# CE 580
# Lake Mixing Project – Lake Mead

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Cover Photo: <http://www.hikinglasvegas.com/Photos/Lake_Mead/image15.htm>

## 1 – Abstract

Reservoir models are dynamic tools for prediction of variations in temperature, salinity and density in lakes. There are a variety of hydrodynamic models currently available. DYRESM is one such model which can be applied to lakes and reservoirs satisfying the one-dimensional approximation. It is based on the idea that the variations of temperature, salinity and density in the horizontal direction are negligible compared to that in the vertical direction. DYRESM was applied to Lake Mead, Nevada. Lake Mead is a reservoir that is formed behind the Hoover Dam. Daily data for the lake are available from a variety of sources. These data include depth, temperature, and chemical properties of the lake. Due to the length and quality of data available, Lake Mead was ideal for this analysis. All of the data for the reservoir inflows and outflows were available for the year 2002, which was chosen as the year for analysis of the reservoir. It is assumed in this study that given the extent of the lake, the one-dimensional model DYRESM would be a suitable hydrodynamic model to analyze Lake Mead. Results show that DYRESM performs reasonably well for simulating the water-surface elevation and temperature profile changes with time. However, the one-dimensional approximation does not appear to be suitable for simulating changes in salinity with time and depth.

## 2 – Introduction to Lake Mead

America’s largest man-made reservoir, Lake Mead was created in the 1930s and named after Dr. Elwood Mead, Reclamation Commissioner from 1924 to 1936. The lake extends over 170 km beyond the Western Hemisphere’s highest concrete dam, Hoover Dam. Named after former United States President Herbert Hoover, Hoover Dam controls the Colorado River to provide water to the surrounding farmlands, homes and businesses in southern Nevada, Arizona, southern California and northern Mexico. When full, the lake contains roughly 36 billion cubic meters, the same amount of water as would have otherwise flowed through the Colorado River over a two-year period. About 96 percent of the water in Lake Mead is derived from melted snow that fell in Colorado, Utah, New Mexico and Wyoming (USBR, FAQ 2004).

Lake Mead is divided into four major basins: the Pierce, Gregg, Virgin, and Boulder. On average, the outflow of Lake Mead exceeds the inflow in order to meet downstream municipal and agricultural demands. In terms of overall elevation, Lake Mead is typically at its highest in the late fall and early spring months. During the late spring and early summer, the lake experiences a standard drop due to the desert heating up and the increased need for agricultural and municipal water. During the summer months, temperatures often exceed 40° C. On the whole, Lake Mead is a deep, warm, monomictic reservoir. At its deepest point, the lake is approximately 180 meters deep. Thermal stratification develops in May and June, and a classic thermocline is known to develop in July between a depth of 10 and 15 meters (CCNCP 2005). Turnover initiates in October and the reservoir is totally destratified by January. Though the water released through the dam can be used to generate over 2,000 megawatts of electricity, power generation comes second to the aforementioned agricultural and municipal water demands.

Highly ecologically diverse, the Lake Mead National Resource Area (NRA) is home to three of America's four desert ecosystems; the Mojave, the Great Basin and the Sonoran Deserts. As a result, this seemingly barren environment contains a plethora of plants and animals, some of which are found nowhere else in the world. Specifically, the Lake Mead NRA is home to bighorn sheep, mule deer, coyotes, kit foxes, bobcats, ringtail cats, numerous lizards and snakes and a wealth of bird species.

Currently, the water level in Lake Mead is lower than it has been in over 40 years, due to significantly less runoff from the Colorado River and no change in the amount of outflow (Appendix A, page 27). Specifically, Lake Mead was at roughly two-thirds of its full capacity in May 2003 (Allen 2003). This drought has led to a significant drop in the overall elevation of the lake (Appendix B, page 28). Ultimately, however, there is still sufficient water in Lake Mead to meet all irrigation and residential needs. Though the current drought is a dramatic fluctuation from the norm, it is part of the natural and historic cycle of the lake. Nevertheless, the many Americans that depend on this water source will monitor it closely in the years to come.

## 3 – Model Description

Computer models help solve the complex interactions that occur between weather, temperature stratification, hydrodynamics, and water quality in lakes. They are used for a variety of purposes e.g., predicting the impact of reducing the water level in a lake and predicting how land- use change or even climate change could influence lake ecology in the long term. Three-dimensional models are commonly used for detailed and short simulations of single events, and one-dimensional models are used for seasonal or long-term simulations of the vertical salinity and temperature distribution. DYRESM (DYnamic RESservoir Simulation Model) is a one-dimensional lake thermal model for predicting the vertical distribution of temperature, salinity and density in lakes and reservoirs (Imberger and Patterson 1981). It has been developed by the Centre for Water Research in Western Australia. The model uses mass balance equations to calculate a water budget, a salt budget, and a heat budget for each of the vertical water layers. Each water layer has a storage term (i.e., volume, heat, or salt mass) and may have inflow, outflow, and vertical mixing exchange terms.

Vertical mixing is strongly dependent on the density differences between layers, so that heating or reduced salinity from freshwater inflows greatly restrict vertical mixing. Cooling and evaporation will increase the density of the surface mixed layer and allow greater mixing with underlying layers. Mixing exchanges of water, heat, and salinity are directly related.

DYRESM is a one dimensional model, i.e. it only accounts for the variations in the vertical direction. The horizontal variation is neglected, which means that horizontal layers are formed inside the lake that shift vertically to represent change. Due to inflows and outflows, the layers move up or down. This results in the change in width of the layers according to the bathymetry of the lake. The one dimensional model works on the assumption that daily time scales are used to model the reservoir. This is due to the fact that the horizontal variations occur over several thousand kilometers on time scales less than a day. It is also assumed that the density stratification usually inhibits vertical motion. Imberger and Patterson (1990) have also checked the validity of the one dimensional assumption using Lake Number, $L_N$.

DYRESM is based on a Lagrangian layer scheme which states that the layers within have uniform properties but different thicknesses. These layers are modified by the inflows, outflows, radiation and precipitation. There is a limit to the thickness and volumes of these layers. This ensures that the resolution does not go down and that there is an optimum number of layers. Density is calculated as a function of temperature, pressure and salinity.

The surface heat, mass and momentum exchange are the primary driving mechanisms for the model. The surface fluxes include heating due to shortwave, radiation penetration, evaporation, sensible heat, long wave radiation and wind stress. Figure 3.1 shows a typical cross-section of lake and the heat fluxes.

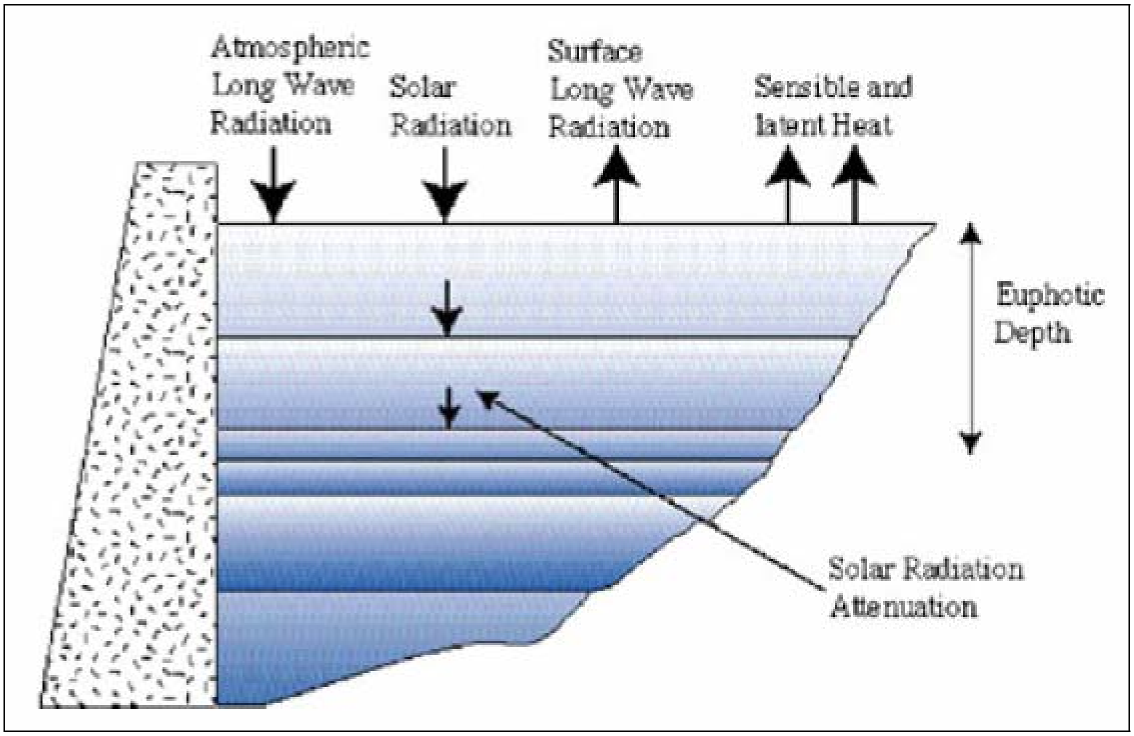


**Figure 3.1** Surface Energy Flux Exchanges. Reproduced from: (http://www2.cwr.uwa.edu.au/~ttfadmin/cwrsoft/doc/dyresm_science/ch3.html)

The surface mixed layer model uses simple energy arguments to mix the water column based on the kinetic and potential energy available. Mixing is done by conserving mass and momentum on a layer-by-layer basis, starting from the free surface. The method is to compute the energy available for mixing two layers with the energy required to mix the two layers. If there is sufficient energy, the layers are mixed. Any excess energy is then available for mixing subsequent deeper layers. When there is not enough energy available to mix further layers mixing stops. Any remaining mixing energy is carried over for mixing in the next time step.

Inflows to the model can be in the form of surface or subsurface flows. Subsurface inflows can be either buoyant or dense compared to the ambient fluid at the level of inflow, and different algorithms are used for these two cases. There are three stages to surface water inflow to the reservoir. As a stream enters the lake it pushes the stagnant water ahead of itself until buoyancy forces, due to the density differences which may be present, become sufficient to arrest the flow. At this point the flow either floats over the reservoir surface if the inflow is lighter than the lake water or it plunges beneath the reservoir water if it is heavier. If the entrance point to the reservoir is a well defined drowned river valley, then the side of the valley will confine the flow and a plunge line will be visible across the reservoir at which point the river water submerges uniformly and travels down the channel in a one dimensional fashion.

For the outflows, the model determines the elevation of the outlet and the out is extracted from the adjacent layer(s). After each layer is altered the layer structure is reconstituted. In case of overflow, all water or layers above the crest are removed until the elevation of crest is equal to the water surface.

The properties of the lake, e.g. temperature, salinity, density etc., are calculated by the model taking into account the above mentioned text. There is more physical basis to the model than described above. The detailed description of the model can be found in the DYRESM Science Manual (Antenucci and Imerito 2002).

## 4 – Data Section

This section describes the data and assumptions that were needed in order to create the input files to run the model. Data were obtained from a variety of sources, and in many cases, assumptions needed to be made to use this data. This was due to factors such as missing data or location of the source in relation to the reservoir.

### 4.1 – Configuration File (.cfg)

This file specified the operating conditions of the model. Parameters such as the time step, simulation length and start day, and type of output was entered into this file. For this simulation, the time step was 86400 s (1 day), and the simulation ran for 365 days starting on 2002001 (January 1, 2002). The desired output was salinity, temperature, and density which were calculated for each day of the year. Other values such as boundary and layer thicknesses, and light coefficients were not changed from the sample configuration file of the program.

### 4.2 – Physical Data and Morphometry File (.stg)

Lake bathymetry data in DYRESM is entered as a series of horizontal slabs of fluid. Therefore, values for elevation versus lake surface area needed to be obtained. These surface areas were estimated using a DEM of the Lake Mead area created from a study by the USGS from 2001 to 2003 to map the present lake floor (Twitchell 2003). This study was undertaken because the current lake floor elevation is higher than the original elevation due to sediment impoundment occurring over the life of Hoover Dam. Figure 4.1 below shows a profile of the present Colorado River thalweg in comparison to the pre-impoundment condition.

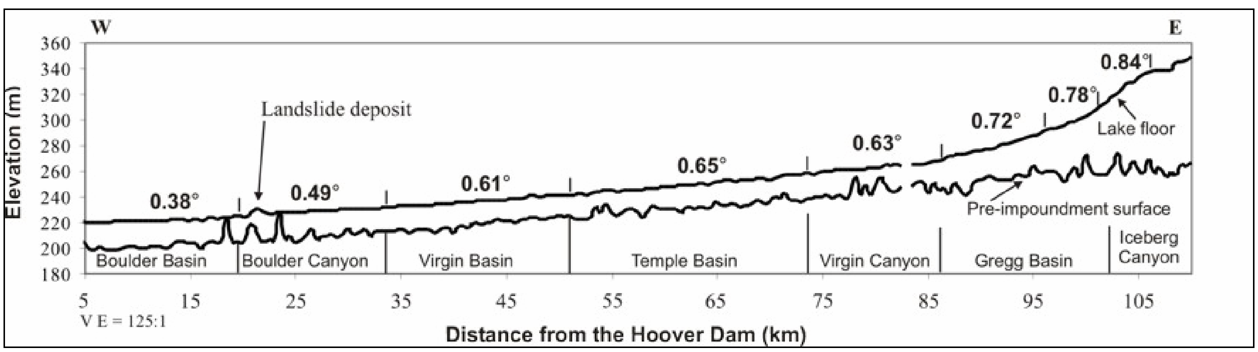


**Figure 4.1** Pre-impoundment and present day elevations of Colorado River thalweg. Present day slope estimation is also shown. Reproduced from: (Twitchell 2003).

From this figure it was estimated that the lowest elevation in the reservoir was 220 m above sea level. With this information, the present day DEM was analyzed with simple Matlab code to find the lake surface area at 10 m intervals. This code can be viewed in Appendix C on page 29. The surface areas were estimated up to 380 m in order to capture the maximum reservoir operating level of 364 m (USBR, Ecological). The estimated surface area of 63900 hectares at elevation 370 m was within 5% of the actual surface area known at elevation 372.4 m given by the USBR (Hoover). For the purpose of the study, this error was assumed to be allowable.

Also included in this file was data that described the flow into the lake. In the case of Lake Mead, 98% percent of the inflow is contributed by the Colorado River. Therefore, only one inflow was input into the model. This flow was specified to enter at the surface of the lake. Slope of the inflow, 0.0344 degrees, was estimated from Colorado River elevation data through the Grand Canyon, which is located upstream of Lake Mead. The half-angle, 75, and drag coefficient, 0.015 were not changed from the sample values in the DYRESM manual since no information about them was available.

Finally, elevation data describing the outflow from the lake was necessary for this file. There are two outflows for the model, downstream releases from the reservoir and pumping. Downstream releases occur at an elevation of 281 m (USBR, Ecological). Pumping for agricultural, residential, and industrial use was set at an elevation of 300 m. This is the elevation of the Southern Nevada Water Authority's extraction from the lake (ITA 2004).

A diagram of each of the elevations of interest for the lake is shown below in Figure 4.2. The initial height of the lake is input into the Initial Profile file.

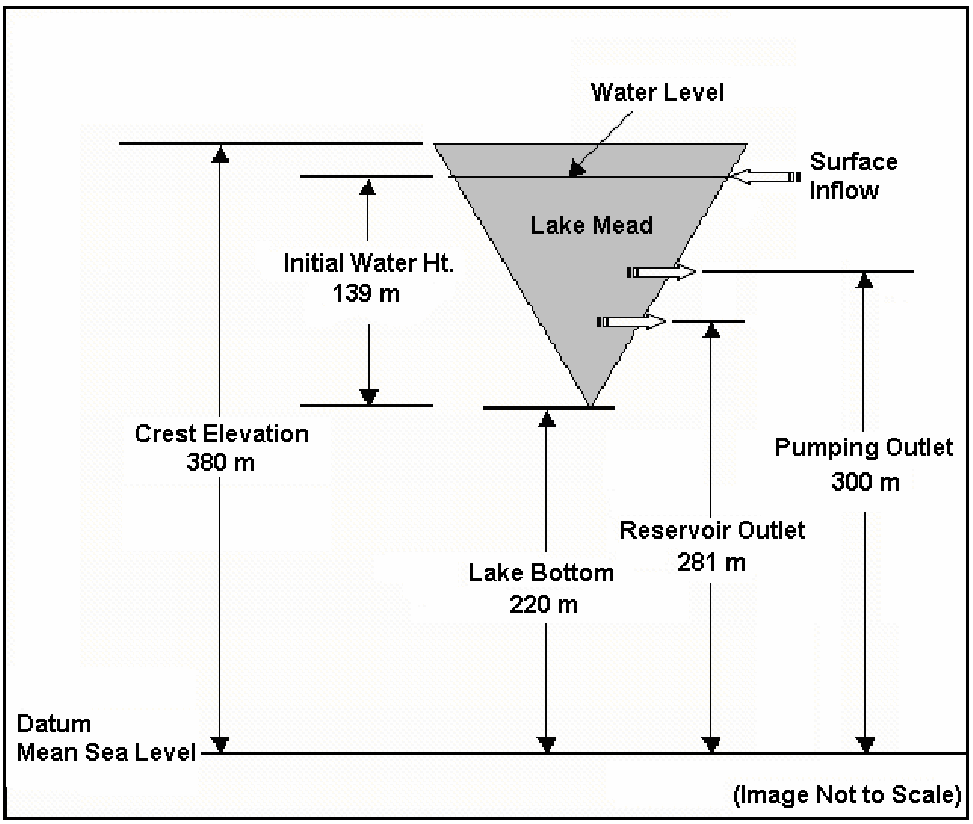


**Figure 4.2** Elevations for use in DYRESM model. Adapted from: (DYRESM User Manual).

## 4.3 – Initial Profile (.pro)

The Initial Profile contains the vertical temperature and salinity structure of the lake at the start time of the simulation. Data for this file was available from Water on the Web (2005). The source of their data was the USGS Water-Quality Monitoring at Lake Mead Sentinel Island Station. Temperature was a given value in the data. Salinity data had to be calculated as a function of temperature and specific conductance. The calculation was performed using the 1978 Practical Salinity Scale Equations (IEEE 1980). The start date of the simulation is the first day of 2002. This date is in the winter where the temperature and salinity profiles of the lake are nearly constant. This is reflected in the values used in the initial profile where temperature was 12.7 C and salinity 0.61 PSU for every elevation in the lake. Refer to the Results section to see these plots in Figures 5.5 and 5.8 on pages 18 and 20, respectively.

**4.4 – Meteorological Data (.met)**

This was the most extensive file and required shortwave radiation, cloud cover, air temperature, vapor pressure, wind speed, and rainfall. Rainfall was input as a daily total while the rest of the measurements were input as daily averages.

Shortwave radiation, wind, and air temperature were measured by the USGS Water-Quality Monitoring at Lake Mead program. Also measured at this site was relative humidity, from which vapor pressure was calculated using Equation (1) below (Antenucci and Imerito 2002):

$$ea = \left(\frac{h}{100}\right)\exp\left(2.303\left(\frac{7.5 \cdot T}{T + 237.3}\right) + 0.7858\right) \qquad (1)$$

Where: *ea* is vapor pressure (hPa)
*h* is relative humidity of air (%)
*T* is air temperature (C).

These data were available in 20 minute intervals from the USGS (Westenburg 2005). Therefore, it was necessary to convert each into daily averages. According to correspondence with the USGS, it is necessary to note: ALL DATA PROVISIONAL AND SUBJECT TO REVISION. All of these readings were taken from the Sentinel Island measurement platform. A schematic diagram of this platform is provided below in Figure 4.3.

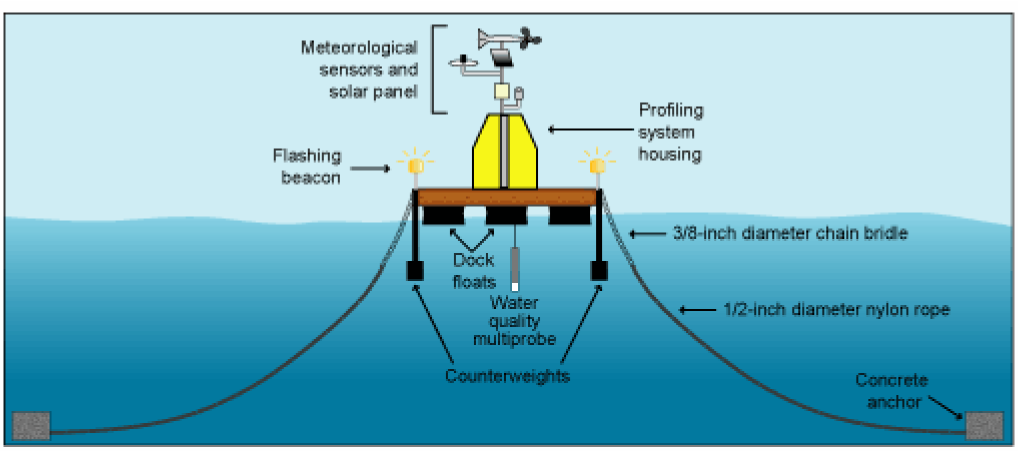


**Figure 4.3** Sentinel Island platform schematic diagram. Reproduced from: (USGS, Instrumentation 2005).

One factor that should be noted is the 90 day absence of data from the Sentinel Island site in the late summer of 2002. To account for this missing data, 2003 data were used in its place for each of the four measurements made at this site. Figures 4.4 and 4.5 below and on the next page, respectively, compare the 2002 and 2003 monthly averaged data showing a relatively small difference between the two measurements. For this reason, the error between the actual and substituted data was assumed negligible.

Daily cloud cover values were estimated by the NOAA Comparative Climatic Data for Las Vegas, NV. Cloudiness is summarized for 47 years of data through 2003. For each month, the mean number of clear days (0 – 30% coverage), partly cloudy days (40% – 70% coverage), and cloudy days (80% - 100%) was given. Using this information, the daily cloud cover was set so that the average number of clear, partly cloudy, or cloudy days matches the mean for the last 47 years. This was done in a way that was consistent with the precipitation data. On days when it was raining, the cloud cover was given as cloudy. The annual average for the area is 210 clear days, 82 partly cloudy days, and 73 cloudy days.

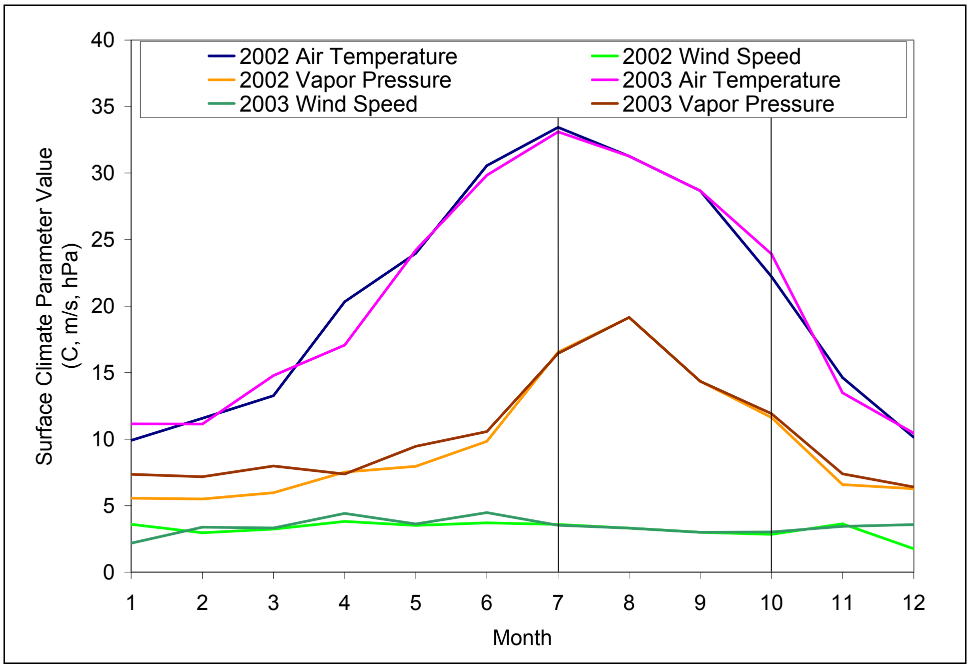


**Figure 4.4** Monthly average values for air temperature, vapor pressure, and wind speed. Data for 2002 from July to October was estimated from 2003 data. (ALL DATA PROVISIONAL AND SUBJECT TO REVISION)

Precipitation data were obtained from the National Climatic Data Center, NOAA for Las Vegas – McCarran Airport Station. The precipitation was given as a total daily value at the end of each specified 24-hr period. There were only around 10 days of measured precipitation for the entire year. Figure 4.6 on the next page illustrates this fact.

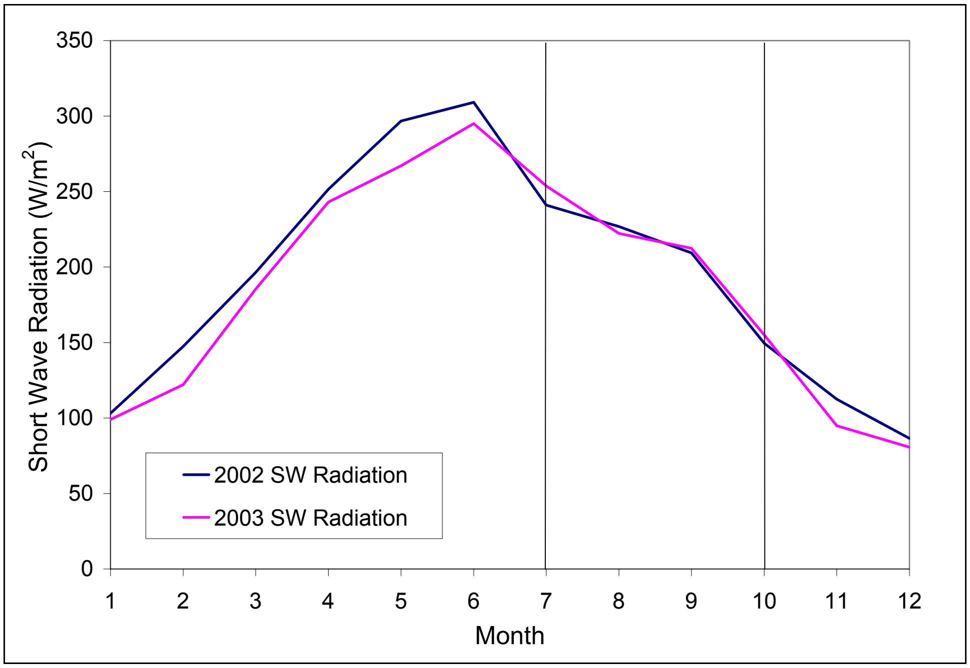


**Figure 4.5** Monthly average values for short wave radiation. Data for 2002 from July to October was estimated from 2003 data. (ALL DATA PROVISIONAL AND SUBJECT TO REVISION)

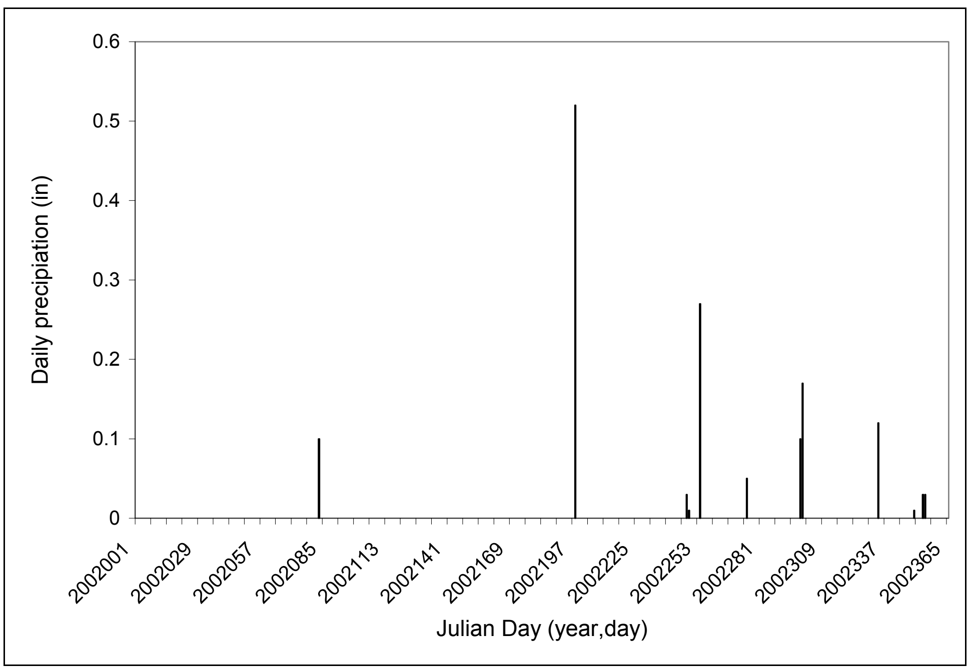


**Figure 4.6** Daily precipitation values for 2002 at McCarran Airport Station in Las Vegas.

## 4.5 – Stream Inflow (.inf)

In the Physical Data and Morphometry File, it was specified that 98% of the flow into Lake Mead was from the Colorado River. Therefore, data for only this one inflow were needed for the file. Discharge data were available from the USGS gage 09404200 Colorado River above Diamond Creek Nr Peach Spring. The approximate location of this gage in relation to the lake can be viewed in Figure 4.7 below. These discharges were increased by 2% to account for flow into Lake Mead from other sources. Since a daily time step was used in the DYRESM simulation, the discharges were converted to an equivalent daily volume.

Also needed in this file were values for temperature and salinity of the inflowing data. As was the case with the lake's initial profile data, salinity needed to be calculated as a function of temperature and specific conductance since those were the only available data. These values were obtained from the USGS (GCMRC 2005). The monitoring site is located on the Colorado River near Grand Canyon Village. This location of this site in relation to Lake Mead can be viewed in Figure 4.7 below. It was assumed that the effect from distance upstream of the monitoring site from the lake is negligible since there are no reservoirs between that would have a major impact on the temperature or salinity. The data from these sites were in 15 minute intervals. These values were used to obtain a daily average in order to fit the simulation time step.

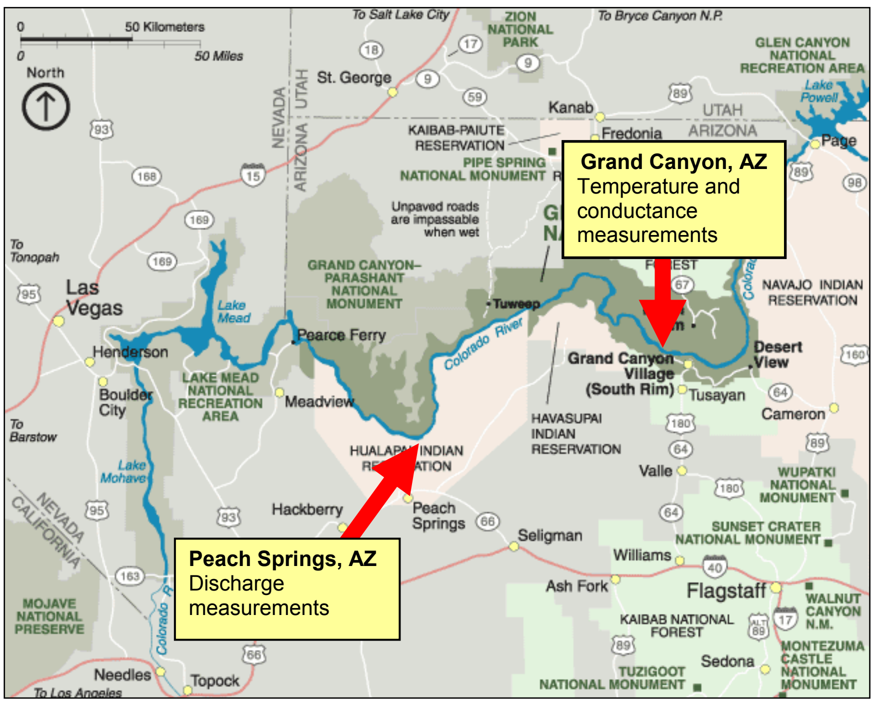

**Figure 4.7** Locations of inflow discharge, temperature, and conductance measurements in relation to Lake Mead. Adapted from: (NPS 2005).

Each of the inflow measurements varied throughout the year. The monthly averages of temperature and salinity can be viewed in Figure 4.8 on the next page. Monthly average flows into the reservoir can be viewed in Figure 4.9 on the next page. Each of these values is heavily controlled by releases from Glen Canyon Dam located upstream of the Grand Canyon on the Colorado River.

## 4.6 – Withdrawal File (.wdr)

This file simply has the daily volumes of the two outflows specified in the Physical Data and Morphometry File. These discharge values were available from the USBR (Archives 2005). To show the variation throughout the year, a time-series plot showing average monthly values is shown in Figure 4.9 below. Demand for water increases during the summer which is evident by the increase in pumping during these months. This, along with an increase in evaporation, also explains the decrease in releases during these months.

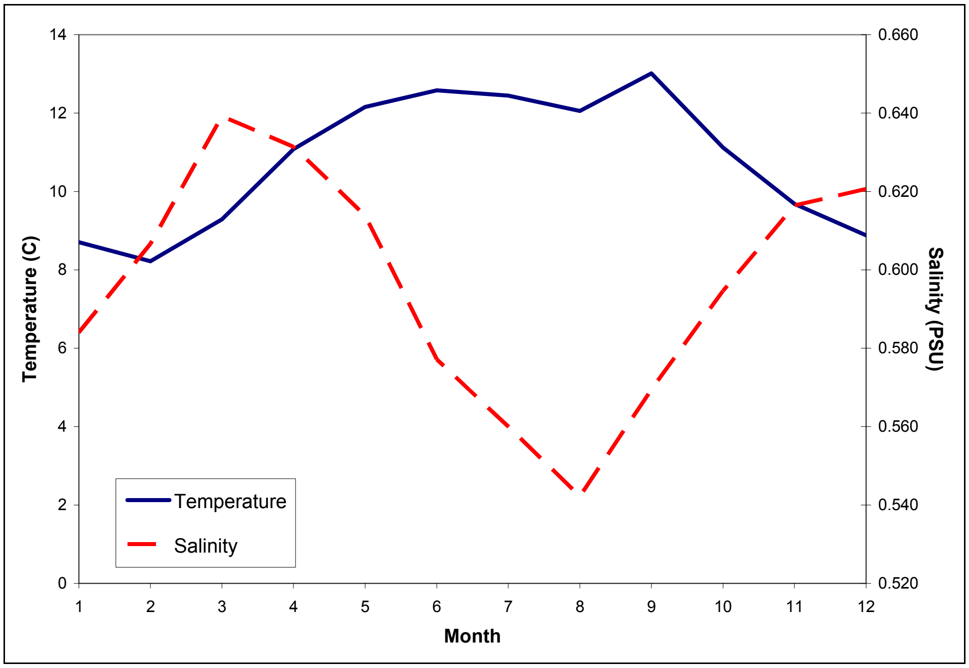


**Figure 4.8** Monthly average values for temperature and salinity.

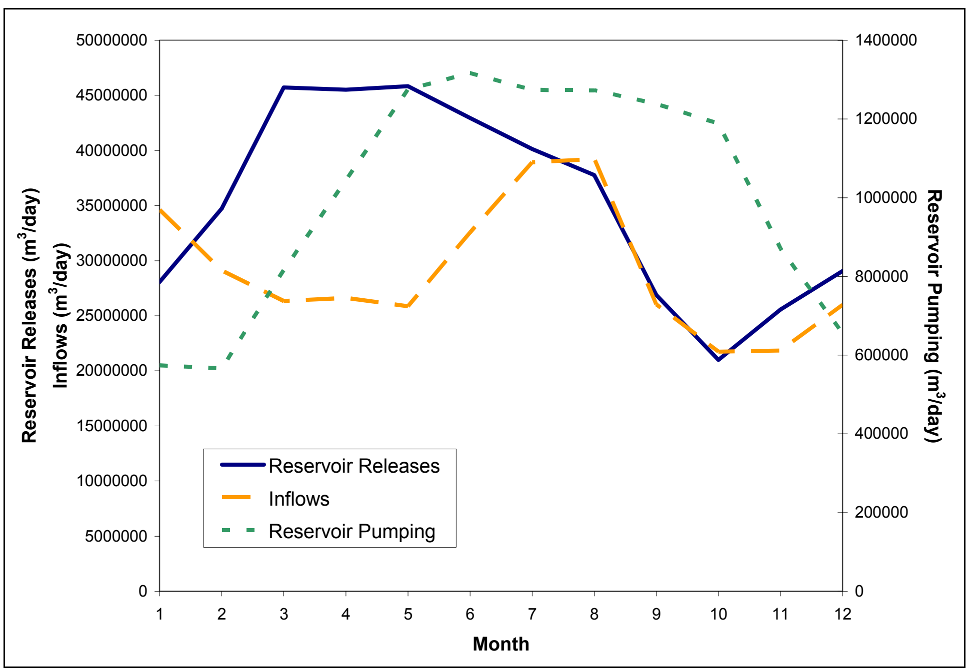


**Figure 4.9** Monthly average values for the inflows and outflows of Lake Mead.

## 4.7 – Field data file (.fld)

The field data file consisted of measured profiles of the lake. For this file, profiles were obtained for 1 to 2 days each month depending on the availability of the data. This provided a comparison of the variation in the lake characteristics throughout the year to the model simulated values. Line plots of these measured profiles can be viewed in Figures 5.5 and 5.8 in the Results section on pages 18 and 20, respectively. These measurements were taken by the USGS Water-Quality Monitoring at Lake Mead Sentinel Island Station and available at Water on the Web (2005). A schematic of the instrumentation used for these measurements can be viewed in Figure 4.3 on page 9.

## 4.8 – Parameter File (.par)

This file contains various physical constants and coefficients used in the model simulation. All of the values were determined from lab and field experiments. The values used in the simulation were all from the DYRESM sample parameter file. For a more extensive description of these values, consult the DYRESM Science Manual (Antenucci and Imerito 2002).

# 5 – Model Results

Comparisons were made between observed and simulated water surface elevation, and temperature and salinity profiles in Lake Mead for the year 2002. Observed temperature and salinity profiles were measured at the Sentinel Island monitoring site.

## 5.1 – Water-Surface Elevation

Observed water surface elevations for 2002 were taken from Allen (2003) and shown in Figure 5.1. The year 2002 is delineated to highlight the time period that was modeled. DYRESM results for water surface elevation are shown in Figure 5.2. The average elevation of Lake Mead for 1939 – 2003 is shown as a line at 357.5 meters on Figures 5.1 and 5.2 for comparison. The maximum simulated water surface elevation is 359 meters (Figure 5.1), which agrees with the highest observed water surface elevation for 2002 (Figure 5.2). At the end of the 2002 simulation, the water surface elevation is approximately 351 meters (Figure 5.1), which is also consistent with the observed water surface elevation (Figure 5.2).

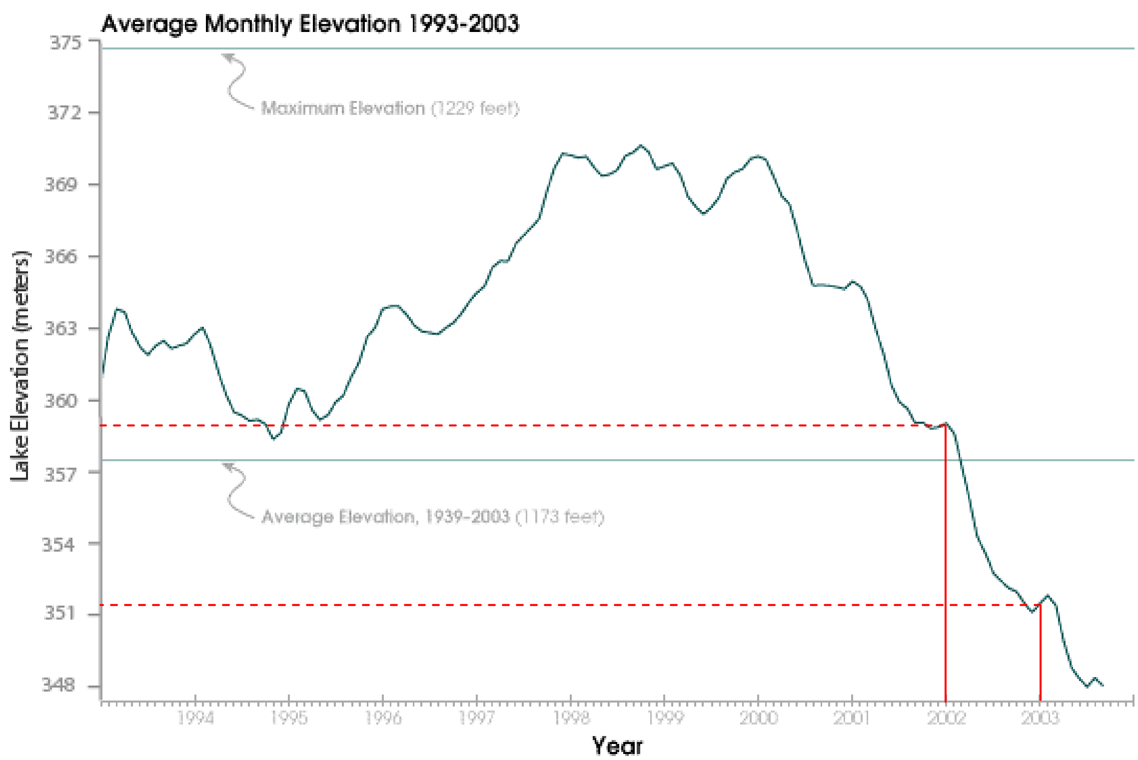


**Figure 5.1** Observed average monthly water-surface elevation (ft) from Allen (2003), with vertical scale converted to meters. The year 2002 is highlighted and to be compared with Figure 5.2.

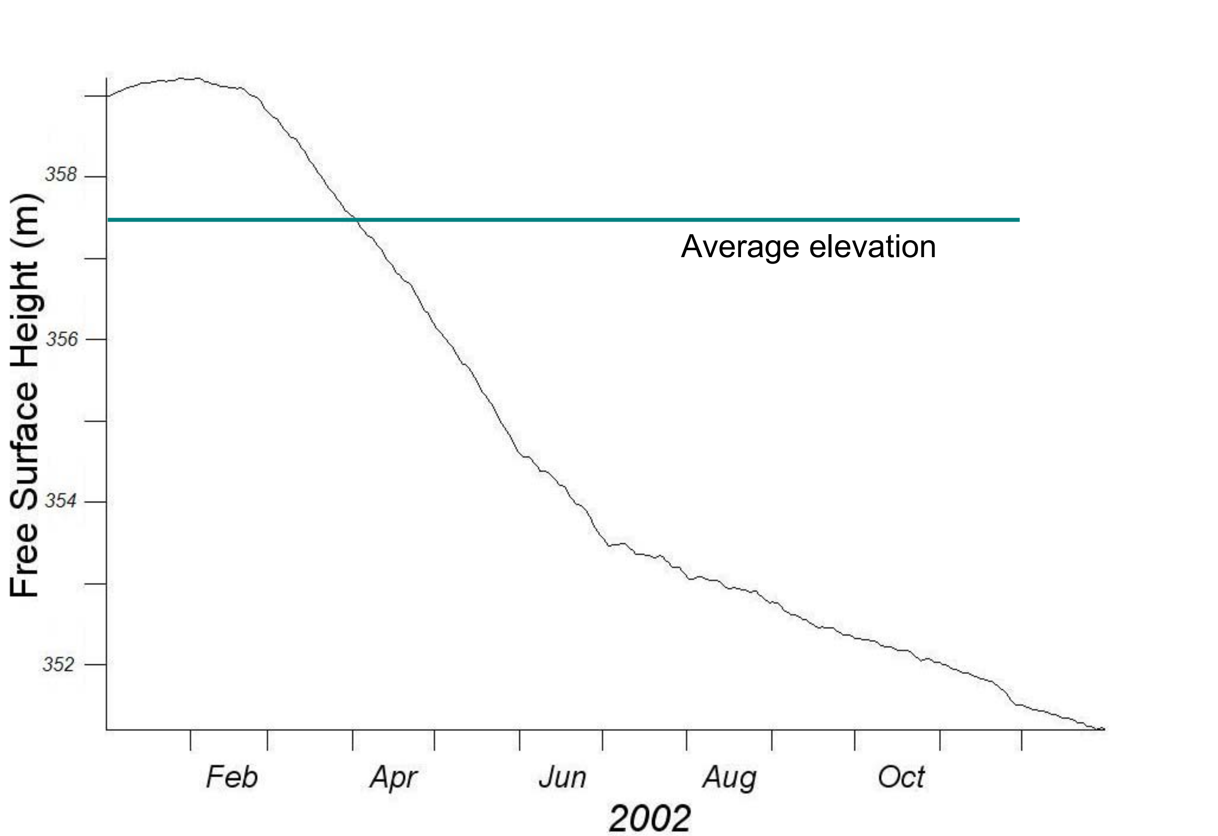


**Figure 5.2** DYRESM water-surface elevation results (m). The average elevation line shows the average for 1939 – 2003 as given in Figure 5.1.

## 5.2 – Temperature

DYRESM output includes a temperature contour map showing the changes of temperature with time and depth (Figure 5.3, top). A field data input file was also included in the DYRESM simulation so that this data could be plotted as a contour map showing changes of temperature as a function of time and depth (Figure 5.3, bottom). Qualitatively comparing these two contour plots demonstrates that the DYRESM model sufficiently simulates the stratification properties of Lake Mead. In the winter months (December through March), the lake displays isothermal conditions. There is very little vertical change in temperature. The lake transitions to a stratified lake in the spring (April through June), and is strongly stratified in the summer (July and August). In the fall (September through November), the lake transitions back to isothermal conditions. However, it is noticeable that the observed conditions are showing a deeper thermocline than that of the DYRESM results. Figure 5.4 is a graphical comparison of the difference in degrees Celsius between the simulated temperature and the observed temperature. From this plot (Figure 5.4), the maximum difference between the observed and simulated temperatures is 3 degrees Celsius. This maximum difference normally occurs near the surface where the simulation overestimates the temperature and just below the simulated thermocline where the simulation underestimates the temperature.

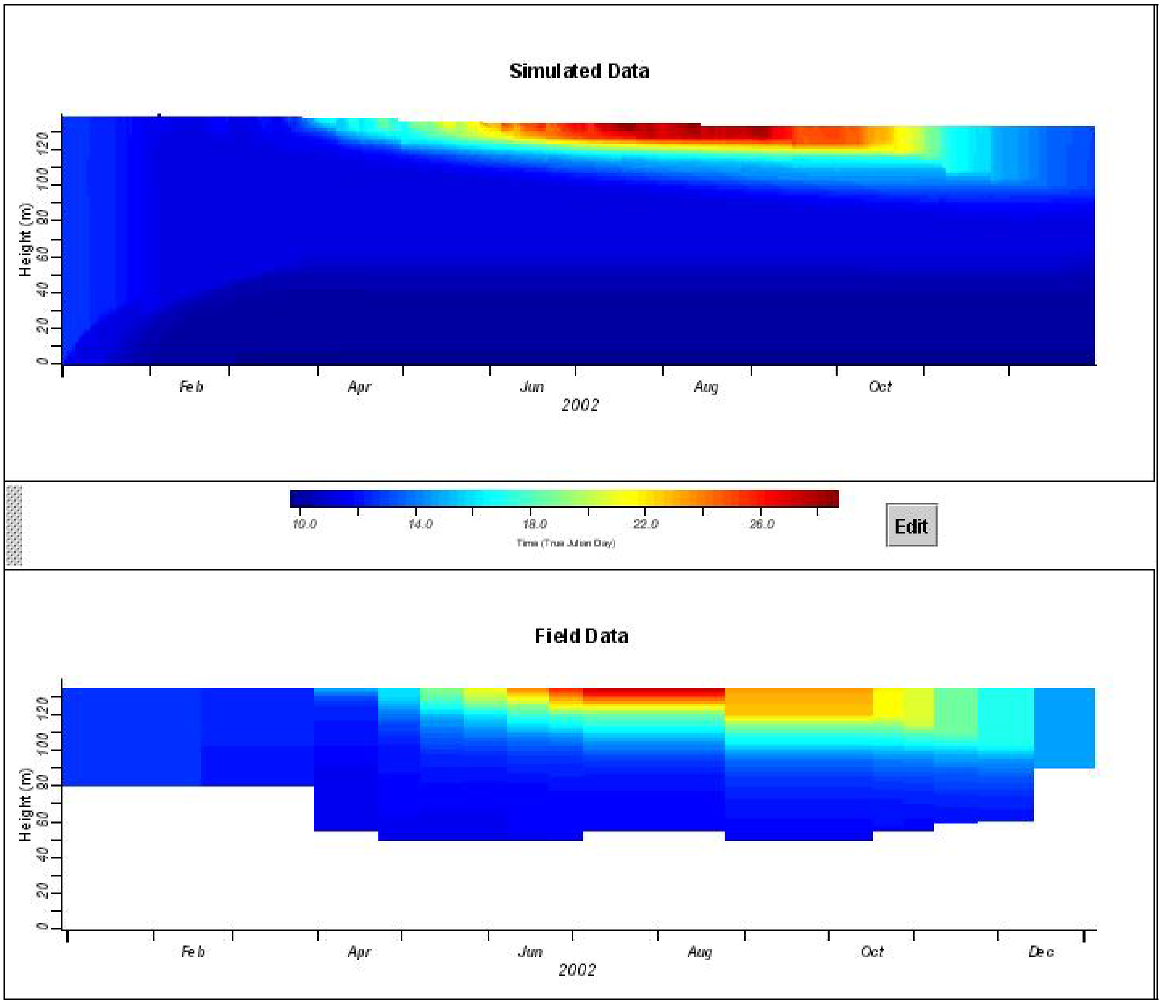


**Figure 5.3** Temperature contour plots for both simulated (top) and observed (bottom) profiles as they change with time. The contour legend bar is the same for both the top figure and the bottom figure.

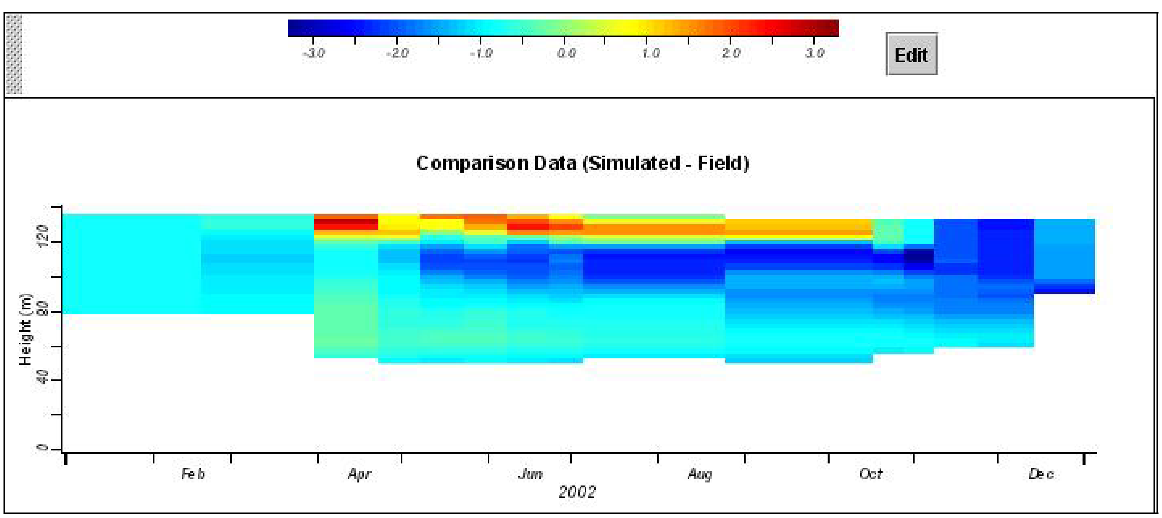


**Figure 5.4** Contour plot of the difference between the simulated and observed temperature.

Figure 5.5 is a plot of temperature profiles for specific days of the year representing winter (1/30/02), early spring (3/20/02), late spring (5/10/02), early summer (6/25/02), late summer (7/10/02) and fall (10/10/02). This plot also shows that the model simulation agrees with the progression of stratification in Lake Mead with time. However, the simulated thermocline is steeper and shallower than the simulated thermocline.

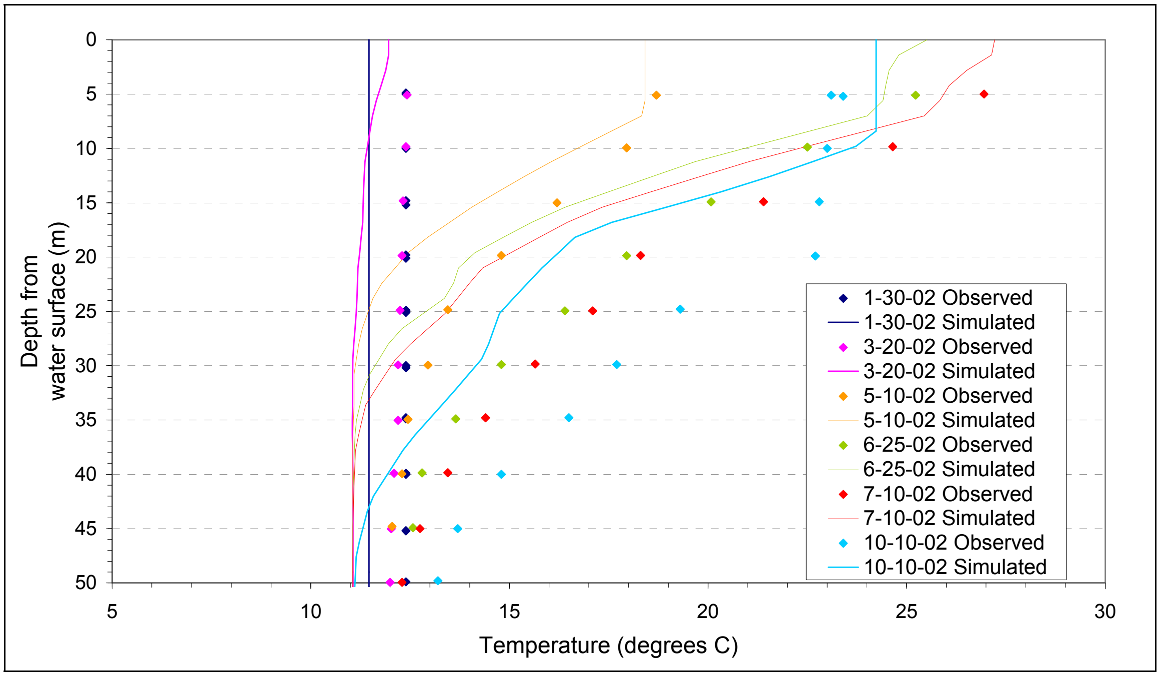


**Figure 5.5** Comparison of observed and simulated temperature profiles for specific dates.

## 5.3 – Salinity

The DYRESM model also was used to simulate salinity in Lake Mead. Figure 5.6 shows contour plots of salinity as they change with depth and time for simulated results (top) and field observations (bottom). Qualitatively, these two plots appear very different, with the simulated salinity values increasing in the summer months and the observed salinity values decreasing in the summer months. Figure 5.7 shows the differences between the simulated and observed salinity, and the maximum difference is approximately 0.2 PSU. This difference is a significant portion of the observed range of salinity values of approximately 0.3 PSU.

A closer investigation of the salinity profiles of specific days shows the obvious differences in the simulated and observed salinity values. The observed data shows increasing salinity with depth while the simulation is showing slightly decreased salinity with depth for the late spring and summer (Figure 5.8).

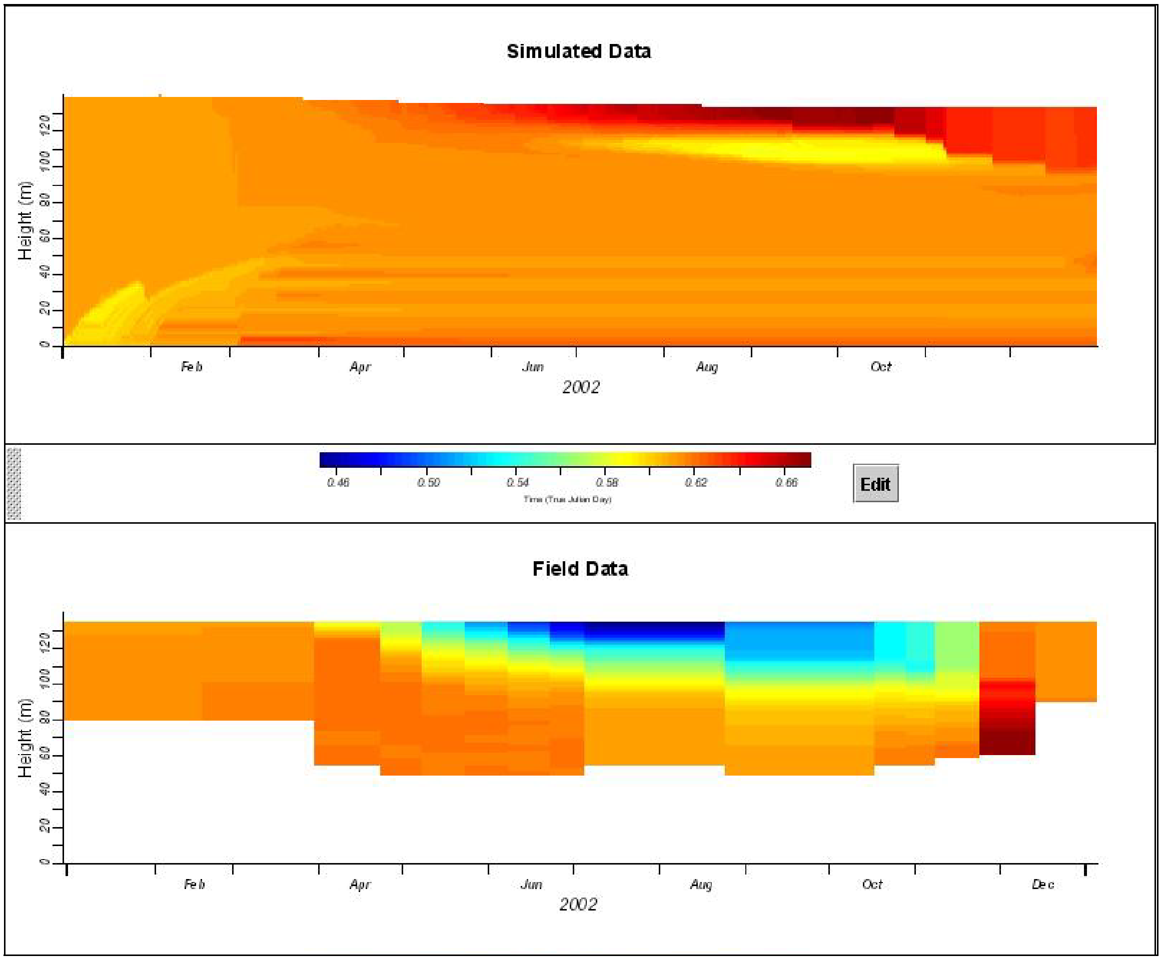


**Figure 5.6** Salinity contour plots for simulated (top) and field observations (bottom). The contour gradient scale in the center applies to both the top and bottom plots.

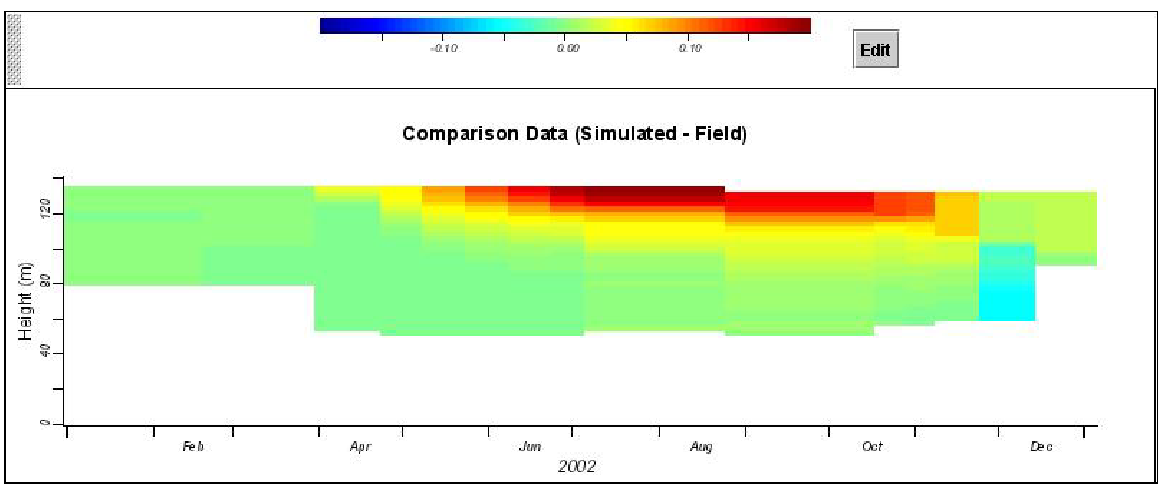


**Figure 5.7** Salinity contour plot showing the difference between the simulated and the observed values.

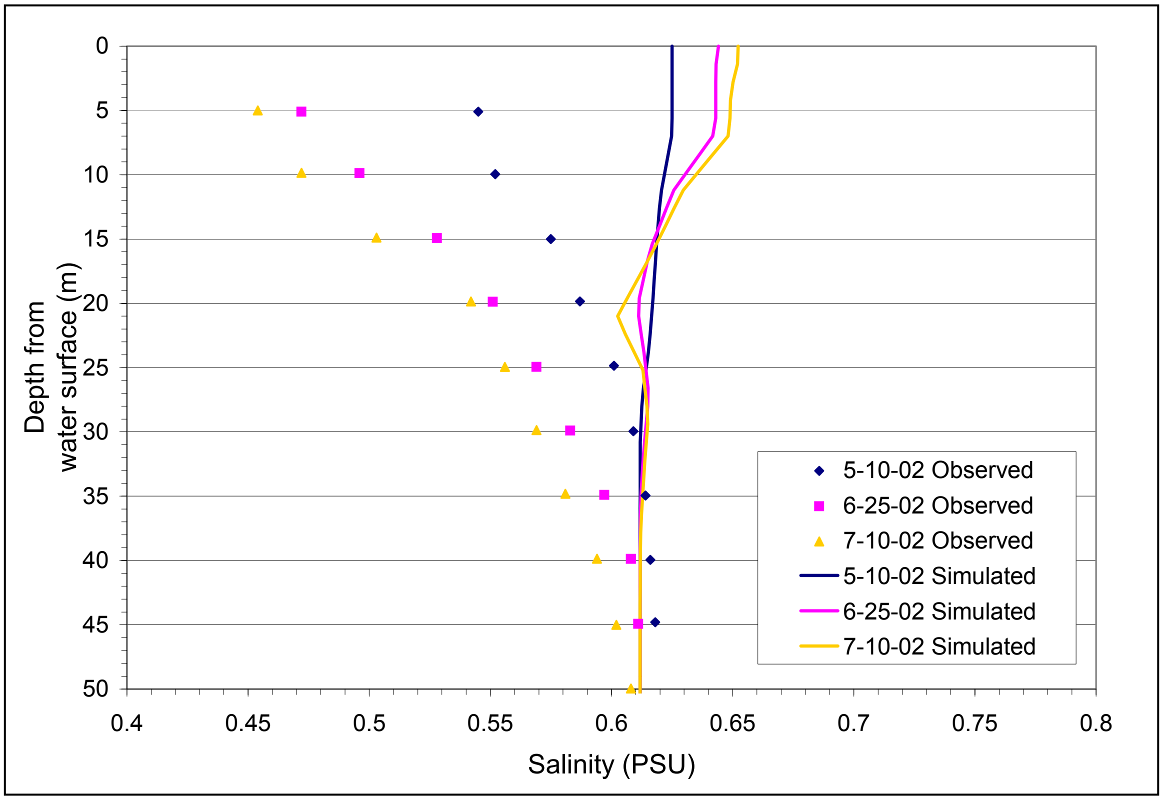


**Figure 5.8** Salinity profiles for specific days in the late spring and summer. Observed and simulated profiles are compared.

## 6 – Discussion

A major difference between the simulated and observed temperature profiles was the slope of the thermocline. The model simulation predicts a steeper, shallower thermocline as demonstrated in Figure 5.5 and Figure 6.1. Because of this difference with the thermocline, the strength of stratification was investigated. An indicator of the strength of stratification is the buoyancy frequency (*N*). Assuming a linear relationship between depth and density, this Equation (2) is as follows;

$$N = \sqrt{\frac{g}{\rho_o}\left(\frac{\Delta\rho}{H}\right)} \tag{2}$$

where $g$ is the gravitational constant, $\rho_o$ is a reference density, $\Delta\rho$ is the change in density over the layer, and $H$ is the thickness of layer (Fischer et al. 1979). The assumption of linear density change with depth was reasonable in this case because the buoyancy frequency was calculated for layers varying from 1.5 m to 10 m. The thicker layers were only used for cases where the density changed very little. The results of the strength of stratification are shown in figure 6.1 for 10/10/02. On this particular day, the strength of stratification for the simulation is slightly higher than that for the observed data. The highest value of $N$ also occurs at a depth approximately 5 to 10 m shallower for the simulation than it is for the observations. This is also the case for other specific days in 2002 (Appendix D, page 29).

Potential errors in the simulation with respect to the resulting temperature profiles could be the result of the meteorological input data or several of the standard input parameters such as the light extinction coefficient in the configuration input file and the other physical constants in the parameter input file. The recommended values for the light extinction coefficient and the other physical constants were used in the Lake Mead simulation (Antenucci and Imerito 2002). Values of these constants help determine how far radiation penetrates the lake water and how radiation is reflected. The meteorological input data was averaged for a daily time step. The original data was given in 20-minute increments (Westenburg 2005). The cloud cover data was determined from monthly average number of days that are clear, partly cloudy, and cloudy in Las Vegas, NV. The averaging and the uncertain nature of the cloud cover input data could be attributing to small errors in the temperature profile simulations.

Another potential error with respect to the resulting temperature profiles is the initial temperature profile that was specified. Observed data for the 1$^{st}$ of the year did not exist for the Sentinel Island data collection site. The initial temperature profile was taken from data collected on 1/24/02. Comparing temperature profiles gathered at this site and others in Las Vegas Bay show that the temperature at the first of the year is slightly higher than the temperature later in the month of January in other years (Water on the Web 2005). A slight increase in the initial temperature profile may also help the agreement between the observed and simulated data on 1/30/02 and 3/20/02 (Figure 5.5), where the shape of the profiles agree, but the simulated temperature is less than the observed temperature.

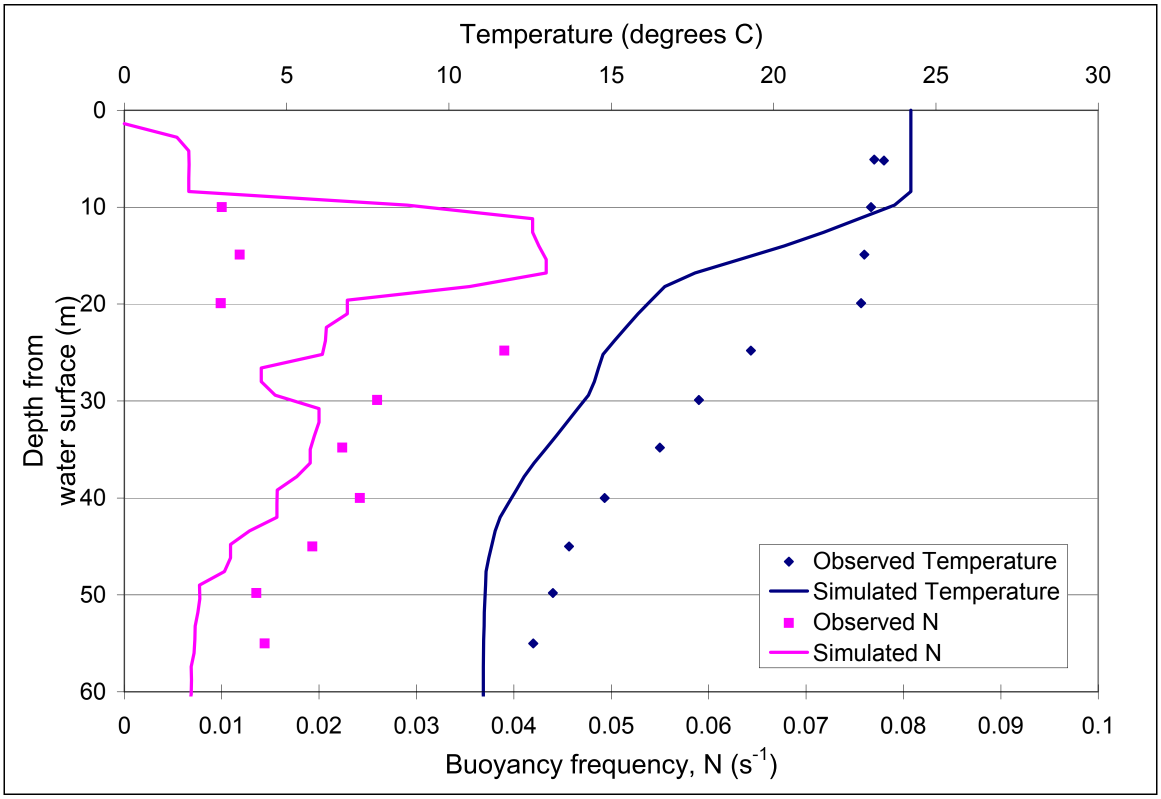


**Figure 6.1** Observed and simulated temperature profile and buoyancy frequency for 10/10/02. Buoyancy frequency is an indicator of strength of stratification.

In terms of salinity, DYRESM did not simulate the observed salinity profiles accurately (Figures 5.6, 5.7, 5.8, and 5.9). Salinity is probably the largest water quality issue facing the Colorado River basin (Hart and Hooper 2000). Therefore, it would be beneficial to have a model that could more accurately simulate the changes in salinity with depth and time. A major contributor to the error in the simulation of salinity is most likely the location of the observed data collection site compared to the location of the inflow. Initial salinity values were given as a function of depth according to the observed data. Salinity changes with time were driven by the salinity values associated with the inflow. The inflow from the Colorado River, which is 98% of the total inflow, enters Lake Mead at the western end of the reservoir. The salinity profile measurements that are used to evaluate the simulation results were taken on the eastern end of the lake at Sentinel Island (Figure 6.2). The shape of Lake Mead is complex, and there is a constriction in the lake near Boulder Canyon between the inflow source and the data measurement location in Boulder basin. DYRESM is a one-dimensional model that cannot simulate changes in the horizontal directions of the lake (Antenucci and Imerito 2002). Another lake hydrodynamics model may be more useful in the simulation of water quality parameters in Lake Mead.

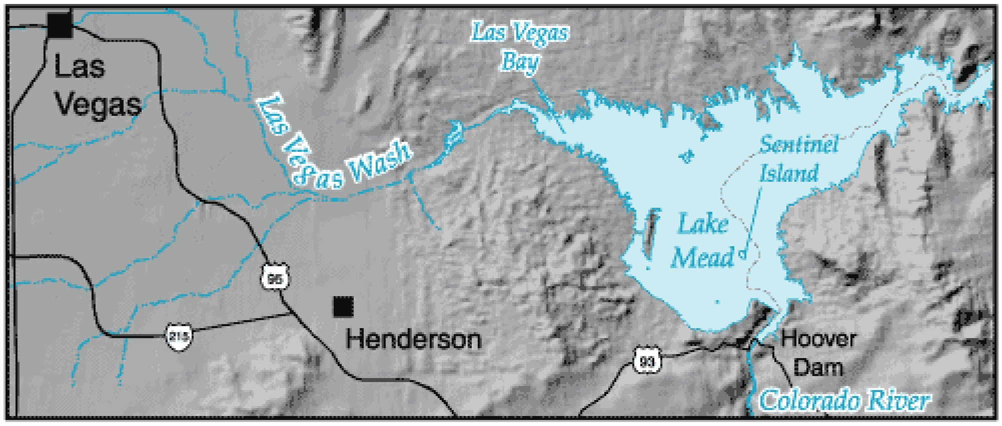

**Figure 6.2** Map of Boulder Basin of Lake Mead and the measurement location at Sentinel Island. The remaining basins of the lake (Virgin, Pierce, and Gregg basins) are to the right of this map closer to the inflow from the Colorado River. (The Colorado River shown on this map is not flowing into Lake Mead, it is carrying the outflow from Lake Mead.) Adapted from: (Water on the Web 2005).

## 7 - Conclusion

The DYRESM model was successfully applied to Lake Mead, NV. The extensive data input requirements of DYRESM were satisfied with data from a large data collection network on the lake concerned with water quality and water quantity. The results show that the model was able to accurately simulate the changes in water-surface elevation for the year 2002. The model also was able to provide a reasonable simulation of temperature changes with time and depth. While the simulated thermocline was steeper and shallower, possible adjustments to physical parameters and meteorological input data may alleviate this discrepancy. With respect to water quality parameters, such as salinity, DYRESM did not perform as well as it did for water-surface elevation and temperature. It is a one-dimensional model that cannot simulate changes in the horizontal direction. Because of the complex shape of Lake Mead, a multi-dimensional model may be better suited for modeling some water quality parameters. This is especially true for parameters that are driven by inflow characteristics. In the case of Lake Mead, DYRESM performs better for simulating lake properties that are dependent mainly on the meteorological data, such as water-surface elevation and temperature, rather than for simulating lake properties that are dependent on inflow characteristics, such as salinity.

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## **Appendix A –** Lake Mead August Elevation 1939-2003

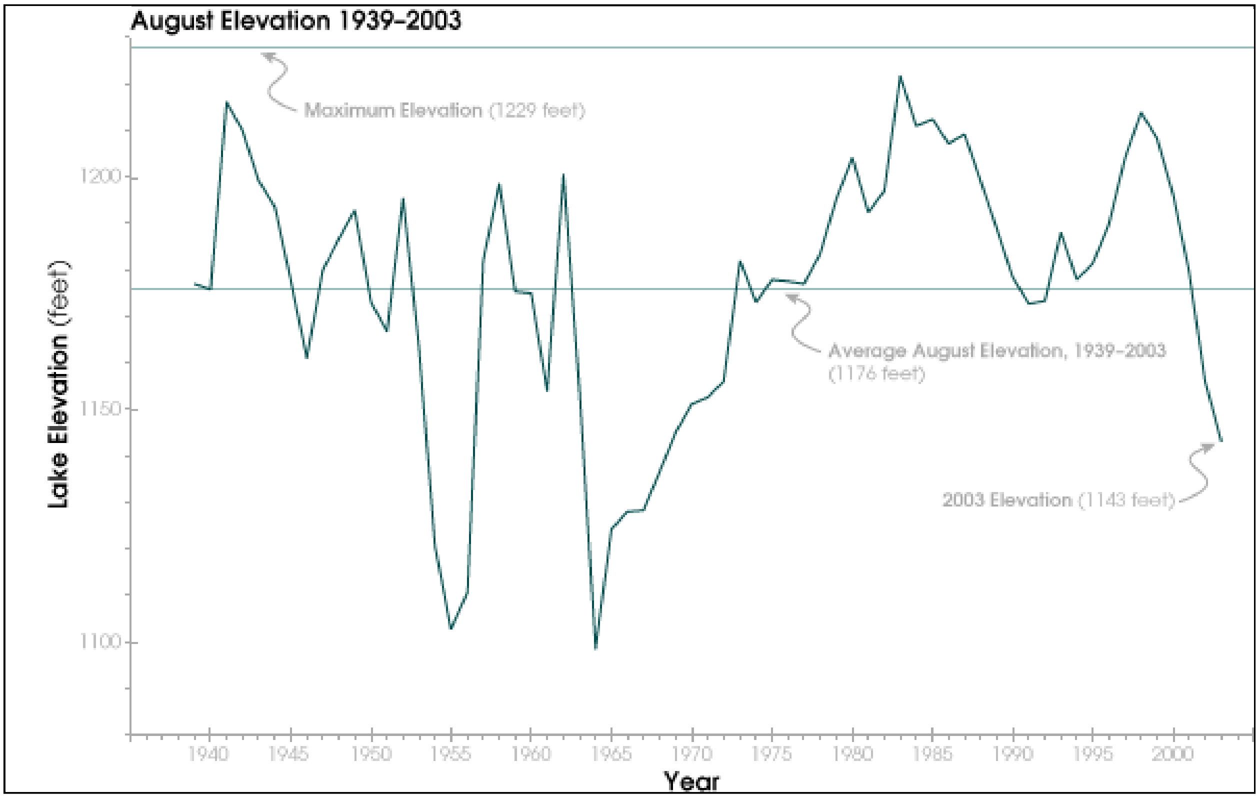


**Figure A1** Elevation variation from 1939-2003 in the month of August (Allen 2003).

## **Appendix B –** Lake Mead Satellite Photos

**Figure B1** Lake Mead: May 3, 2000 (Courtesy of Landsat 7)

**Figure B2** Lake Mead: May 28, 2003 (Courtesy of the Terra satellite)

## **Appendix C** – Matlab code for DEM analysis

```
m-code:

load mead.mat;

% min el=220m
% max depth=170m
% Divide depth in 17 bands of 10m each
% surface area of the layer is taken for different depths
% grid size is 30.89m
% nrows=3574
% ncols=4378

h=[10:10:180];
min_el=220;

sarea=zeros(1,17);
vol=zeros(1,17);

for i=1:17
    count=0;
    count1=0;
    for j=1:3574
        for k=1:4378
            if mead(j,k)<(min_el+h(1,i))
                count1=count1+((min_el+h(1,i))-mead(j,k));
                count=count+1;
            end
        end
    end
    sarea(1,i)=count*30.89*30.89;
    vol(1,i)=count1*30.89*30.89;
end
```

**Appendix D** – Daily Profiles and Stratifications

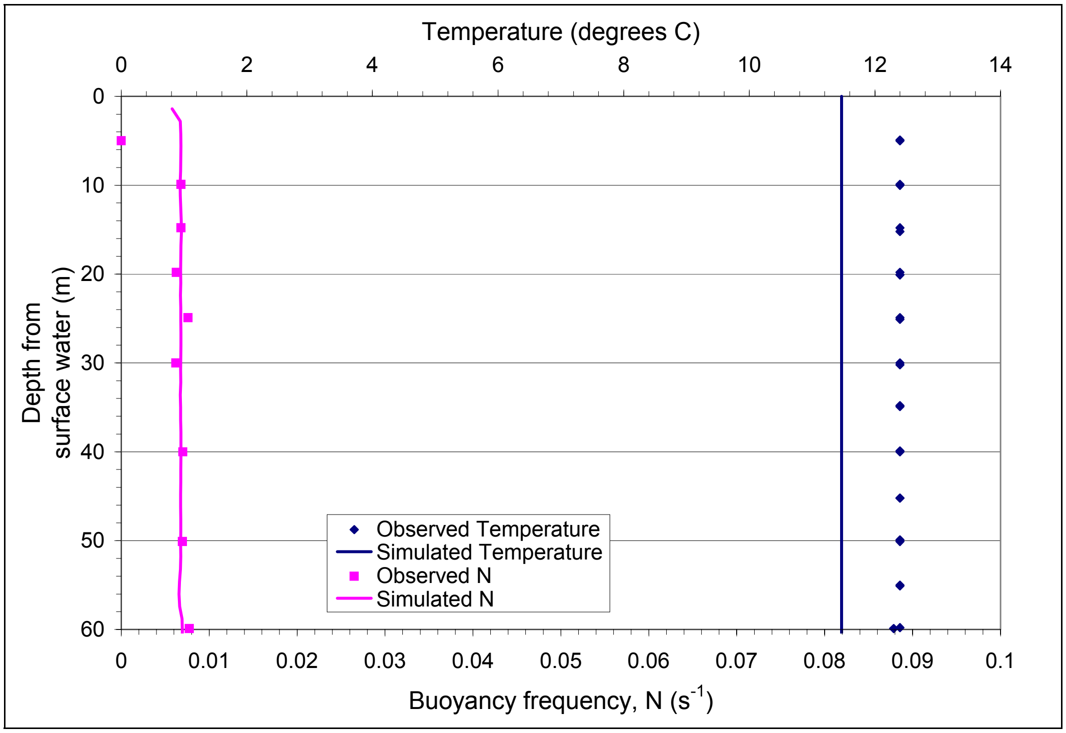


**Figure D1** Temperature profiles and strength of stratification (buoyancy frequency) for 1/30/02.

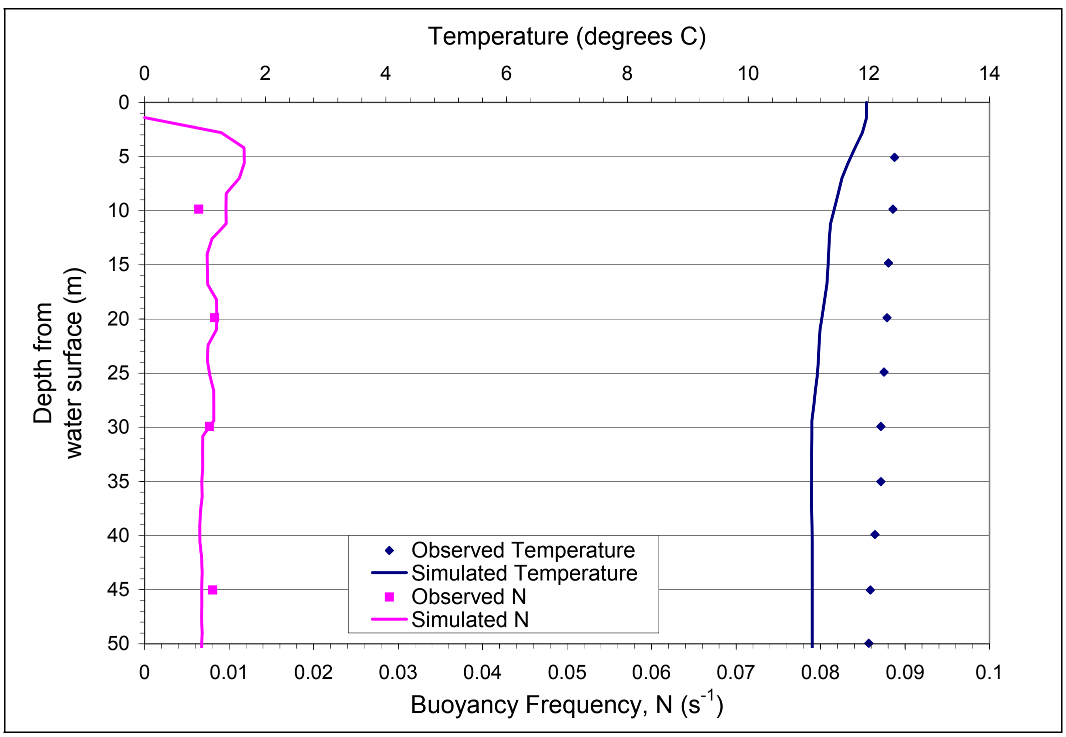


**Figure D2** Temperature profiles and strength of stratification (buoyancy frequency) for 3/20/02.

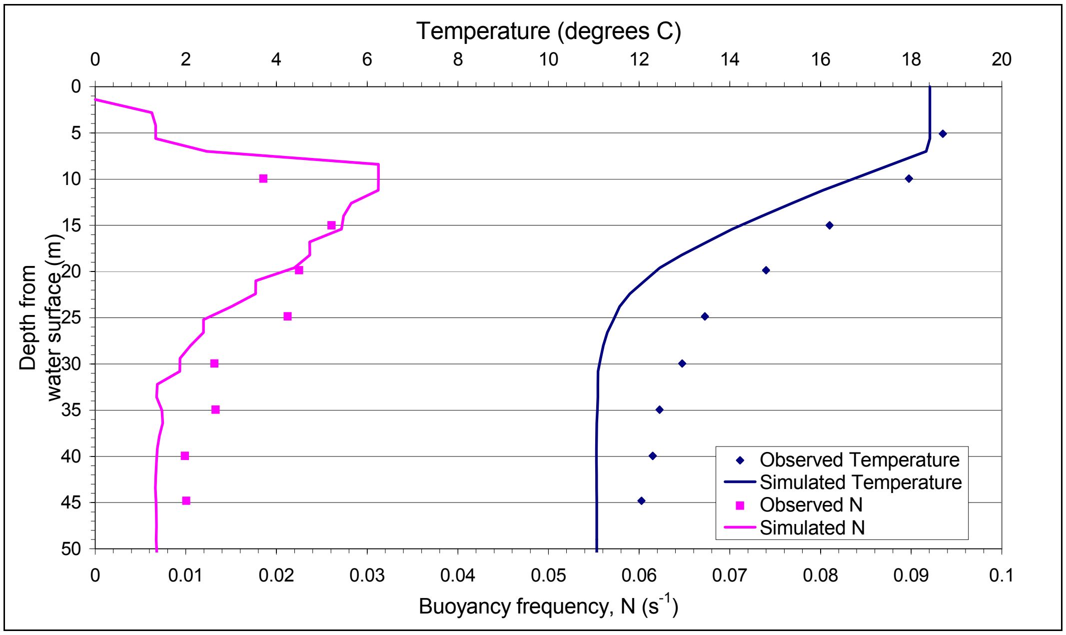


**Figure D3** Temperature profiles and strength of stratification (buoyancy frequency) for 5/10/02.

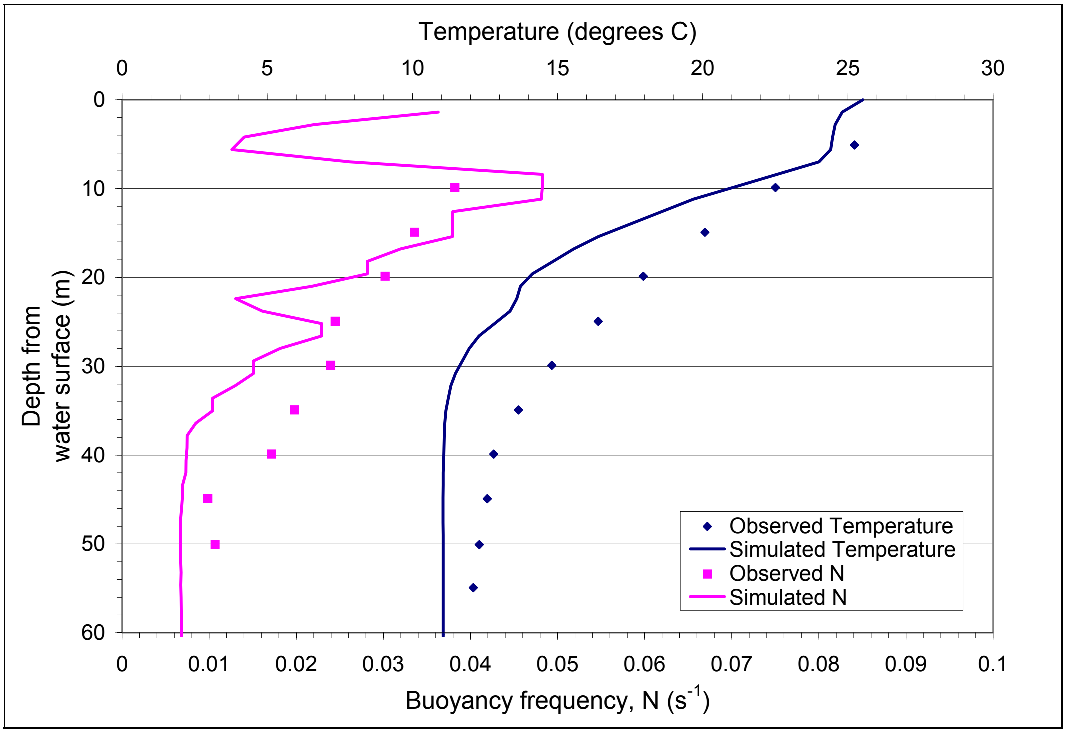


**Figure D4** Temperature profiles and strength of stratification (buoyancy frequency) for 6/25/02.

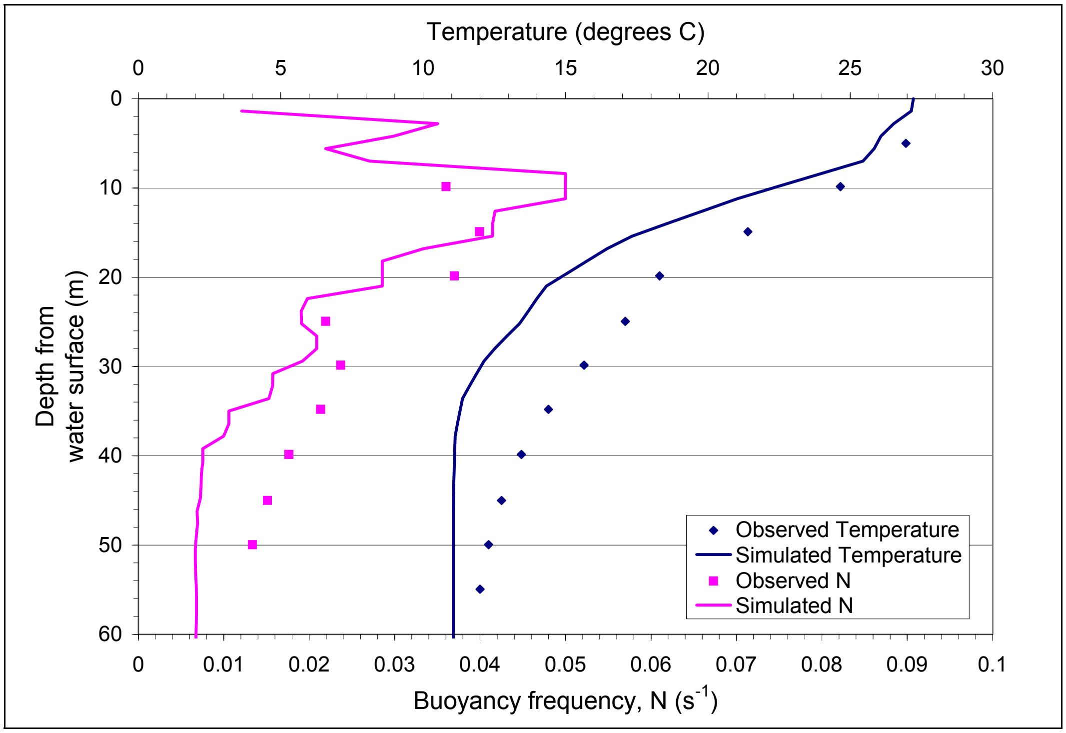


**Figure D5** Temperature profiles and strength of stratification (buoyancy frequency) for 7/10/02.