Chapter 13. The Salmon Smolts Spring Migration

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The declining salmon runs on the Snake and Columbia river system is one of the most serious environmental problems in the Pacific Northwest. The salmon have disappeared from 40% of their historical breeding ranges despite a public and private investment of more than $1 billion. The annual salmon and steelhead runs have dwindled to 2.5 million, less than a quarter of the run sizes of 100 years ago. This chapter describes a model which may be used to simulate one piece of the complex and threatened salmon system. It focuses on the spring migration of hatchery smolts to the ocean. It may be used to test the relative merits of barging fish or drawing down the reservoirs to help the smolts reach the ocean.

Background

A smolt is a juvenile salmon that migrates from its stream habitat to the ocean. It undergoes physiological changes called smoltification to adapt from freshwater to saltwater. This chapter concentrates on hatchery smolts. The juveniles are raised in the hatchery until they are ready to be released into the river for the spring migration. After two days, the smolts reach the Snake River where they encounter the slack water behind Lower Granite dam. Lower Granite's location is shown in Figure 13.1. It is the first of eight dams the smolts will encounter in their journey to the ocean. The dams are owned and operated by the federal government primarily for hydro-electric generation. (They also provide flood control, irrigation, and transportation.) The reservoirs are connected, one after the other, so the smolts will experience slack water all the way to the Bonneville dam. The slack water slows their migration compared to the era when the Snake and Columbia flowed freely to the ocean.

Figure 13.1. Map of the Snake and Columbia system.

Speed is important if the smolts are to reach the ocean before their bodies complete the physiological changes for saline conditions. The smolts that remain in fresh water too long will die from the high stress of smoltification. Other threats along the way include predators, disease, and starvation. The smolts are also vulnerable to turbine mortality if they are swept into the currents leading to the turbines at each of the dams.

Model Organization and Policies

The model is organized as a series of "sectors" to keep track of the smolt's progress toward the ocean. The first sector simulates the smolts' release from the hatchery and their travel to the first

reservoir. Each of the next eight sectors is associated with a reservoir and dam. The smolts must survive their travel in the reservoir, and they must pass safely through or around each dam. The final sector tracks their progress in the final reach of the river between the Bonneville dam and the ocean. The model assumes that the smolts remain grouped in a relatively tight schooling pattern. So it makes sense to take advantage of the "conveyor" stock, as explained in Chapter 10. We will begin the simulation by releasing 10 million smolts in day zero. Stocks will be measured in millions of smolts; flows will be measured in millions of smolts per day. The model time horizon is 40 days, a sufficient time interval for the smolts to either reach the ocean or to die from smoltification.

The model will be used to test the two commonly discussed policies to improve the chances that the smolts reach the ocean:

- The first policy is barging -- the transport of smolts around many of the dams and reservoirs. Barging allows the smolts to avoid turbine mortality, and it speeds their journey. The model simulates barging at Lower Granite and Little Goose on the Snake as well as McNary on the Columbia. Barging has been used extensively, and you will learn that tagging studies yield valuable insights on its effectiveness. We will take advantage of the tagging studies to include the "latent deaths" from barging in the model.

- The second policy is drawing down reservoirs to create higher water flow during the migration period. Draw down proponents argue that faster water flow will speed the smolt's migration to the ocean, thereby reducing the danger of smoltification. The model accepts travel times as the key inputs. You may set these inputs based on the estimated reduction in travel time to be achieved by a draw down.

The model may be used to indicate whether a draw down or barging is better under different weather conditions.

Model Structure

Figure 13.2 shows the first two sectors of the model. The first sector keeps track of the hatchery smolts shortly after their release and prior to their arrival at the slack water in the Lower Granite reservoir. The model begins with the *smolts released from hatchery*. This input is set at 10 million in the first day of the simulation. All the stocks in the model are initialized at zero. *Upstream smolts* receives the 10 million smolts released from the hatchery. The smolts spend two days in this stock where they are subject to a mortality of 25%/day based on the estimate by Olsen (1992). With this assumption, we would expect to lose five million smolts in this sector. The other five million leave the upstream sector and arrive at the first reservoir.

The arrival at Lower Granite can be represented in either of two ways. We may connect the flow draining the stock of smolts in the upstream sector with the stock of smolts behind Lower Granite. This is relatively easy at the interface of the two sectors in Figure 13.2, but similar connections will be quite cumbersome elsewhere in the model. So the approach in this chapter is to use an information link between the corresponding flows. We simply set the flow of smolts arriving at Lower Granite to the value of the flow leaving the upstream sector.

The smolts behind Lower Granite reservoir are represented by a conveyor whose transit time is called *days in res 1*. The time interval is set at 25% of the total time on the Snake reservoirs. The total time on the Snake is a key input which you will set based on flow conditions or your decision about a draw down. (The 25% is based on relative size of this reservoir.) The loss in the Lower Granite reservoir is caused by starvation and predation. A loss of 2%/day is assumed for each of the Snake River reservoirs based on the estimate by Olsen (1992). The smolts that survive the reservoir are represented by a flow that drains the stock and arrives at the dam.

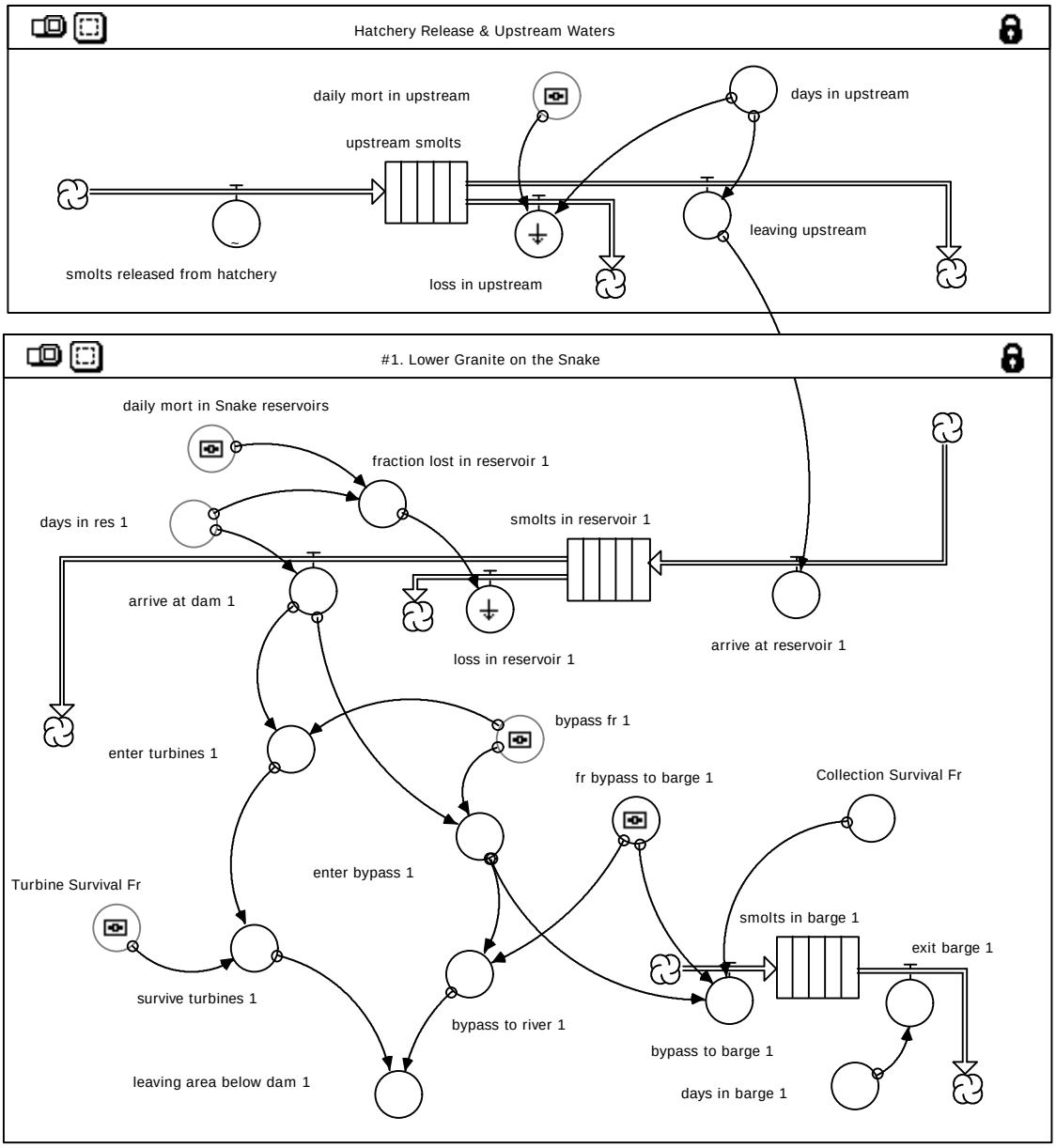


Figure 13.2. The first two sectors of the model.

Smolt Traffic at the Dam

The home page sketches the various routes of travel through or around each dam. One route is downward through the turbines. Smolts swept in this direction are exposed to 15% mortality. A less dangerous route is around the dam via the spillway or the sluiceway. Bypass is a third route at some dams which have installed screens to divert the smolts away from the turbines and into a collection system. The losses from bypass and spillways are relatively low compare to turbine losses. Our approach is to keep the simulated traffic as simple as possible by sending the smolts in one of two directions. The "dangerous direction" is toward the turbines. The "safe direction" is into the bypass system. You will control the traffic by your selection of the bypass fraction. The maximum feasible fraction is around 70% based on optimum design of the diversion screens.

To illustrate the calculations at each dam, imagine that 4 million smolts arrive at the first dam, and you have set the bypass fraction to 70%. The model would send 2.8 million into the bypass system and 1.2 million to the turbines. The turbine survival fraction is set at 85% for all the dams based on the estimate by Olsen (1992). With this assumption, 1.02 million smolts will survive the turbines. Now, what about the 2.8 million smolts in the bypass system? These are under your control. You may place some or all of them in a barge, and they will be transported around the remaining dams and released in the final reach below Bonneville. Or you may return them to the river to join their schoolmates that have survived the trip through the turbines. The smolts leaving the area below the 1st dam arrive immediately at the reservoir behind the 2nd dam. Smolt survival in each reservoir is represented in the same manner as Lower Granite. Smolts that arrive at the Little Goose dam face the same traffic options as Lower Granite, so the model assigns the same combination of stocks, flows and converters to simulate the second reservoir.

The smolts that leave the area below the 2nd dam arrive immediately at the 3rd reservoir, as shown in Figure 13.3. Lower Monumental does not have barging facilities, so the traffic at the dam is somewhat simpler than the previous dam. The user simply specifies the bypass fraction to match the bypass or spillway fractions at the dam. In this case, a default value of 30% is used to represent 30% of the smolts passing over the spillway. (Spillway losses are assumed to be negligible.) The other smolts must pass through the turbines where they are exposed to 15% mortality.

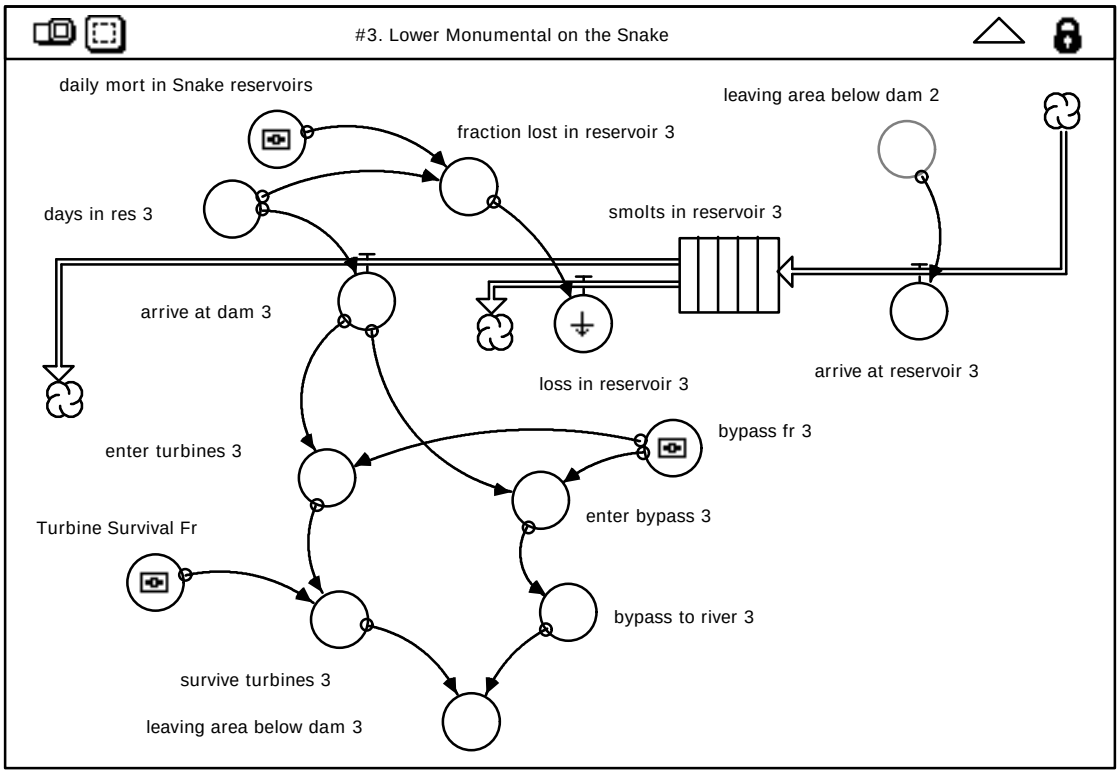


Figure 13.3. The Lower Monumental sector.

The stocks and flows for Lower Monumental are used for each of the five dams without barging. The previous approach is applied to the other three dams.

The smolts that survive the journey through eight reservoirs and dams will arrive at the final reach of the river below Bonneville. Figure 13.4 shows the final sector to simulate their progress to the ocean. Notice the three ghosted variables in the upper right corner. These represent the smolts exiting the three barges. The barge trip survival fraction is set to 98% since only around 2% of the barged smolts are observed to die in transit (Olsen 1992).

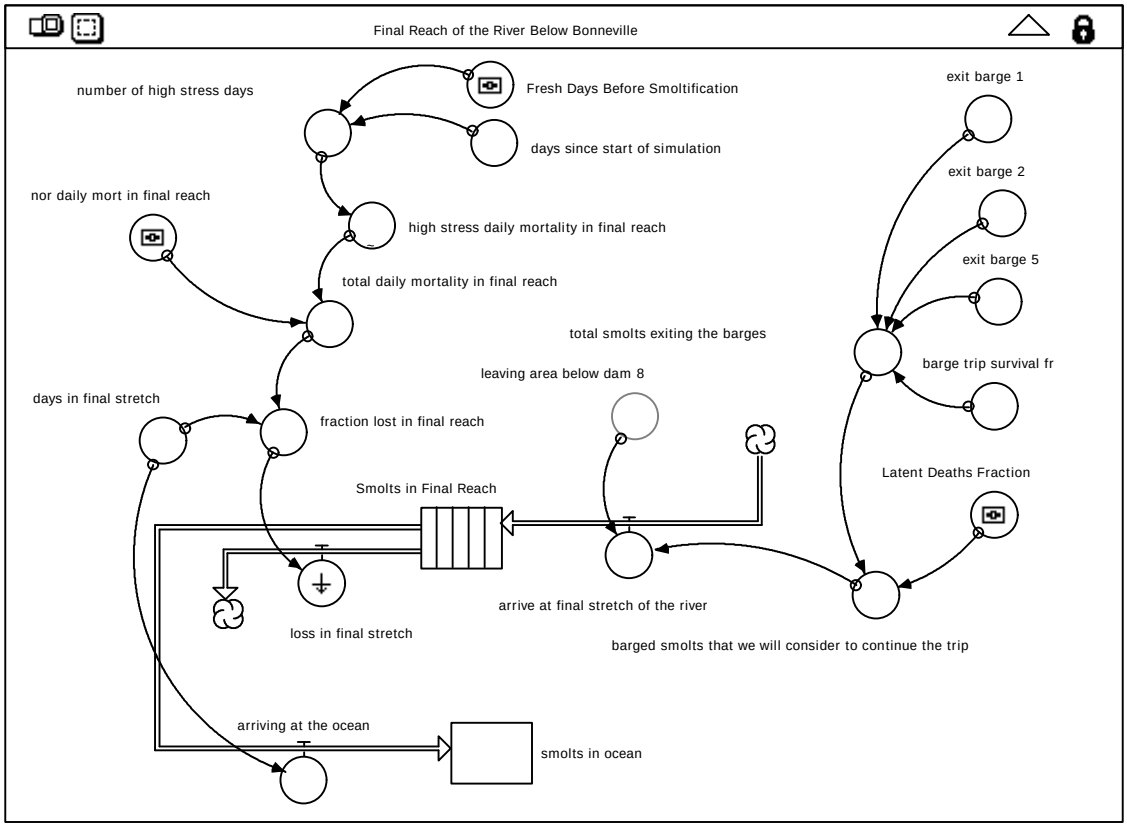


Figure 13.4 Smolts in the final reach below the Bonneville dam.

A far larger fraction of the barged smolts are expected to encounter problems later in their life cycle. A *Latent Deaths Fraction* stands for the fraction of the exiting smolts that will die later in their life cycle because of the disruptive effects of barging. You'll learn shortly that the *latent deaths fraction* is around 50%. In other words, only half of the *total smolts exiting the barges* are counted as *barged smolts that we will consider to continue the trip*. They are added to the smolts *leaving area below dam 8* to create the flow into a conveyor for the *Smolts in Final Reach*.

The loss in the final reach depends on the *days in final reach* and the *total daily morality in final reach*. The estimated travel time is around 4 days based on a 3 days to travel from the barge release point to the Columbia River estuary (Mundy 1994, p. 108) plus one day for the Bonneville smolts to travel to the release point. During the final days in the river, the smolts are subjected to *normal daily mortality in the final reach* (due to predators, disease and starvation). But they are also subject to the additional mortality effects of smoltification. The *high stress daily mortality in final reach* is found using a graph function (~). The graph assumes zero mortality unless the smolts are still in the fresh water after a threshold of, say, 25 days. This input is called *fresh days before smoltification*. We will assume that the *high stress mortality* increases with each successive day that the smolts have not reached the saline waters of the estuary. A maximum rate of 50%/day is applied if they are still in fresh water 5 days later. This plausible combination of assumptions allows the model to match the estimated losses by Olsen (1992).

Travel Time Inputs

The key inputs are the travel times, the days spent traveling the four reservoirs on the Snake and the days traveling the four reservoirs on the Columbia. In a year with average weather (medium flows), the smolts are expected to need 12.4 days on the Snake and 8.9 days on the Columbia. Since the

Snake reservoirs are all around the same size, the 12.4 days is split 25% to each reservoir. The splits are not as even on the Columbia.

Smolt travel times are linked in a complex manner with water particle travel times. If you have ever played with a water hose, you know that water tends to travel faster when there is more flow passing through a fixed area. And you know that you can speed the flow by compressing the area. The river system water travel times are similar. We expect water travel times to be low in "wet years" with high flow, and we expect them to be high in "dry years" with low flow. Water travel times may be increased by augmenting the river flows. And they may be increased by lowering the river level in order to send the same flow through a smaller cross-sectional area.

Experts are relatively confident that they can predict changes in water travel times under different flow assumptions. But there are unanswered questions about the relationship between water travel time and smolt travel time. This model does not answer these questions. Rather, it requires you to specify the smolt travel times as inputs. The model may then be used to learn if the changes in smolt travel times are important. To put the travel time assumptions into perspective, let's compare the total time from hatchery to ocean under medium flow conditions:

upstream sector:	2.0 days
days in Snake reservoirs:	12.4 days
days in Columbia reservoirs:	8.9 days
days in final reach:	4.0 days
total days:	27.3 days

with the estimate that the *fresh days before smoltification* is 25 days. With this combination of assumptions, mortality effects from smoltification are expected under average flow conditions. With high flow conditions, the total time from hatchery to ocean is around 23 days, so the smolts would escape the high stress of smoltification. The years with low flow conditions are much different. With low flows, the total time from hatchery to ocean is around 39 days, and the smolts would be exposed to a prolonged period of high stress due to smoltification.

Base Case Results and Interface

Figure 13.5 shows the simulated migration with base case assumptions. Ten million smolts are released at the hatchery, and half of these arrive at the first reservoir in the second day of the simulation. The time graph shows the downward slant for smolts in the 1st reservoir. A similar pattern appears in each of the remaining reservoirs. (The 7th reservoir is the small reservoir behind The Dalles dam. The travel time through this reservoir is so short that the smolts curve appears as a spike in Figure 13.5.) The down trend in the eight reservoirs is caused by the 2%/day mortality from starvation and predation assumed for slack water.

There is no barging in this simulation, so all of the smolts that pass through or around the Lower Granite dam arrive at the 2nd reservoir. If you look closely, you will notice a drop between the end of the curve in the 1st reservoir and the beginning of the curve for the second reservoir. This is caused by the mortality in the turbines at the first dam. Similar declines appear wherever a significant fraction of the smolts pass through the turbines at the remaining dams.

Some of the smolts survive to reach the river below Bonneville dam. Their final challenge is to reach the ocean before they feel the deadly effects of smoltification. This part of the simulation is represented by *Smolts in Final Reach*. Figure 13.5 shows that this curve does not decline in a constant, linear manner like the previous curves. It shows a steeper and steeper downward slope as the smolts spend more time in the final reach, a sign that the losses from smoltification are becoming more serious with each passing day. The simulation concludes when the remaining smolts reach the saline waters of the estuary and enter the ocean. This first test suggests that 1.16 million smolts would survive the trip to the ocean.

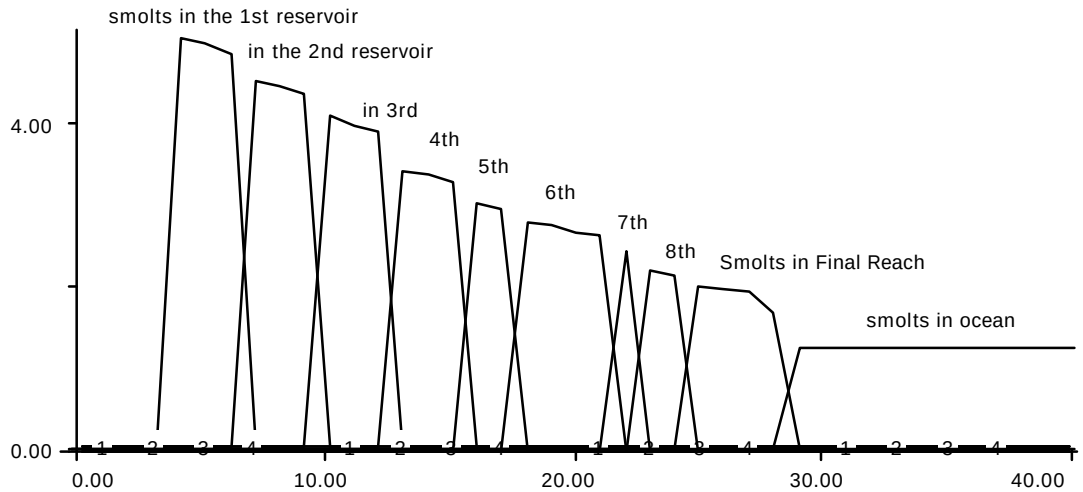
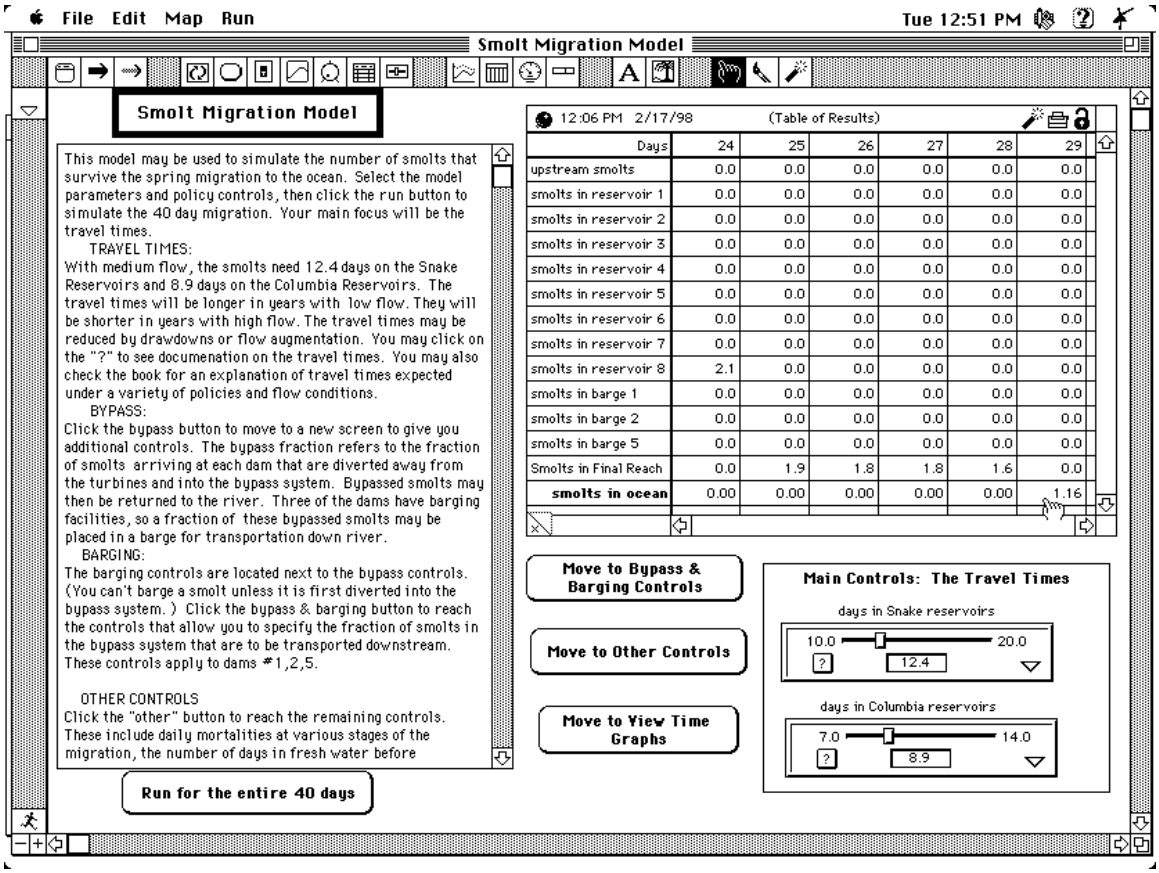


Figure 13.5. Base case simulation with average weather and no barging. (This graph is adapted from three separate Stella graphs.)

Figure 13.6 shows an interface to facilitate your use of the model. You'll see this interface when you download the model from the home page. It provides instructions in the scrolling field and a table of results. This "screen capture" shows the monitor of a Macintosh computer at the conclusion of the base case simulation. The cursor ("finger") is pointed at the key result in the final row of the table. The *smolts in ocean* reaches 1.16 million by the end of the simulation.



Days	24	25	26	27	28	29
upstream smolts	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 1	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 2	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 3	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 4	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 5	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 6	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 7	0.0	0.0	0.0	0.0	0.0	0.0
smolts in reservoir 8	2.1	0.0	0.0	0.0	0.0	0.0
smolts in barge 1	0.0	0.0	0.0	0.0	0.0	0.0
smolts in barge 2	0.0	0.0	0.0	0.0	0.0	0.0
smolts in barge 5	0.0	0.0	0.0	0.0	0.0	0.0
Smolts in Final Reach	0.0	1.9	1.8	1.8	1.6	0.0
smolts in ocean	0.00	0.00	0.00	0.00	0.00	1.16

Figure 13.6. Base case results on the main screen of the interface.

The main controls appear as “sliders” in the lower right corner of the screen. The slider positions reveal the base case assumption that 12.4 days are required for the reservoirs on the Snake and 8.9 days for the reservoirs on the Columbia. Other controls are located on additional screens which may be reached by clicking the buttons on the main screen. The model may be used to test policies to increase the fraction that survive the trip. So far, we have 1.16 million, only 11.6% of the original 10 million. Perhaps barging will improve on this result.

Barging, Tagging Studies and Latent Deaths

Limited transportation of juveniles began in the late 1960s for research purposes. The smolts were transported by tanker trucks, fish trailers and eventually by barges. Mass transportation of juveniles began in 1981 (with five tanker trucks and four barges). For evaluation purposes, some smolts are tagged with a PIT, a passive integrated transponder. (The tags are installed when the fish are held in the bypass system.) Some of the tagged fish are transported; others are returned to the river. The transported fish are called “T fish.” The control fish are called “C fish.” By measuring how many actually return as adults, tagging studies provide some perspective on the benefits of transportation. Mundy (1994, p. 70) describes studies over the time period from 1968 to 1989. The most important observation is that return counts tend to be quite small. The returning “C Fish” can range from 0.01% to 0.3%. The returning “T Fish” range from 0.02% to 0.6%. The study of yearling Chinook tagged at Lower Granite in 1975 is illustrative:

C fish return:	0.31%	
T fish return:	0.64 %	
T/C ratio		2.0

The T/C ratio may be used to help us estimate the size of the latent deaths fraction. We use the smolt model to simulate the relative values of the T fish and the C fish surviving the trip to the ocean. To mimic the collection and tagging of fish at Lower Granite, for example, we may set the Lower Granite bypass fraction to 100%. Then set the fraction of bypassed fish to barge at 1.0 to simulate the T fish. Then conduct a second simulation with zero barging to simulate the C fish. These two simulation were performed with the bypass fractions at the downstream dams set to values said to characterize the 1970s. The simulation with barging shows 4.14 million smolts reaching the ocean. The simulation with the control fish returned to the river shows 1.01 million smolts reaching the ocean. Now, suppose there were no differences between these two groups as they carry on with their life cycle. Let’s assume that 1% of each group returned to the counting station. Then a tagging study would show:

returning T fish:	1% * 4.14 million = .0414 million
returning C fish:	1% * 1.01 million = .0101 million
expected T/C ratio:	4.1

Now, we face a contradiction. The expected T/C ratio is 4.1, but the observed T/C ratio is 2.0. This contraction can not be explained, but it is sometimes interpreted as evidence that the barged smolts are less capable of finding their way back as adults. (Marmorek and Peters (1996) explain the considerable evidence of the delayed mortality from barging.) The term “latent deaths” is used to remind ourselves that the cause of the low returns is not understood. We may then estimate the size of the latent deaths fraction to reconcile the two T/C ratios. In our case, the latent deaths fraction is set at 51%, so 49% of the transported fish will survive. This allow us to reconcile the simulation results with a typical tagging study as follows

returning T fish:	1%*4.14 million*49% = .0202 million
returning C fish:	1%*1.01 million = .0101 million
expected T/C ratio:	2.0

The 51% latent deaths may surprise you, and you may wonder how we can proceed with this assumption without more details on how the barging disrupts the salmon life cycle. But to ignore the

latent deaths is equivalent to ignoring the data that has been gathered from the tagging studies. The best approach is to proceed with a rough estimate of latent deaths and to remember that this parameter is likely to be highly uncertain. The 51% latent death fraction is somewhat lower than the 62% estimate used by Olsen's (1992).

Using the Smolt Model

You've seen one example of a simulated migration without barging. To test the impact of barging at Lower Granite, set the barging fraction at 100%. Recall that you can't barge a smolt until it is captured in the bypass system, and the maximum feasible bypass fraction is 70%. So full barging means that 70% of the smolts arriving at Lower Granite will be transported to the release point below the Bonneville dam. You should try this test with the model. It will show that 1.73 million smolts reach the ocean. Compared with the base case, barging increases the survival from 11.6% to 17.3%.

This sounds like a promising result, but you might be wondering whether we could get better results with a draw down. With this policy, we leave the fish in the river and look for shorter travel times to improve their prospects to survive the migration. Figure 13.7 summarizes travel times for regular river operations and for two types of draw downs. The shaded entries show the base case travel times described previously. These are based on "regular" operations in which the flows are controlled primarily for hydro-electric generation. The shaded entries appear in the "medium flow" column which describes travel times in a year with average runoff.

on the Snake:	low flow	medium flow	high flow
Regular Operations	20 days	12.4 days	10 days
Modest Reduction (i.e., draw down to minimum operating pool)	14.8 days	10.8 days	9.2 days
Major Reduction (i.e., draw down to spillway crest)	10.3 days	8.4 days	8.0 days
on the Columbia:	low flow	medium flow	high flow
Regular Operations	12.9 days	8.9 days	7.0 days
Modest Reduction (i.e., draw down to minimum operating pool)	10.5 days	7.9 days	7.1 days
Major Reduction (i.e., draw down to spillway crest)	12.9 days	7.9 days	7.0 days

Figure 13.7. Suggested travel times.

Smolt travel times are described in great detail in the 1992 "Options" environmental impact statement by the US Army Corps of Engineers (EIS 1992). The EIS looks at water particle travel times for a variety of "options" for managing the river. Their "medium flow" conditions correspond to 80 kcfs (thousand cubic feet per second) on the Snake and 200 kcfs on the Columbia. The EIS links smolt travel times to particle travel times following the approach by Berggren and Filardo (1991). The EIS shows 8.9 days on the Columbia and 9.3 days on the Snake. The 8.9 days appears in Figure 13.7, but the 9.3 day estimate has to be expanded by 133% to arrive at the 12.4 days to be used in the model. The expansion is needed to account for the Lower Granite reservoir (which was not included in the EIS measurement.) A comparison of the columns in Figure 13.7 shows that the travel times are much shorter with high flow conditions and substantially longer with low flow conditions.

One of the options in the "Options Study" is to draw the reservoirs down to minimum operating pools during the time of the smolts migration. With average weather, the time on the Snake would be reduced by 1.6 days; the time on the Columbia by 1 day. The 2.6 days is a "modest reduction" which could be achieved by a variety of measures studied by the Environmental Defense Fund (EDF 1995) as well as the Corps (EIS 1992).

One of the more ambitious policies is to draw down the reservoirs to the spill way crest during the smolts migration. This approach would be much more disruptive to normal river operations. At Lower Granite, for example, the spillway crest is 57 feet below the maximum operating elevation of the reservoir (EIS 1992, p. 2-10). The minimum operating level, on the other hand, is only 5 feet below the maximum operating elevation. The draw down to spillway crest would cut the travel time on the Snake to 8.4 days under medium flow conditions. (The EIS did not estimate travel times for the Columbia, so Figure 13.7 shows the same estimate used with a modest draw down.) The two draw downs in Figure 13.7 have been selected to illustrate "modest" and "major" changes in travel times that might be achieved by a wide variety of measures. There are many ways to achieve the modest reduction of 2.6 days. The major reduction of 5 days may be viewed as an upper limit on the reductions that could be achieved (EDF 1995, p. vi).

Summary

This chapter describes a model designed for an analysis of the relative merits of barging versus draw downs to aid the smolts spring migration. The stock and flow structure of pieces of the model are explained here. You can see the entire structure by downloading the model from the home page. The parameters have been estimated from travel times reported by Corps of Engineers (EIS 1992) and the Environmental Defense Fund (EDF 1995). Many of the loss fractions have been estimated from the spread sheet modeling by Olsen (1992). You may learn more of the detailed thinking behind each parameter by studying the documentation that accompanies the model. (Documentation is visible by clicking on the "?" button on any slider or by double clicking on any variable in the mapping mode.) If you have lived in the Northwest, you'll know that there is a lot of heat in the debate over whether smolts should be barged or left in the river. The exercises call upon you to use the smolt model to shed some light on this hotly debated topic.

Exercises

1. Model Check: Zero Mortality
Use the slider controls to eliminate all sources of mortality in the model. Then run the model to verify that the 10 million hatchery smolts will reach the ocean within 30 days under average flow conditions.

2. Model Check: Turbine Mortality
Using a hand calculator, estimate the number of smolts that would reach the ocean if turbines were the only source of mortality. (The mortality at each dam is 15% and there are 8 dams on the river.) Set the turbine survival fraction at 85%; set the bypass fractions to zero; and run the model. You should see 2.725 million smolts reach the ocean.

3. Barging or Modest Draw Down?
Assume that the coming hydroelectric year will experience medium flows. You are asked to recommend either a modest draw down or 100% barging at Lower Granite. (But you can't recommend both.) Which policy would allow more smolts to reach the ocean?

4. Barging or Major Draw Down?
Assume that the year will experience medium flows, and you are asked to recommend either a major draw down or 100% barging at Lower Granite. (But we can't do both.) Which would you recommend to allow more smolts to reach the ocean?

5. What About Low Flow Conditions?
Repeat the analysis from the 3rd and 4th exercises with low flow conditions. Remember you must recommend either a draw down or barging, but not both. Which would you recommend?

6. What About High Flow Conditions?
Repeat the analysis from the 3rd and 4th exercises under high flow conditions. Would you recommend barging or a draw down?

7. Sensitivity Test: Latent Mortality
Lower the *latent deaths fraction* from 51% to 25% and repeat the analysis from the 3rd exercise. Then raise the fraction from 51% to 75% and repeat the analysis. Would you change your recommendations from the third exercise based on the sensitivity tests?

8. Why Study Draw Downs?
The Northwest region has long experience with barging. More recently, it has begun testing the feasibility of draw downs. The draw down tests are vigorously opposed by groups that advocate "regular river operations." They claim that there is no reason to experiment with draw downs when we have barging. Does your analyses shed any light on why the region would be interested in both barging and a draw down?

9. Fish Friendly Turbines
Researchers at INEEL, the Idaho National Engineering and Environmental Laboratory, are working on a new turbine design that would lower smolt mortality. Let's suppose they succeed in reducing the turbine mortality from 15% to 7%. Now, let's suppose we have initial funding to install the new turbines at ONE of the dams. You might install them at Lower Granite, at Bonneville or at any of the dams in between. Which dam would you select if your goal was to install the new turbines where they would deliver the most benefit to the smolts?

10. Friendly Turbine Analysis
Expand the model by introducing a new turbine survival fraction at the dam to receive the friendly turbines. Then use the model to check your answer to the previous exercise. You may assume medium flow conditions, regular river operations and no barging.

Further Readings

1. A "backgrounder" from the Bonneville Power Administration (BPA 1986) entitled *The Magnificent Journey* provides a general overview of the life cycle of the northwest salmon.

2. The declining salmon runs in the Northwest are described by the Northwest Power Planning Council (NPPC 1987) and the National Research Council (NRC 1995).

3. Duncan (1994) describes the fragmentation in planning between various federal and state agencies, the Province of British Columbia and the Indian Tribes.

4. Olsen's (1992) spread sheet model provides support for many of the parameter estimates in this chapter, but you should know that his model is not necessarily endorsed by a majority of planners in the region.

5. Marmorek and Peters (1996) describe a "weight of evidence approach" to evaluate competing hypotheses regarding the causes of salmon decline.

6. The *Return to the River* study by the independent scientific group (Williams 1996) provides a review and synthesis of the science underlying the fish and wildlife program of the Northwest Power Planning Council.

References

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2. Duncan, Angus. 1994. Northwest Power Planning Council. A proposal for a Columbia Basin Watershed Planning Council, August.
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