

## Model Merger Exercises for Chapter 5:

### The Brine Shrimp of Mono Lake

It is often useful to merge two models dealing with different aspects of a system because the combined model may teach us something new. That is, we might gain insights into system behavior that could not be gained from operating the two models separately. This collection of exercises provides an opportunity to merge two models dealing with different aspects of Mono Lake. You may use the combined model to reexamine the export policies from Chapter 5.

#### Introduction

Chapter 5 describes a model to simulate changes in the size of Mono Lake based on different policies governing the amount of water exported to Los Angeles. The model helps us understand the long term changes in the size of the lake, but it provides little understanding of whether the food web is in danger. Chapter 5 relies on lake elevation as a proxy for a variety of problems (noted in Figure 5.6 in the book). We use the model to simulate lake elevation, and we interpret low values of the elevation as an indicator of an endangered ecosystem. In this exercise, we move beyond the proxy approach. Our goal is to make our assumptions about the ecosystem more explicit.

Mono Lake is home to a food web comprised of planktonic and benthic algae, brine shrimp, brine flies and a variety of migrating and nesting bird (see Figure 1) This exercise focuses on the brine shrimp (see Photo 1).



Photo 1. The Brine Shrimp  
(photo courtesy of the Mono Lake Committee)

The exercise begins with a model of the brine shrimp population. You are to imagine that the population model has been developed independently of the hydrology model in Chapter 5. Your job is to merge the two models to provide an internally consistent simulation of the size of the brine shrimp population as well as the size of the lake. You will discover what many modeling teams discover when working in large organizations --independently developed models do not necessarily fit together just because they deal with the same topic. You will need to make some adjustments in one or both of the models in order to combine them into a holistic picture of Mono Lake. If you succeed, you may use the combined model to simulate a new policy governing the amount of water exported from the basin.

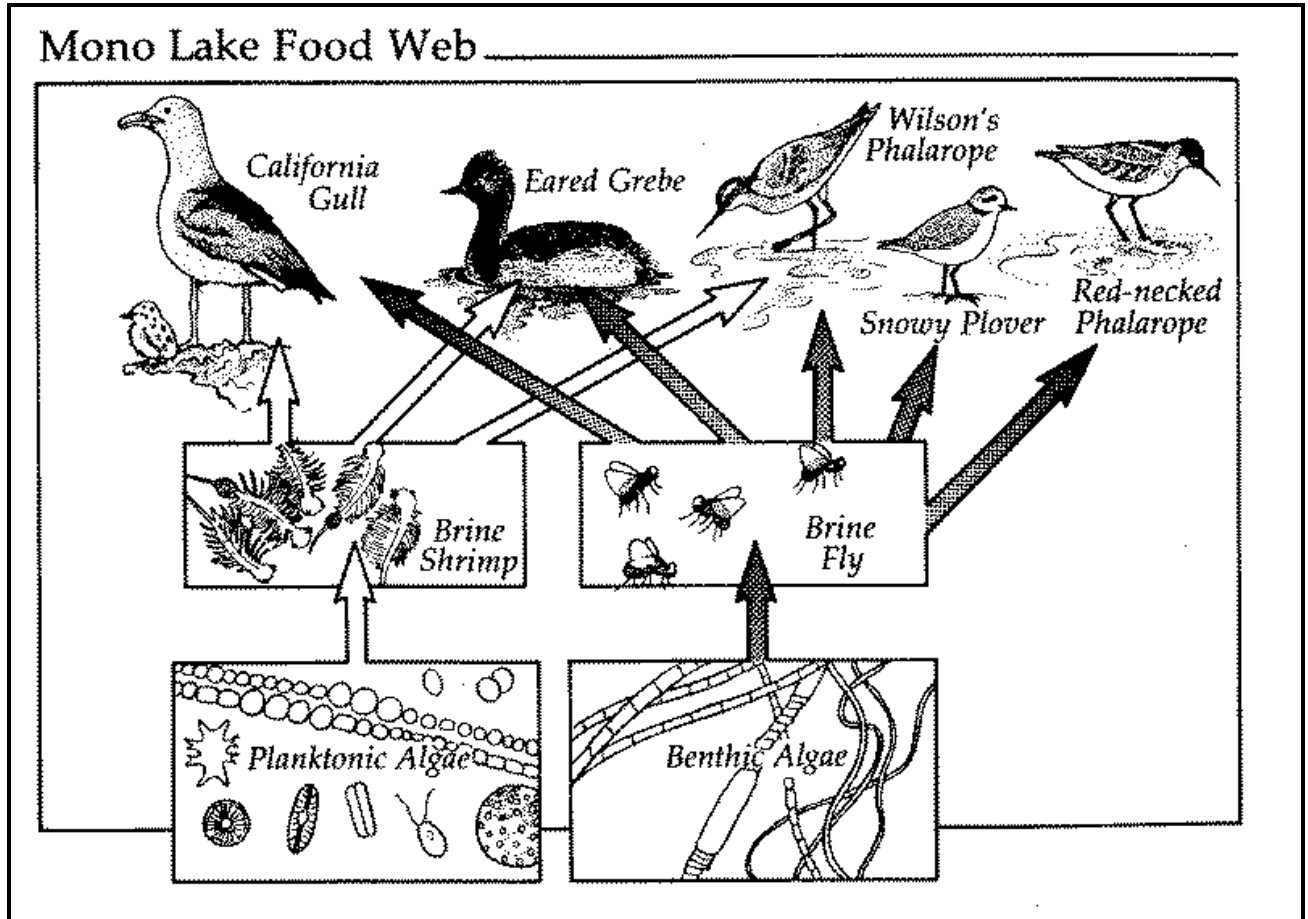


Figure 1. Mono Lake Food Web.

### The Brine Shrimp

The life cycle of the brine shrimp is depicted in Figure 2. The shrimp hatch from overwintering cysts in January through May and the first adults appear in the lake around the middle of May. These early adults may bare live young which will mature rapidly in the warm layer of the lake. This part of life cycle is depicted by the inner loop in the drawing.

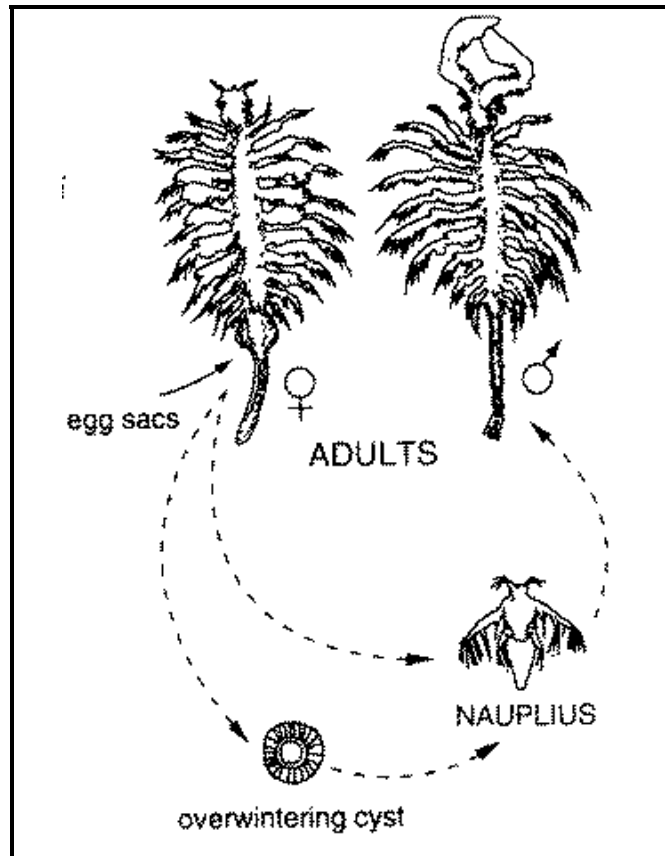


Figure 2. Life cycle of the Brine Shrimp.  
(drawing from Hart (1996), courtesy of Joyce Jonte)

For this exercise, we will concentrate on the larger shrimp population which is born from the cysts. (Their life cycle is depicted by the outer loop). The females switch from live reproduction to oviparous reproduction by June of each year. The diapause eggs lie dormant on the bottom of the lake until the following winter. The brine shrimp may be found each summer in the oxygenated upper waters, but they begin to decline in number by September and are almost absent from the plankton by December. The shrimp feed on (filter) planktonic algae, and the algae concentration varies dramatically from month to month within the year. The algae concentration also varies from year to year depending on the salinity of the lake.

### The Birds

The brine shrimp provide a main source of food for the Eared Grebe, the Wilson's Phalarope and the California Gull, the birds shown in Figure 1. The Eared Grebes use Mono lake primarily as a stopover site during fall migrations, and their departure each year is precipitated by the seasonal collapse of the lake's population of adult brine shrimp. The Wilson's Phalarope is also a migratory bird; it relies on Mono Lake as a stopover and staging site before commencing what may be a nonstop migration to South America (NRC 1987, p. 101). The California Gulls nest on several of the islands and islets in Mono Lake. They arrive in the spring and lay their eggs during a period when the brine shrimp are relatively scarce. Chick hatching occurs mainly in June, and chick growth usually coincides with the period of peak abundance of the brine shrimp.

## The Model

For this exercise, imagine that you are presented with the model shown in Figure 3. You are told that the model is a first step toward a model of the complex food web in Mono Lake. The model developers warn that the food web is not nearly as well understood as the hydrology, so they have decided to concentrate on the brine shrimp in the interest of simplicity. Also, they caution that several aspects of the brine shrimp's complex life cycle are left out of the model.

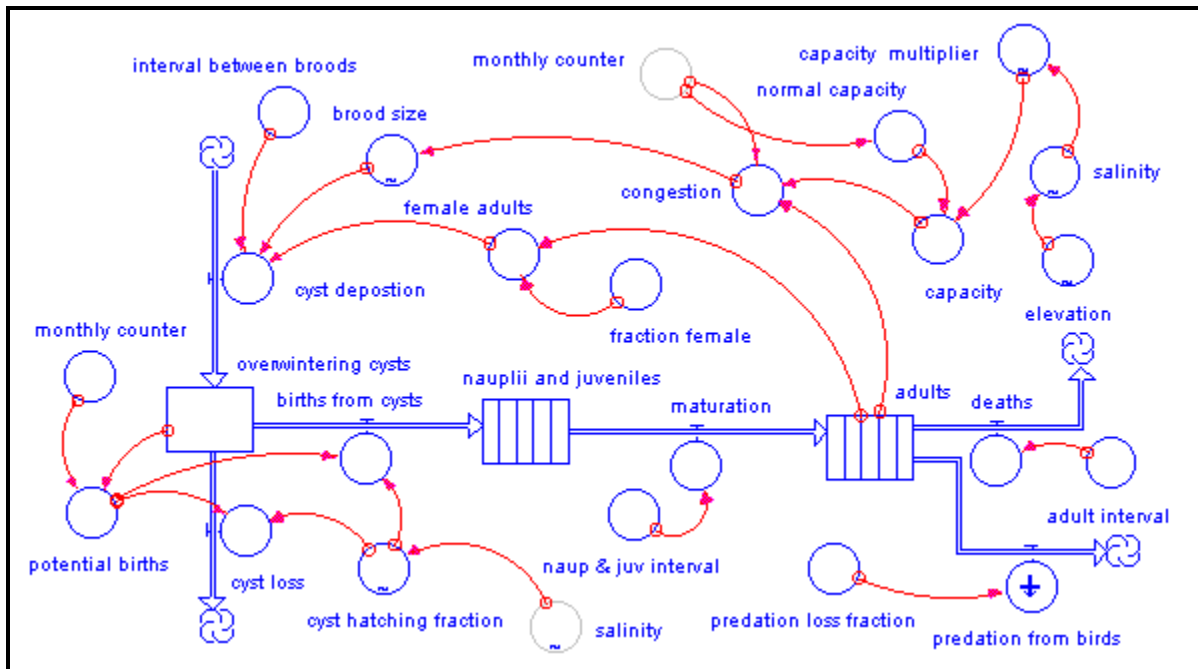


Figure 3. Model of the Brine Shrimp in Mono Lake.

## Testing the Brine Shrimp Model

### First Test: Sustained Population

Imagine that the model developers present the test simulation in Figure 4 as evidence that the simplified model provides a reasonable measure of the magnitude of the brine shrimp population under conditions prevailing in the mid 1980s. The test assumes that the lake elevation is constant at 6380 feet. Botkin (1988, p. 13) reports that the salinity depends on the elevation in a nonlinear manner, and the model uses the following graph function to capture the nonlinear relationship:

$$\text{salinity} = \text{GRAPH}(\text{elevation})$$

(6330, 250), (6335, 210), (6340, 190), (6345, 170), (6350, 155), (6355, 140),  
 (6360, 130), (6365, 120), (6370, 110), (6375, 97.0), (6380, 88.0)

With the elevation fixed at 6380 feet, the salinity remains constant at 88 g/L (grams per liter). The populations are measured in thousands of shrimp per square meter, a unit of measure used to report shrimp concentrations at measuring stations (NRC 1987, p. 74). The model projects that the nauplii and juveniles would appear each spring at around 35 ks/sm (thousand shrimp per square meter). No losses

are assumed for this stage of the life cycle. Consequently, around 35 ks/sm adult shrimp appear each summer. Predation from birds lowers the adult population during the course of the summer.

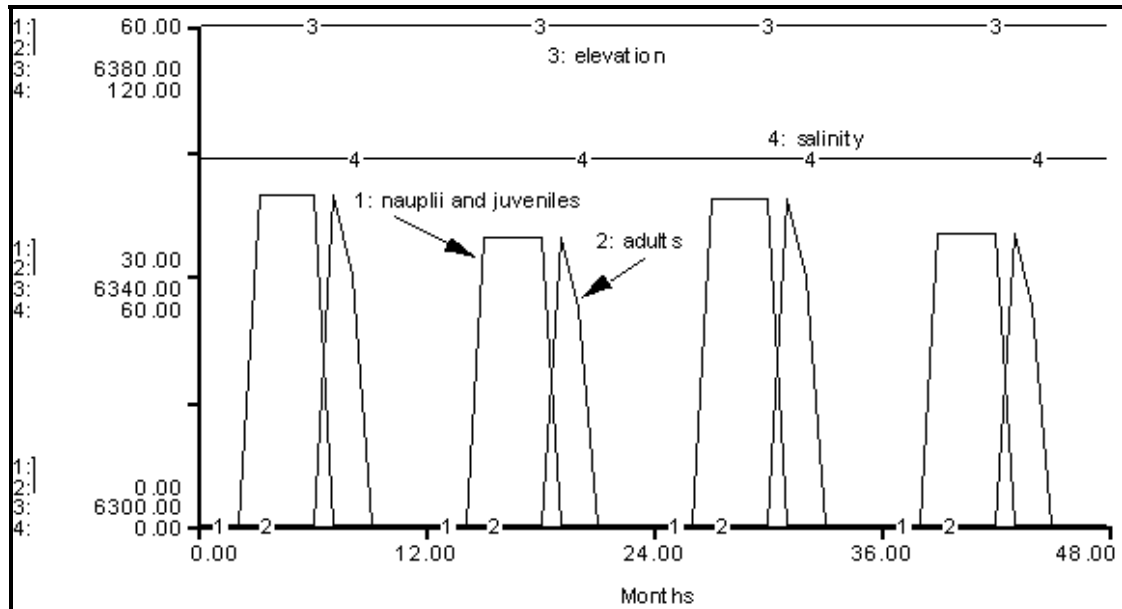


Figure 4. Test of the Brine Shrimp Model with Constant Elevation.

Figure 2 is presented as evidence that the model provides a reasonable simulation under conditions in the 1980s. The model developers are pleased that the projected level of 35 ks/sm agrees with measurements taken from the lake in 1985 (NRC 1987, p. 74). They are also pleased that the model shows a sustainable brine shrimp population from one year to the next because the shrimp are expected to do well if the salinity is maintained at 88 g/L (Botkin 1988, p. 13).

### Second Test: Increasing Salinity and Declining Population

Now, imagine that you are shown the test results for a 100 year simulation in Figure 5. The test begins with the elevation held constant at 6380 feet as before. The salinity is at 88 g/L, and the adult population appears as a spike on the graph with the height of each spike at around 35 ks/sm. After 120 months, the elevation is lowered by 5 feet. This raises the salinity to 97 g/L, and the model responds with a downward adjustment of the adult population that would appear in the lake each summer. With 97 g/l, the population is still above 30 ks/sm.

After another ten years, the elevation is lowered to 6370 feet causing the salinity to increase to 110 g/L. Figure 5 shows another downward adjustment in the number of adults to appear in the lake each summer. During this part of the test, the brine shrimp population is between 20 and 25 ks/sm. This is the general vicinity of the "threshold" density for the grebes (NRC 1987, p. 98). (When the shrimp density falls this low, feeding is sufficiently difficult that the grebes could have trouble putting on weight.)

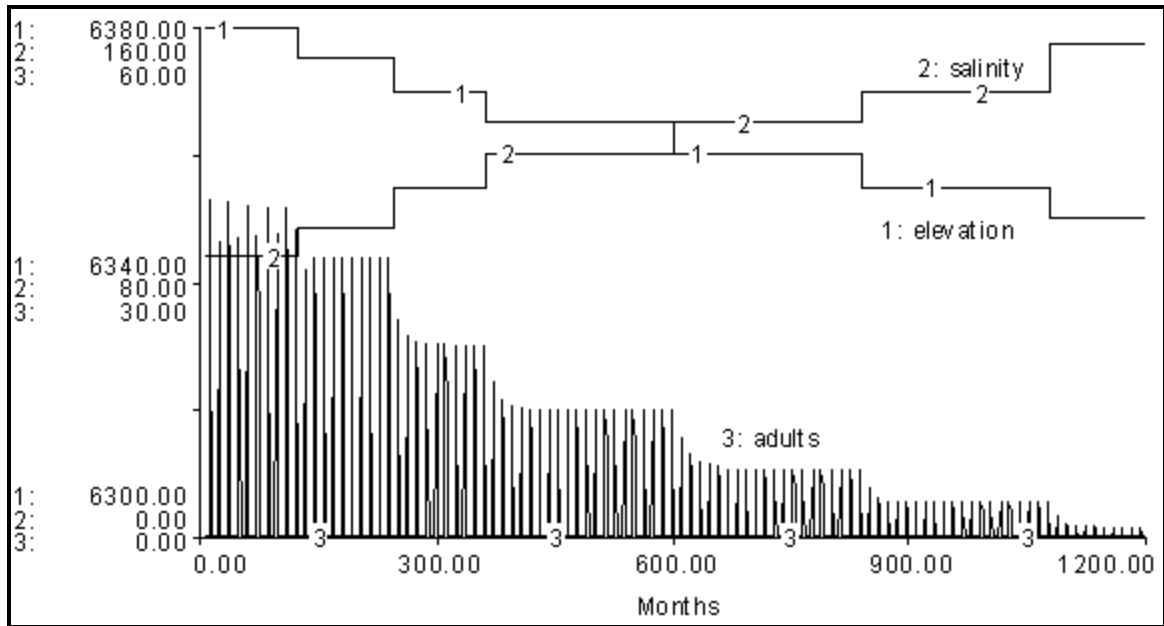


Figure 5. Test of the brine shrimp with increasing salinity.

The remainder of the simulation continues to step down the elevation in increments of five feet. By the end of the test, the elevation is at 6350 feet, and the salinity has climbed to 155 g/l. With these conditions, the model shows a negligible population. You are told that this final portion of the test agrees with Botkin's (1988, p. 10) view that a salinity level of 150 g/L would lead to the "demise of the lake ecosystem" because of reduced brood size and reduced hatching survival. Botkin (1988, p. 10) warns that "at this point, the present aquatic ecosystem will have been destroyed except perhaps for small refuge populations of shrimp and flies where fresh water is flowing into the lake."

### Model Details

The results in Figures 4 and 5 seem reasonable, so imagine that you press the developers for more details. You are told that the model is based on a simplified life cycle which ignores live births and concentrates on births from cysts. The stock of overwintering cysts is initialized at 250 ks/sm and is fed by cyst deposition and drained by two outflows. The two outflows are timed to occur in the 2nd month of each year:

```

potential_births = if (monthly_counter=2) then overwintering_cysts else 0
births_from_cysts = potential_births*cyst_hatching_fraction
cyst_loss = potential_births*(1-cyst_hatching_fraction)

```

The potential births is the entire stock of overwintering cysts that exist when the monthly counter reaches 2. The births flow is potential births multiplied by the hatching fraction; the loss flow is the potential births multiplied by (1-hatching fraction).

These flows will empty out the stock of overwintering cysts during the 2nd month of each year. (Set DT = 1 month and select the "Euler" integration method to allow these flows to do their job correctly.) The cyst loss flow removes cysts from the system; the births from cysts begins the next generation of animals that will eventually mature into adults.

The cyst hatching fraction can range from zero to 60% depending on the salinity:

```
cyst_hatching_fraction = GRAPH(salinity)
(50.0, 0.6), (75.0, 0.2), (100, 0.12), (125, 0.07), (150, 0.03), (175, 0.01), (200, 0.00)
```

The nauplii and juveniles stages of the shrimp life cycle are combined into a single conveyor with no losses. The transit time is represented by the naup & juv interval which is set to 4 months. The adult interval is set to 2 months, and the predation loss fraction is set at 50%. Both of the conveyors are initialized at zero. With these assumptions, the adults will not appear until the 7th and 8th months of each year. These are the months when the shrimp feed on planktonic algae, but the model does not simulate the algae concentration explicitly. Rather, it defines a capacity of the lake to accommodate the shrimp's need for food. The capacity may vary with the month of the year and with the salinity of the lake, as shown in the following equations:

```
capacity = normal_capacity*capacity__multiplier
normal_capacity = if (monthly_counter=7) then 30 else 20
capacity__multiplier = GRAPH(salinity)
(50.0, 1.00), (75.0, 1.00), (100, 1.00), (125, 0.9), (150, 0.5), (175, 0.1), (200, 0.00)
```

The capacity is normally at 30 ks/sm for the 7th month and 20 ks/sm for the 8th month. These monthly levels may decline, however, if the salinity climbs above 100 g/L. At 150 g/L, for example, the monthly capacities are cut in half. The adult shrimp population is compared with the capacity to find congestion, a dimensionless variable representing the balance between the shrimp and their food supply. The congestion is then used to find the brood size. The brood size determines the cyst deposition, as shown below:

```
brood_size = GRAPH(congestion)
(0.00, 50.0), (0.25, 20.0), (0.5, 15.0), (0.75, 12.0), (1.00, 10.0), (1.25, 8.00), (1.50, 5.00),
(1.75, 1.00), (2.00, 0.00)
congestion = if (monthly_counter=7 or monthly_counter=8) then (adults/capacity) else .5
cyst_deposition = female_adults*brood_size/interval_between_broods
female_adults = adults*fraction_female
fraction_female = .5
interval_between_broods = 1
```

At this point, you know enough to build and verify the brine shrimp model. If you study the food web in Mono Lake (NRC 1987; Botkin 1988), you may become interested in expanding the model. You could challenge yourself to improve the model by adding

- live shrimp births,
- an explicit treatment of the algae concentration or
- an explicit treatment of one of the bird populations.

For now, however, the merger exercises take you in a different direction. You are asked to assume that the shrimp model is a good first approximation to the vulnerability of the lake to changes in elevation. Your challenge is to combine the shrimp model with the water balance model from Chapter 5.

## Model Merger Exercises

### 1. Build and Verify the Simulation with a Sustained Population

Build the model in Figure 3, set the step size to 1 month and generate a 48 month simulation to verify the results in Figure 4.

### 2. Verify the Simulation with a Declining Population

Set the length to 1200 months and adjust the elevation to match the step down pattern in Figure 5. Simulate the model to verify that the population of adults agrees with the results in Figure 5.

### 3. Monthly version of the buffer policy model:

A monthly version of the model can be useful if we are planning a merger with a monthly model like the brine shrimp model. Let's convert the annual model (exercise 5-5 in the book) to its monthly equivalent. First, change "time" from years to months, set DT to 1 month and time to run from 0 to 240 months. (A simulation will correspond to 1990 to 2010, the same time interval as the previous exercise.) Retain the familiar parameter values in Table 5.1. For example, the sierra gauged runoff is 150 KAF/yr (rather than 12.5 KAF/month). Then introduce a new converter named "months per year" and set its value to 12. Use this converter to make sure that each of the five flows operates in KAF/month. (The ghost will be useful here.) Turn in a time graph of elevation and exports with the same scales as in the previous exercise and check that you get the same results.

### 4. Model Merger and Sustained Population Test:

Combine the Mono Lake hydrology model from exercise #3 with the Brine Shrimp model from exercise #1. Eliminate the buffer policy by making the water export constant at 100 KAF/yr. For clarity, use Stella' sector tool – one sector for the hydrology model and another sector for the brine shrimp model. Set the initial volume of water in Mono Lake to ensure that the simulation begins with the elevation near 6380 feet. Set the water export at a constant value that will ensure that the elevation remains near 6380 feet. Run the new model over a 48 month interval to verify that the brine shrimp population matches the results in Figure 4.

### 5. Impact of High Exports

When you are satisfied with the previous test, change the export to 100 KAF/year and simulate the model over a 600 month interval to show the impact of maintaining exports at the high level that was permitted in the past.

### 6. Reacting to Reduced Brine Shrimp Population

Conduct a test similar to Figure 5.14 in the book using the size of the brine shrimp population as an indicator of the health of the lake. Set export at 100 KAF/yr in the early years of the simulation. Locate the time point in the simulation when the adult shrimp population in the 7th month falls below 20 ks/sm. Set export to zero at this point and for the remainder of the simulation. Turn in a time graph similar to Figure 5.14 to document your results. Does the time graph show a rapid recovery of the brine shrimp population?

### 7. Export Policy Based on Brine Shrimp

Recall the buffer policy from exercise 5.5 which controls the water export as a function of the simulated lake elevation. Examine a new buffer policy with export controlled by the size of the brine shrimp

population that appears in the lake each summer. Assume that our goal is to maintain the shrimp population at 25 ks/sm or higher. (For example, we may want to maintain suitable summer stopover habitat for the Eared Grebe.) Can you devise an export policy that protects the simulated brine shrimp population? How does the annual water export under the new policy compare with the water export allowed in exercise 5.5?

#### 8. Export Policy with Uncertainty in Cyst Hatching

Many of the parameters in the brine shrimp model are highly uncertain. Let's select the cyst hatching fraction for closer examination. Assume that the 60% hatch at low salinity is well known and the 0% hatch at extremely high salinity is also well established. But the hatching fractions for intermediate values of the salinity are highly uncertain. Change the nonlinear relationship between the cyst hatching fraction and the salinity in two sensitivity tests. For the first test, assume that the decline in hatching fraction occurs more rapidly than in the original model. For the second test, assume that the decline does not occur until the salinity reaches higher levels. Simulate the model with these new assumptions to learn if your export policy from the previous exercise is a "robust policy." Is the brine shrimp population protected in all three tests of the export policy? Is the long term water export from the basin the same in all three tests of the policy?

### **Grant Lake Exercise**

9. Grant Lake Diagram: The exercise does not involve the brine shrimp, but it is still a useful exercise. Grant Lake is a small, fresh water lake in the Sierra. Evaporation from its surface creates a flow out of the basin. Table 5.3 in the book shows Grant Lake evaporation (minus precipitation) amounts to only 1.3 KAF/yr. The model in exercise 5.8 shows this loss as if it removes water from Mono Lake. This can be confusing.

To clear up the confusion, we need a model with the net evaporation loss removing the water directly from Grant Lake. Draw a new stock and flow diagram with a stock of water in Grant Lake. Then add an outflow to represent Grant Lake net evaporation removing water from Grant Lake. The stock of water in Grant Lake will be fed by Upper Rush Creek flow and drained by Lower Rush Creek flow. A portion of Lower Rush Creek flow will be diverted south to Los Angeles, and the remainder will be allowed to reach Mono Lake.

Rush Creek accounts for around 60 KAF/yr of the 150 KAF/yr of Sierra Gauged Runoff. Create a separate flow for the Other Sierra Gauged Runoff. (It's value would be 90 KAF/yr in an average year.) Then define a separate diversion fraction that will divert some of the other flow to Los Angeles; the remainder will be allowed to reach Mono Lake.

This is a diagramming exercise; there is no need to build the new model. However, if you were to simulate the flows in and out of Grant Lake, it would make sense to build from the monthly hydrology model in the 3<sup>rd</sup> exercise.

## Feedback and Discussion Exercises

### 10. Feedback in the Brine Shrimp Model

Draw a causal loop diagram to show the feedback loops in the model shown in Figure 3.

### 11. Feedback in the Combined Model

Draw a causal loop diagram to show any feedback loops that work their way through the hydrology sector and the brine shrimp sector of the combined model.

### 12. Feedback with the Water Export Policy

Draw a causal loop diagram to show any feedback loops that may be attributed to the water export policy from exercise #5.

### 13. Is the Whole Model More Than the Sum of its Parts?

Did you arrive at a satisfactory export policy in the 6th and 7th merger exercises? Now imagine that you do NOT have the combined model at your disposal, but you do have access to the two, separate models. Conduct a combination of simulations with the two models operated separately to study the export policy. Do you arrive at a similar conclusion by operating the two models separately?

### 14. When Are Model Mergers Useful?

Do you feel that the merger of the two Mono Lake models was useful? Did it teach you something new that you could not have learned from operating the two models separately? Under what conditions would you recommend that model mergers be undertaken?