BWeb Notes for
Chapter 4: Accumulating the Flows

(There are 3 BWeb notes in chapter 4.)

1st Note, Concerning Figure 4.3:

When will the reservoir hold the most water? When will it hold the least water? The answers may be found on the BWeb.

You can answer these question by sketching the *Water Stored in Reservoir* over the 12-month year. Pick a plausible value for storage at the start of the year. (If you want a specific number, try 60 KAF which means the reservoir starts with one year of inflow.) Then mark this same value at the end of the year since we are told that water storage will return to the starting value by end of the year.

The outflow exceeds the inflow for the first four months, so you know that the storage will decline during this period. The outflow and inflow are in exact balance at time = 4 in the diagram, so this is the end of the period of decline. **Time = 4 is the time of minimum storage.**

The next three months show the inflow exceeding the outflow. The extra inflow is particularly dramatic in the 5th month, so the storage will be increasing rapidly during this month. The inflow is declining in the next two months, but it still exceeds the inflow. The inflow and outflow are in exact balance when time = 7. This is the end of the period of growth. **Time = 7 is the time of maximum storage.**

The inflow is lower than the outflow for the remainder of the year, so we know the storage will decline for the rest of the simulation. You sketch should show the storage returning to the value at the start of the simulation.

Students who take the time to perform the accumulation carefully will can arrive at these answers. But the interesting finding from exercises with a variety of students is that many fail to properly accumulate the effect of the flows. For one reason or another, subjects will misread the impact of the flows on the storage in the reservoir. One tendency is to focus on the peak value of the inflow in the 5th month and assume the storage will peak in this same month. The students might be described as following a "pattern matching" heuristic (rather than carefully accumulating the effect of the inflow and the outflow).

The failure to judge the accumulation has profound importance for environmental systems, especially systems with long delays in the adjustment of the stock variables. Further information on the implications of subjects' failure to anticipate accumulation is given in the *System Dynamics Review*:

- Linda Booth Sweeney and John Sterman, Bathtub Dynamics: Initial Results of a Systems Thinking Inventory, *System Dynamics Review* 16(4), 2000.

- Erling Moxnes, Not Only the Tragedy of the Commons: Misperceptions of Feedback and Policies for Sustainable Development, *System Dynamics Review*, 16(4), 2000.

- John Sterman and Linda Booth Sweeney, Cloudy Skies: Assessing Public Understanding of Global Warming, *System Dynamics Review*, 18(2) 2002.

2nd Note, Page 43 under Final Suggestion:

The temptation to match DT to a real-world time interval occurs among those who envision the world advancing in discrete steps. (Perhaps crops are planted each spring, and the market prices are evaluated when they are harvested in the following fall.) If you want a model to match this vision of the world, turn to different modeling methods (BWeb).

Chapter 14 (software) will describe how system dynamics may be used to keep track of seasonal changes (i.e., the crops are planned in the spring, harvested in the fall). The models use “monthly counters” and “conveyor stocks” to simulate systems with “schooling behavior” in which major changes appear in very specific months of the year. The salmon population model in chapter 15 illustrates by simulating the return of the Spring Chinook to the mouth of the Columbia in the spring of each year. The salmon model, like all models in the book, proceeds in a continuous manner through time. Such simulations are sometimes called “real-time” simulations since time advances in a familiar, chronological manner.

However, some modeling methods do not proceed in a continuous fashion thought time. Some simulations are based on the idea that time is advanced in discrete increments. (For example, a model of annual crop production might advance in one-year steps with the harvest in one year setting the price that will determine the planting and harvest in the following year.) Discrete simulations keep track of the current simulation time in whatever units are suitable for the system being modeled. Discrete-event simulations are different from “real-time” simulations (shown in *Modeling the Environment*) because time ‘hops’ from one spot on the calendar to another. The simulated events are instantaneous as the software “clock” skips to the next event as the simulation proceeds through its version of time. More information on discrete event simulation methods may be found in:

- Averill M. Law and W. David Kelton. *Simulation modeling and analysis - third edition*. McGraw-Hill, 2000.

- Jerry Banks, John Carson, Barry Nelson and David Nicol. *Discrete-event system simulation - fourth edition*. Pearson, 2005.

3rd Note, Page 44 under Number of Steps for Numerical Accuracy:

I recommend that we think twice about simulations that require more than 1,000 steps. The BWeb discusses ways to avoid such simulations. It explains that the standard integration method is first-order integration, sometimes called Euler integration. The BWeb discusses higher-order integration methods to obtain faster simulations. As a general rule, simulations should not require us to resort to higher-order methods.

Chapter 17 (Modeling Pitfalls) explains that we can often avoid simulations with over 1,000 steps by replacing "high-turnover stocks" with an algebraic calculation. By getting rid of the high-turnover stocks, we can obtain numerical accuracy with a reasonable value of DT and a simulation that is completed in 1,000 steps or less.

The standard simulation method (in both Stella and Vensim) is the 1st order method, sometimes called Euler[1] integration. The integration is performed using the value of each stock and each converter at the beginning of the time interval to find the flows for the next time step. The flow is assumed to be constant over the time step, and the stocks are adjusted as illustrated in Fig. 4.5. I recommend you stick with the Euler method. Higher-order methods should not be needed if you pay attention to the high-turnover stocks in your model.

However, both Stella and Vensim provide the option for higher-order methods to accumulate the effect of the flows over time. These methods do not rely simply on the value of the flow at the start of the time interval. Rather, they guess values of the flows that apply during the middle of the time step (as this would lead to more accurate integration than using the values at the start of the time interval). Both Stella and Vensim support the higher-order methods known as 2nd order Runge Kutta and 4th order Runge Kutta.[2] Further information on these methods is readily available with the Help features of Stella and Vensim.

---

[1] The Euler method is named after Leonhard Euler, a Swiss mathematician and physicist.

[2] These methods are named after the German mathematicians Carl Runge and Martin Kutta.