That Dam Model[1]

Hydroelectric dams in the northwestern United States have been in the news a great deal in the past two decades. There are complex issues around fisheries, power, flood control, and irrigation uses of the Columbia River basin. The focal point for these is the system of dams along the Columbia/Snake Rivers. To begin to understand something about how a dam might operate, this story was developed. The model for a hydroelectric dam as described in this scenario could eventually become part of a larger study of salmon population or power consumption policies for the northwest region.

Problem 1a

The dam you're going to model is the Brownlee Dam on the upper Snake River. All of the river flow data (for now) are for what is called a moderate water year and are given in cubic feet per second (CFS). The dam can hold 1420 kilo-acre-feet (KAF) of water.[2]

The dam starts out containing 1200 kilo-acre-feet of water. Since the river flow data are in cubic feet per second, you'll have to convert it into kilo-acre-feet per month. Since we're trying to keep this model simple (to begin with), we'll consider every month to consist of 30 days. The equation to convert CFS to KAF per month is (show how you figured this out):

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[1] This lesson was written by Scott Guthrie and Diana M. Fisher.

[2] One KAF=1000 acres of water one foot deep. This is a volume measurement.

Now calculate the river flow for a moderate water year for each month below:

Month[3]	Average river flow CFS per month	Average river flow KAF per month
1	10204	
2	9086	
3	16505	
4	26363	
5	40837	
6	52065	
7	39402	
8	19501	
9	12673	
10	6952	
11	6082	
12	13570	

Figure 1: The data for the river flow

You may have noticed that the curve of the "Moderate Water Year" graph looks kind of strange. This is because a water year actually starts in the month of September.

We are going to have to make one additional change to the graphical function definition of water flow. If we want to have the average river flow reflect the value you calculated in the table above we are going to make the graphical function definition show steps rather than connected segments. To do this, after you have created your graphical function to contain the water flow shown in the table, click on the little graph displayed in the lower left corner of the graphical function definition window. The icon looks like the figure shown at the right. It will change appearance to look like a stepwise function.

Design a simple STELLA model to incorporate the river flow data and the dam volume. Set the DT to 0.125 and have the simulation run for 12 months. Be sure to allow the stock to contain negative values even if negative values do not make sense for this simulation. Create a graph that includes the current volume of the dam and a component that indicated the maximum allowed for the dam volume, so these values can be compared. Set up a table that displays values only every month, not every DT.

Problem 1b

Obviously this model had significant deficiencies. A dam cannot hold more than its maximum capacity. If too much water flows into the dam, the excess is sent through a "spillway." There will be a control device on the spillway that will open the floodgates

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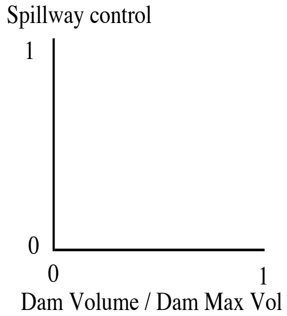
[3] In STELLA, months 1–12 will be represented as 0–11.

if there is too much water behind the dam, and it will adjust the opening based on water levels behind the dam. To incorporate this spillway control, we need to know the ratio of the current dam volume compared to the maximum dam volume. We will assume that the maximum amount of water that the floodgates can release at any time is 2700 KAF. Set up a spillway control (graphical) that will open the floodgates to full volume if the dam to dam max ratio is 80% or greater. It should not open the floodgates at all if the ratio is less than or equal to 40%. Set up a gradual increase from 40% to 80% volume.



Draw the graph you used to define the spillway control on the axes at the right.

Were you able to keep the dam from flooding?

If not, try adjusting the spillway control until you control the dam volume.

Problem 2a

Now that you have the basic dam working (a river, a dam, and a spillway), it's time to make it look more like a real, power-generating dam.

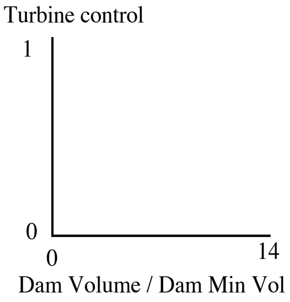
Let's add the flow of water through turbine generators to the dam model. These devices can use a *maximum* of 750 KAF per month. Add turbines to your dam.

Should this component be another outflow or should it be contained in the spillway? (Which is better modeling practice? Give a reason for your answer.)

Design a test that will help you build confidence in your new structure. In the space below, outline the test and criteria you used to assess if it accomplished the goal. How did your model perform compared to the goal?

Problem 2b

You may have noticed that running your turbines at maximum capacity could result in the dam running dry sometime during the simulation. This is a bad thing. When this happens to real dams, gunk (a technical engineering term) goes through the turbines and breaks them. This does not make the taxpayer happy. To prevent this, a minimum "head" of water is kept behind the dam. Modify your model to keep a minimum head of 100 KAF of water behind the dam at all times. You will need to design a turbine control device similar to the spillway control device. The device will depend upon knowing how the volume of water behind the dam compares to the minimum head allowed. The control device should allow maximum turbine output, if needed, almost all the time. It should reduce the turbine output significantly, only if the amount of water behind the dam is coming dangerously close to the minimum amount needed to keep the turbines operating properly.



Draw the graph you used to define the turbine control on the axes at the right.

Design a test that will help you build confidence in your new structure. In the space below, outline the test and criteria you used to assess if it accomplished the goal. How did your model perform compared to the goal?

(*Note:* Turn off the inflow and see if this control still works.)

Problem 3a

Running the turbines continuously at 750 KAF per month is pretty unrealistic. Brownlee Dam was designed to meet the power demands of the area into the next century. The power demand curve is shown in Figure 2. Your task is to meet the power demand as best you can *and* stay within the minimum and maximum amounts of water behind the dam. *Note 1:* The power demand is usually measured in kilowatt-hours per month. But that value has been translated (to simplify the model) to the amount of water that would have to flow through the turbines to meet the electrical demand. *Note 2:* The turbines will no longer need to flow at maximum output. They will need to flow only enough water to meet the electrical demand.

Month	Moderate-year average power demand (KAF) per month
1	298
2	419
3	487
4	580
5	717
6	647
7	531
8	494
9	420
10	368
11	245
12	287

Figure 2: The power demand curve

Explain what you did to build confidence in the model structure at this point.

Problem 3b

As a way to easily determine if you are keeping the power customers happy, add a component that compares the actual turbine outflow with the demand. If the value is one, you have met the demand for that month. If the demand is less than one, some people who wanted power did not get it (at least not from this dam). In order to keep your customers happy, you need to have actual power generated to power demand ratios greater than or equal to one. Increase the power demand to a moderate-high level by increasing the demand by 200 KAF per month. What was the fraction of demand satisfied each month?

Do you think this will be acceptable? Why or why not?

What criteria for power produced would be acceptable for the customers? Support your answer with some reasonable argument.

Problem 4

Return the dam to the moderate-year power demand.

One of the issues facing dam operators on the Snake River is getting the salmon fry (very young salmon) downstream without putting them through the dam's turbines. To do this, they have developed a "controlled spill" plan where they release 150 KAF of water through the spillways, flushing the salmon over the dam (theoretically). This "controlled spill" takes place only during the months of March, April, and May (months 6, 7, and 8).

Can you do this (allow enough water to pass through the controlled spillway) *and* still meet the other demands placed on the dam (power, minimum head maximum amount, etc.)? If so, what did you do? If not, what problem(s) arose?

What would have to occur if the power demand kept increasing?

What are some of the trade-offs that would be required in order to satisfy an increased power demand?

Print out the diagram, equations (with units), a graph (include the dam volume level, maximum dam capacity, and minimum dam water level allowed), and a table (include all components whose values change over time). Write a short paper (outline of the paper provided by the teacher) to explain your model.