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EAS 550/STRATEGY 566: Systems Thinking for Sustainable Development
Lab 5 The Mono Lake

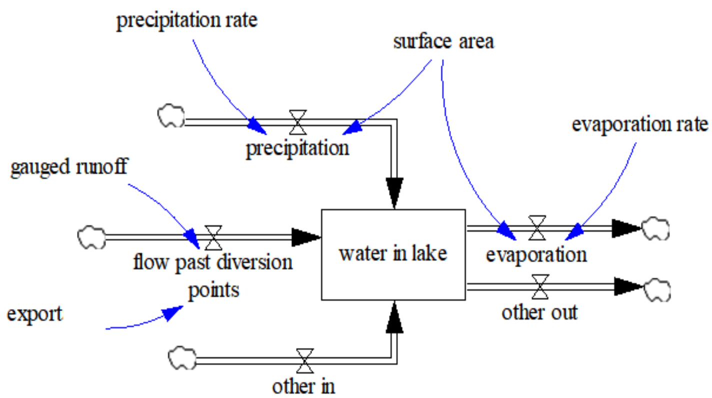
References:
- *Chapter 5, Ford, Modeling the Environment*
- *A water balance forecast model for Mono Lake, California, by Peter Vorster, 1985, http://www.monobasinresearch.org/onlinereports/waterbalance.php*

Mono Lake One:

Instructions: Develop the **First Model of Mono Lake** using the parameters provided below and save the model as "monolake 1".

(**SETTINGS:** Set start time = 1990; end time = 2040; time step = 0.125; Units for Time = Year; integration type = Euler)

a. **Step One:** Create the stock and flow diagram, see structure below:



i. TIPS:
1. Always start with the **stock**
2. Identify the inflows and outflows for the stock
3. Identify the variables that affect the inflows and outflows

   Flow past diversion point = gauged runoff – export
   Precipitation = precipitation rate × surface area
   Evaporation = evaporation rate × surface area

b. **Step Two:** Add in the parameters that we know:

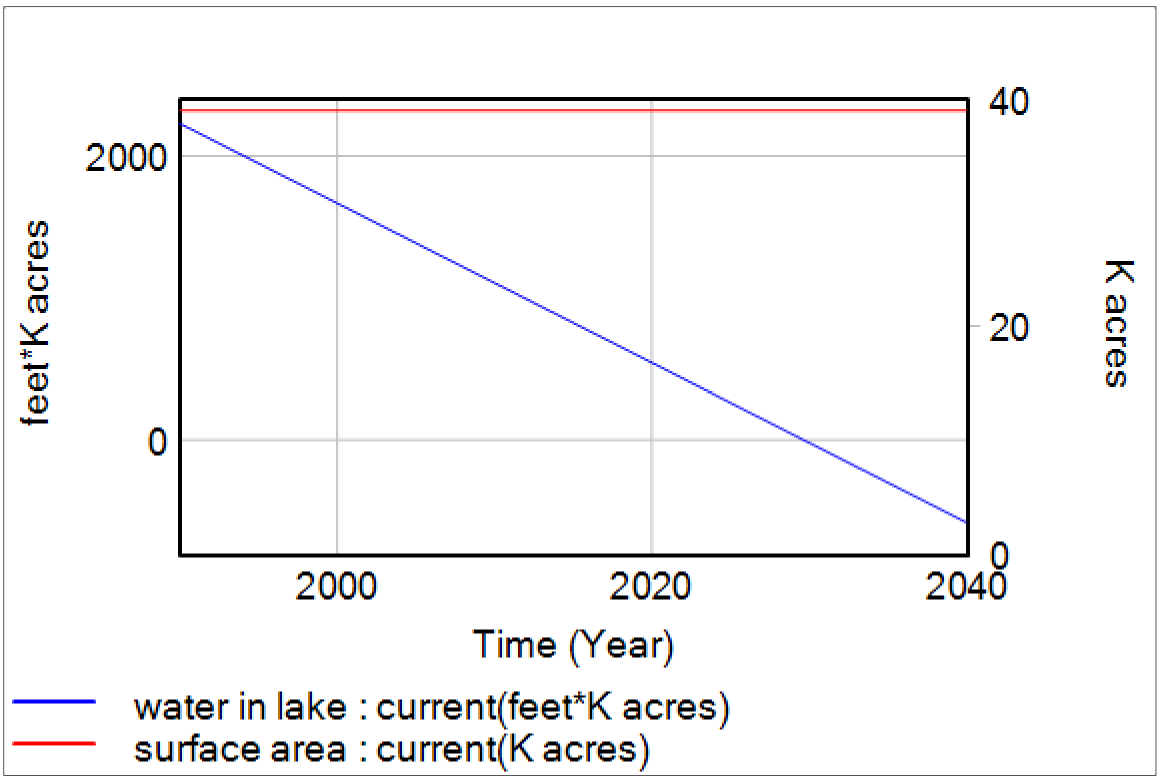
Parameter	*Value*
Initial water in lake	2,228 KAF
Gauged runoff	150 KAF/yr
Export	100 KAF/yr
Other in	47.6 KAF/yr
Other out	33.6 KAF/yr
Precipitation rate	0.67 feet/yr
Evaporation rate	3.75 feet/yr
Surface area	39 K acres

Note: "KAF" is read as "thousands of acre-feet," and can be written as K acres*feet in Vensim. Be careful with your units, make sure to write everything the same.

Name: Chia Wen CHENG

1) **Step Two: Simulate your model**. After the simulation, create a graph of **water in lake** and **surface area** using the **Custom Graph Editor**.
   a. ***Process***:
      i. Go to **Windows** → **Control Panel** → **Graphs**. Click on **New…** button on the bottom. In the pop-up window, use the **Name** box to give a name to your graph.
      ii. **X-Axis** specifies the variable to be used on the X-axis. For this graph, leave the X-Axis box blank, as it will automatically use Time.
      iii. The bottom half is the scaling control that allows you to select the variables that you want to display in your figure and specify their units and Y-axis ranges. Add **water in lake** and **surface area** as the two variables in your graph. Specify their units and range (Y-axis range for water in lake: -800 to 2400; Y-axis range for surface area: 0 to 40). Save and insert your graph below.

QUESTION 1: Insert finished graph here.



Name: Chia Wen CHENG

Mono Lake Two:

2) Develop the **Second Model of Mono Lake** using new information provided below and save the model as “monolake 2” (**New Settings:** Set start time = 1990; **end time = 2090**; time step = 0.125 year; integration type = Euler). You can go to **Model** → **Settings** to adjust the time boundary.

   Note: to avoid recreating your model from scratch, you can click in the top left corner of your first model, drag the mouse so that the model fits in the box you're creating (it will turn black when you let go of the mouse), copy the model by pressing CTRL+C, and pasting the model once you have created a new model in Vensim by pressing CTRL+V. Alternatively, you can save the first model and then “save as” model 2, or create a copy in Files.

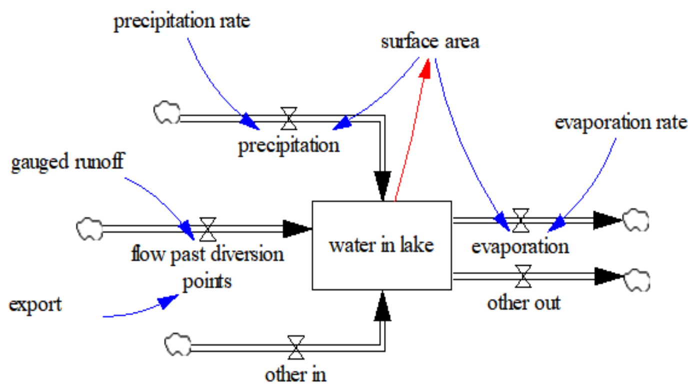
Information you will use:

a. *Data:* Surface area changes with the volume of water in the lake

Volume of water (KAF)	*Surface area (K acres)*
0	0.0
1000	24.7
2000	35.3
3000	48.6
4000	54.3
5000	57.2
6000	61.6
7000	66.0
8000	69.8

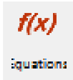
Adapted from Vorster, 1985

b. *Structure:* Change the stock and flow diagram above to reflect this new correlation

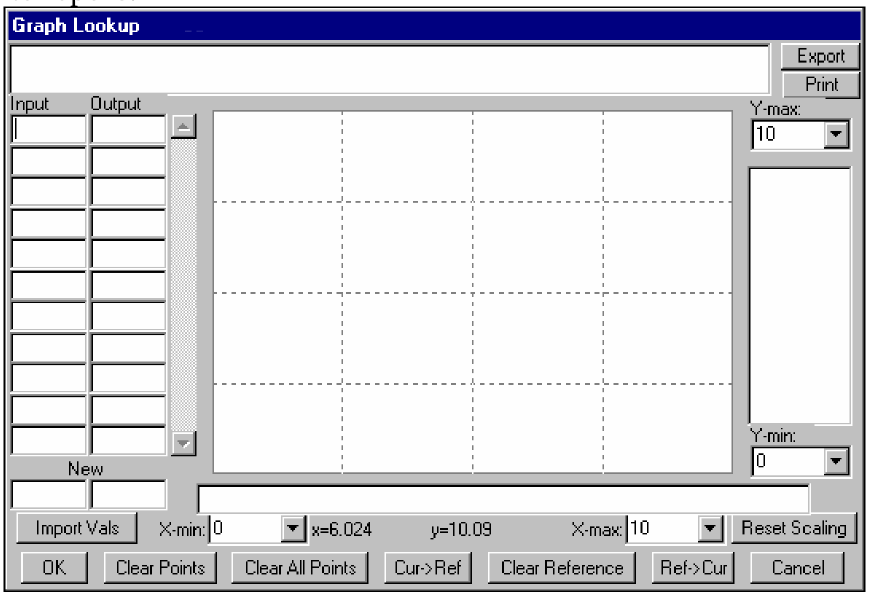


Name: Chia Wen CHENG

Process:

3) After you finished drawing the new structure of the model (above), click on the 

button in the sketch tool bar, and then click **surface area**. Next, we are going to use the lookup function in Vensim PLE. Under the **Type** label, choose **Auxiliary** from the drop down menu. Under the **Sub-Type** label, choose **with Lookup**. Then hit **As Graph**. The following Graph Lookup Editor opens:

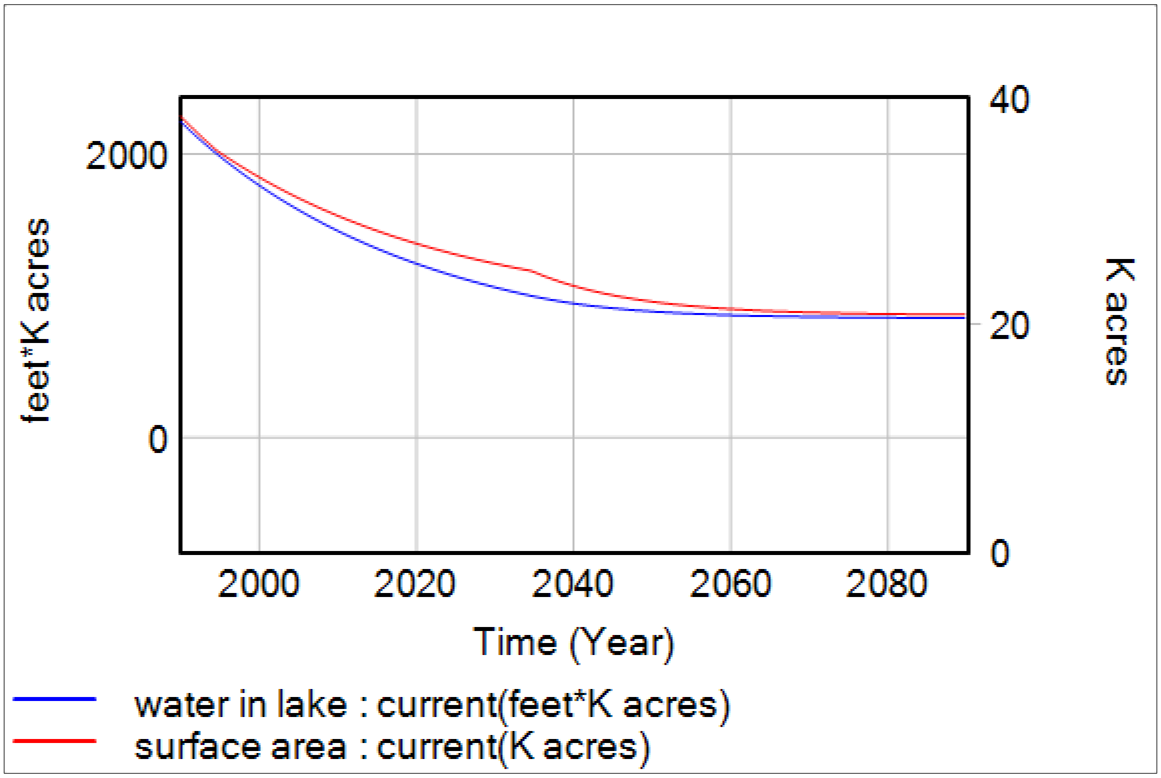


4) Your **surface area** is determined by **water in lake**. Hence, **water in lake** is your input, and **surface area** is your output. Click on the left-hand **Input** box in the first line and type in 0 then press the **Enter** key. The cursor moves to the right-hand **Output** box; type 0 and press **Enter** again. The cursor moves to the **Input** box next line, type 1000 and press **Enter**. Then type 24.7 and press **Enter** again. Continue typing in the rest of the pairs of values above, pressing the Enter key each time a value is typed. The graph will draw itself.

5) When you finish inputting all the values provided above, click **OK**, and an array of numbers will show up in the **Lookup** box. In the Equation box, choose **water in lake** from variables. Then click **OK**. Simulate your model and make the same graph as you did for the First Model.

QUESTION 2: Insert finished graph here.

Name: Chia Wen CHENG



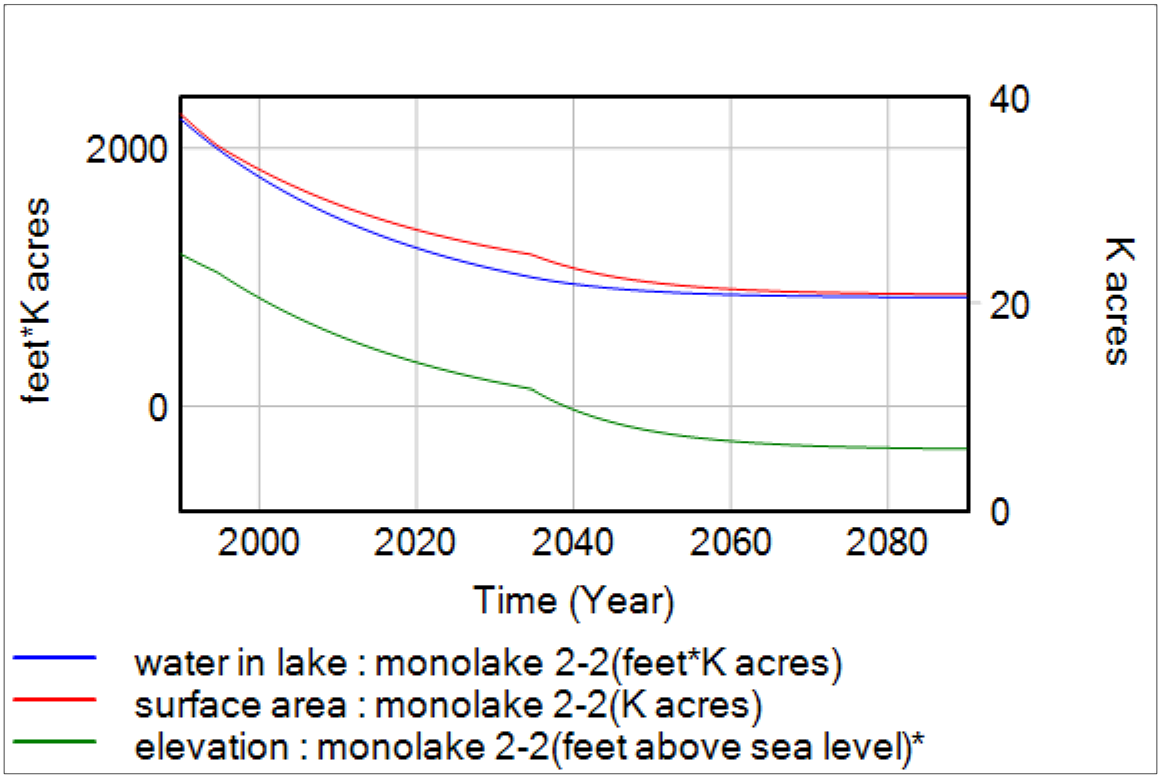
Name: Chia Wen CHENG

6) Lake elevation (water level) is another important indicator of the lake health. Studies have found that when the water level is below 6,352 feet, the whole Mono Lake ecosystem will demise. The relationship between lake elevation and volume of water is provided in the following table. **Add elevation as a variable to your model and draw an arrow from water in lake to elevation.** Then enter the relationship using the same process as 4.

Volume of water (KAF)	*Elevation (feet above sea level)*
0	6224
1000	6335
2000	6369
3000	6392
4000	6412
5000	6430
6000	6447
7000	6463
8000	6477

a. Simulate your model and make a graph with three lines and insert below: one line representing water in lake, one line representing surface area, and one line representing elevation (Y-axis range for water in lake: -800 to 2400; Y-axis range for surface area: 0 to 40; Y-axis range for elevation: 6300 to 6420).

QUESTION 3: Insert finished graph here.



Name: Chia Wen CHENG

QUESTION 4: In which year will the elevation be below 6352 feet? Find your answer using the "**Table Time Down**" tool (on vertical toolbar on the left-hand side).

At the middle of year 2008, the elevation will be exactly at 6352 feet above sea level. So starting from year 2008.625 (because we set time step to 0.125 year), we will have data recorded an elevation below 6352 feet above sea level.

Time (Year)	ation : monolake	elevation : curren
2008	6352.49	
2008.12	6352.36	
2008.25	6352.24	
2008.38	6352.12	
2008.5	6352	
2008.62	6351.88	
2008.75	6351.76	
2008.88	6351.64	
2009	6351.52	

Name: Chia Wen CHENG

Mono Lake Three:

7) Develop the **Third Model of Mono Lake** using the parameters provided below. Provide a figure showing the trends of water in lake, elevation, specific gravity, and surface area. Choose the appropriate scales for each variable. See structure below in (e).

   (**SETTINGS:** Set start time = 1990; end time = **2090**; time step = 0.125 year; integration type = Euler)

   a. One more missing factor
      i. When the water in Mono Lake becomes denser, the rate of evaporation becomes slower.
      ii. Reduction in the vapor causes a pressure difference between the surface of the water and the overlying air
      iii. A fixed amount of dissolved solids held in solution when the volume of water is shrinking

   b. *Data:* Previous evaporation study

Specific gravity	*Effect on the evaporation rate*
1.00	1.000
1.05	0.963
1.10	0.926
1.15	0.880
1.20	0.833
1.25	0.785
1.30	0.737
1.35	0.688
1.40	0.640

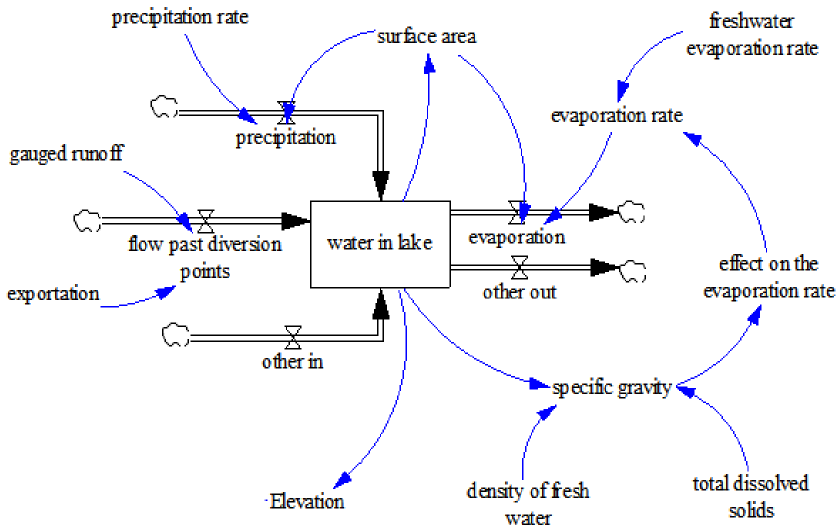
Adapted from Vorster, 1985

   c. Evaporation:
      i. Evaporation rate = freshwater evaporation rate × effect on the evaporation rate
      ii. Freshwater evaporation rate = 3.75 ft/yr

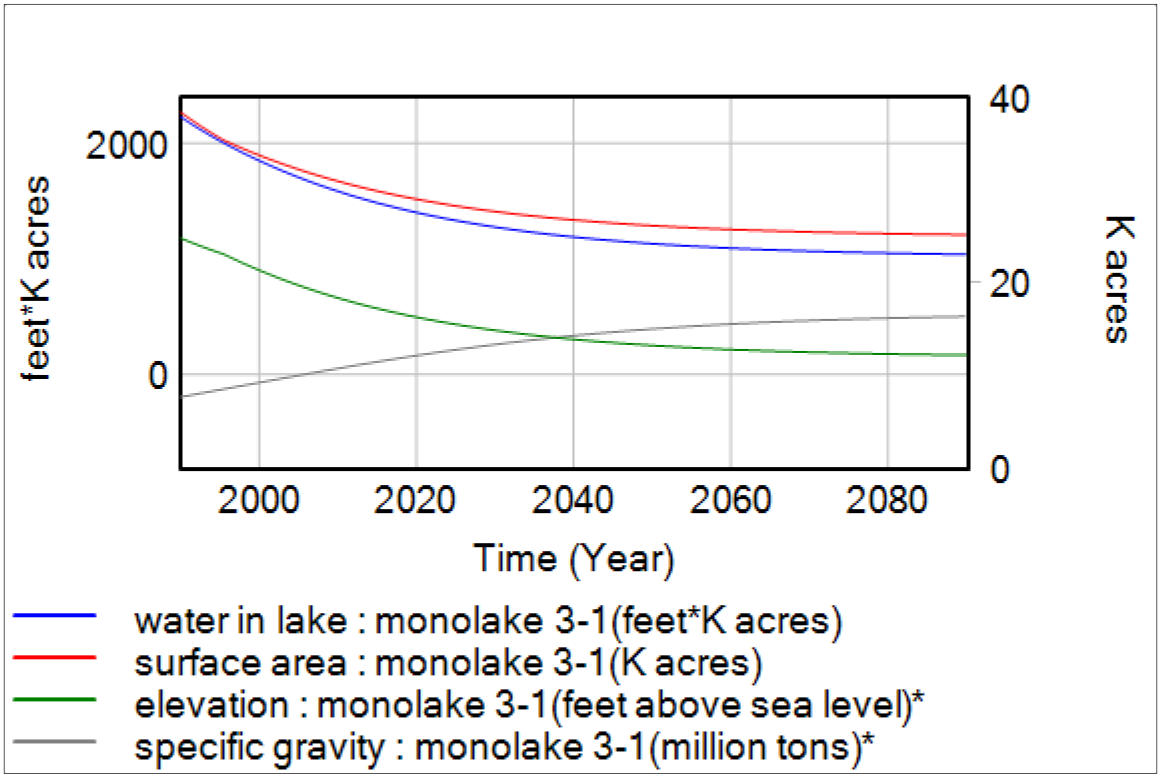
   d. Specific gravity: A measure of water density (e.g., 1.1 means the lake water is 10% heavier than freshwater)
      i. Specific gravity $= \frac{\text{water in lake} \times \text{density of fresh water} + \text{total dissolved solids}}{\text{water in lake} \times \text{density of fresh water}}$
      ii. Density of fresh water = 1.359 million tons/KAF
      iii. Total dissolved solids = 230 million tons

Name: Chia Wen CHENG

e. *Structure:* Change the model to include this missing factor.



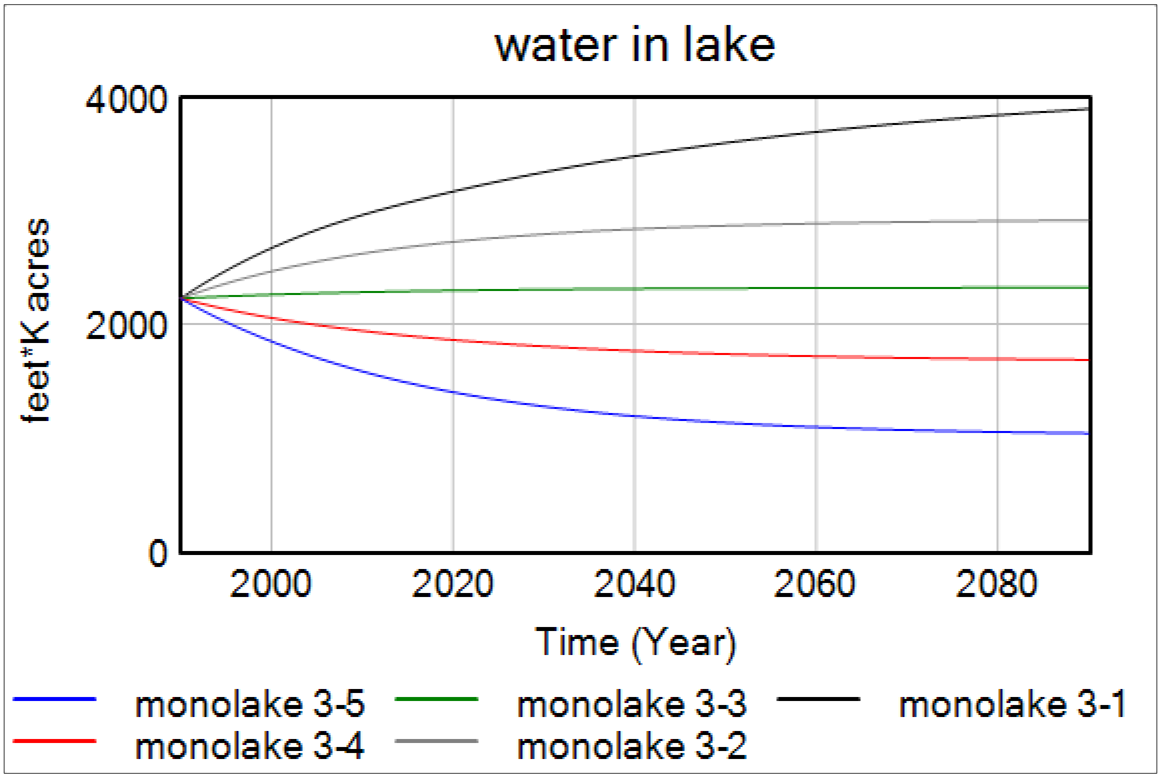
QUESTION 5: Create a graph similar to Q3 that includes water in lake, elevation, specific gravity (Y-axis range is 1 to 1.4), and surface area. Insert the finished graph here.



f. **Sensitivity analysis:** Run five simulations with export set to 0, 25, 50, 75, and 100 KAF/yr.

QUESTION 6: Show the five trends of **water in lake** in one graph so we can compare them.

Name: Chia Wen CHENG



QUESTION 7: If we want the lake water to increase, which range should the export be?

The amount of the water in lake remains almost the same when variable "export" is set to 50 KAF/year. With a smaller value in "export," the amount of the water in lake will increase as time goes on; contrarily, a greater value of "export" will result in the decrease in the amount of the water in lake. Thus, values of the variable "export" lower than 50 KAF/year is helpful in achieving our goal of increasing the amount of the lake water.

8) **Test the policy of implementing a ban on export in 2040**. Assume export = 100 KAF/yr before 2040. Use the PULSE function creatively to implement a ban on export in 2040.

QUESTION 8: What will be the equilibrium water elevation?

For the formula for variable "export," I found it may work when it is:

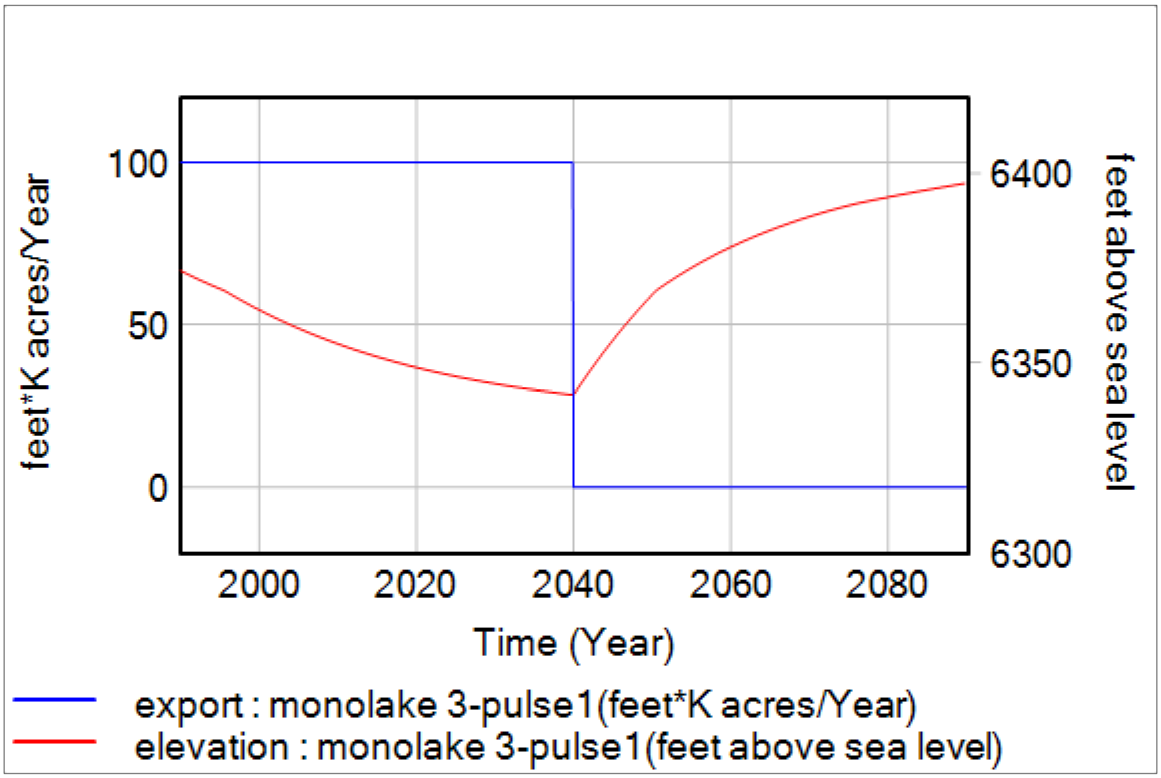
$$\mathbf{100 * \mathit{PULSE}(1990, 50) + 0 * \mathit{PULSE}(2040, 50)}$$

The equation means that the value of "export" is 100 KAF/Year from year 1990 to 2040, and then drops to 0 from year 2040 to 2090.
The equilibrium water elevation is approximately 6397 (or 6397.39) feet above sea level as of year 2090. The decrease has become smaller although it is still reducing a low volume of water yearly.

Name: Chia Wen CHENG

Time (Year)	elevation : monolake 3-q89
2089.12	6397.09
2089.25	6397.13
2089.38	6397.17
2089.5	6397.22
2089.62	6397.26
2089.75	6397.3
2089.88	6397.34
2090	6397.39

QUESTION 9: Provide a graph showing the change of export *and* elevation below.



QUESTION 10: What if we implement the ban in year 2000, and the duration of the ban is 10 years (i.e. after the 10 years, the export returns to 100 KAF/yr immediately)? Include the new graph of export and elevation and describe if/how the equilibrium water elevation changed.

I set the "export" to $[-20, 120]$ so it is easier to read the graph. In addition, the equation for "export" is:

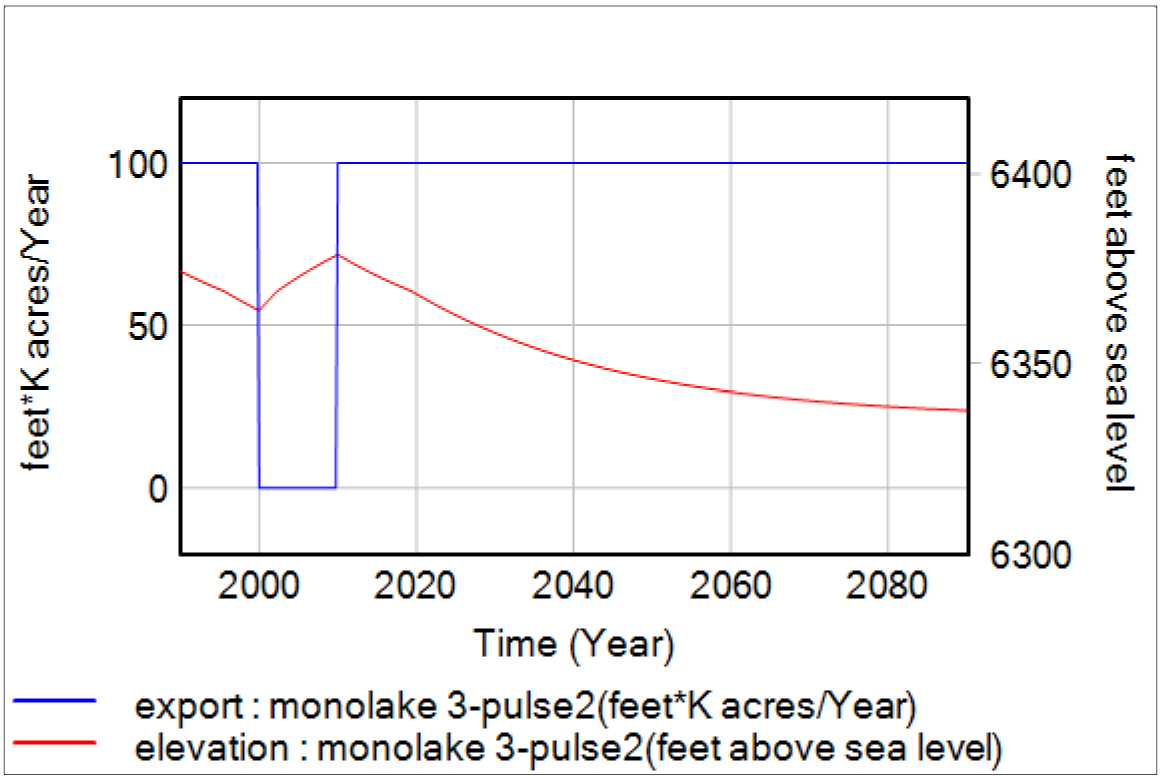
$$100 * PULSE(1990, 10) + 0 * PULSE(2000, 10) + 100 * PULSE(2010, 90)$$

Before the export is banned in 2000, level of elevation decreases gradually. In year 2000, when export is banned, the elevation increases and the level exceeds 1990's elevation level. In year 2010, when the export returns to 100 KAF/year, elevation again decreases yearly. The equilibrium water elevation is approximately 6337 (or 6337.6) feet above sea level as of

Name: Chia Wen CHENG

year 2090. The decrease has become smaller although it is still reducing a low volume of water yearly.

Time (Year)	tion : monolake
2089.12	6337.67
2089.25	6337.66
2089.38	6337.65
2089.5	6337.64
2089.62	6337.63
2089.75	6337.62
2089.88	6337.61
2090	6337.6



9) **Test the buffer policy proposed by the Mono Lake Committee**: if the elevation is 6,380 ft. or lower, no export is allowed. If the elevation is 6,390 ft. or higher, 100 KAF/yr is allowed. If the elevation is within the buffer zone, the export changes in a linear manner (0 KAF/yr at 6,380 ft, 50 KAF/yr at 6,385 ft, and 100 KAF/yr at 6,390 ft.).

QUESTION 11: What will be the equilibrium water elevation and export amount? Also provide a graph showing the change of export and elevation below. *Hint:* consider designing a graphical function.

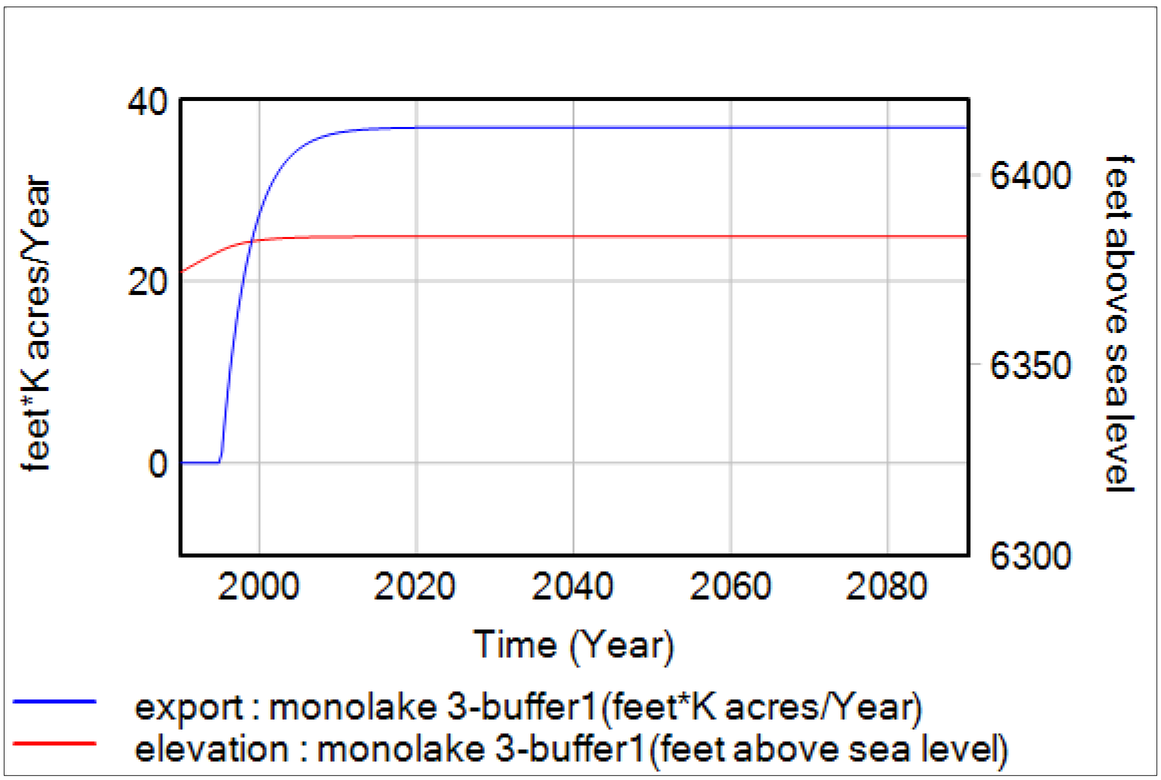
I added a connection from “elevation” to “export.” The equation I used for “export” is:

Name: Chia Wen CHENG

$$\boldsymbol{IF\ THEN\ ELSE(elevation\ <=\ 6380, 0, IF\ THEN\ ELSE(elevation\ >=\ 6390, 100, -63800 + (10 * elevation)\,)\,)}$$

The equilibrium amounts for water elevation and export are 6383.69 feet above sea level and 36.9061 KAF/year respectively.

Time (Year)	elevation : monolake 3-buffer1	export : monolake 3-buffer1
2089.12	6383.69	36.9061
2089.25	6383.69	36.9061
2089.38	6383.69	36.9061
2089.5	6383.69	36.9061
2089.62	6383.69	36.9061
2089.75	6383.69	36.9061
2089.88	6383.69	36.9061
2090	6383.69	36.9061



10) **Test the policy issued by the California Water Resources Control Board**.

- No export allowed until the elevation reaches 6,376 ft.
- At 6,377 ft. exports are 4.5 KAF/yr until elevation reaches 6,384 ft.
- At 6,385 ft. exports are then 16.5 KAF/yr until the elevation reaches 6,389 ft.
- Exports are 30.8 KAF/yr at elevation of and beyond 6,390 ft.

Name: Chia Wen CHENG

QUESTION 12: What will be the equilibrium water elevation and export amount? Also provide a graph showing the change of export and elevation below.

I added a connection from "elevation" to "export." The equation I used for "export" is:

$$\boldsymbol{With\ LOOKUP(IF\ THEN\ ELSE(elevation < 6376, 0, elevation))}$$

The LOOKUP function is:

$([(\mathbf{0},\mathbf{0}) - (\mathbf{10},\mathbf{10})], (\mathbf{6375},\mathbf{0}), (\mathbf{6375.9},\mathbf{0}), (\mathbf{6377},\mathbf{4.5}), (\mathbf{6384},\mathbf{4.5}), (\mathbf{6385},\mathbf{16.5}), (\mathbf{6389},\mathbf{16.5}), (\mathbf{6390},\mathbf{30.8}))$

(Lookup function is used because there are non-linear relationships in this model.)

The equilibrium amounts for water elevation and export are 6389.67 feet above sea level and 26.1136 KAF/year respectively.

Time (Year)	elevation : monolake 3-California 1	export : monolake 3-California 1
2089.12	6389.67	26.1136
2089.25	6389.67	26.1136
2089.38	6389.67	26.1136
2089.5	6389.67	26.1136
2089.62	6389.67	26.1136
2089.75	6389.67	26.1136
2089.88	6389.67	26.1136
2090	6389.67	26.1136

The export did not start until elevation reached 6376 feet above sea level.

Time (Year)	elevation : monolake 3-California 1	export : monolake 3-California 1
1990.88	6375.31	0
1991	6375.46	0
1991.12	6375.61	0
1991.25	6375.76	0
1991.38	6375.91	0
1991.5	6376.06	0.634322
1991.62	6376.2	1.22344
1991.75	6376.34	1.80257
1991.88	6376.48	2.37186