                System.out.println("Enter the month you would like to test
                    (January is 1, February is 2...)");
                int month = todo.nextInt();
                System.out.println("Enter the year you would like to test
                    (from 2005 onwards)");
                int take = todo.nextInt();
                int year = take - 2005;
                double elevation = 1137;
                todo.close();
                int t = 12 * year + month;

                for (int timeIndex = 1; timeIndex <= t; timeIndex++) {
                        double inflowCFS = (1934.7401)*Math.sin((1.0472 *
                            timeIndex + 0.4445)) + 12985.6528;
                        double inflow = 1.04*(-1170.7061 + (138.9516 *
                            Math.log(inflowCFS*60.37)));
                        double outflowCFS = (3928.0371) * Math.sin((0.5236 *
```

```
                    timeIndex - 1.0888)) + 12752.828;
                double outflow = -1170.7061 + 138.9516 *
                    Math.log(outflowCFS*60.37);
                double humanLoss = (-1170.7061 + 138.9516 *
                    Math.log(5800));
                double tempRadians= ((0.5236 * timeIndex) - 2.1199);
                double temp = ((22.5715 *
                    Math.sin(tempRadians)+60+(0.085*timeIndex))-32)*5/9;
                double tempM = 700*(temp + (0.006 *
                    (elevation*0.3048)));
                double a = 100-36.14;
                double tempD2 = 15*(temp - (0.8977*temp - 18.338));
                double evaporationMMD = ((tempM/a)+tempD2) / (80 -
                    temp);
                double evaporation = 0.1*evaporationMMD;

                elevation =
                    elevation-evaporation+inflow-outflow-(Math.pow(0.9999,
                    timeIndex)*humanLoss);
                System.out.println(elevation);
            }
        }
}
```