**Exercises – simulation modeling**

Quantitative Methods in Ecology

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Objectives for this lab:

* Gain comfort with writing down pictures and equations for a model
* Understand the relationship between differential and difference equations
* Be aware of the available tools for tackling simulation models, including separation of variables, Euler’s method for difference equations, and Runge-Kutta method for differential equations
* Practice using a model and numerical methods to answer a question

**Introduction**

In this exercise we will consider a simulation model of chloride (Cl-) in a lake. Increased application of chloride salts for road de-icing has led to substantial increases in the Cl- concentrations of surface waters in many parts of North America, particularly in urban and suburban settings (Kaushal et al. 2005 PNAS). High Cl- concentrations can impair the suitability of surface waters for aquatic organisms, irrigation, human consumption, and other uses.

The citizens of a local city are considering management actions to try to reduce the chloride concentration of their lake. They could decrease road salt application in the watershed, reducing the concentration of chloride in runoff entering the lake. They could also try flushing the lake by pumping chloride-free water from a nearby, uncontaminated spring and diverting it into the lake. They would like to get some sense for how these potential interventions would change the chloride concentration of the lake, and have called you in to develop a model that can address this question.

You have a few pieces of useful information available, including estimates of the volume of the lake, the volume of runoff entering the lake each year, and the concentration of Cl- in the lake. You also have a model structure, as we have discussed together in class:

[1]

Where

* mlake is the mass of chloride in the lake at time t
* vland and cland are, respectively, the volume of runoff entering the lake from the land per time and the concentration of chloride in that runoff
* vflush is the volume of spring water (with chloride concentration = 0) pumped into the lake per time
* vlake is the volume of the lake

**Exercises**

1. To begin, run the whole ‘lakeSalt.R’ script (e.g. by clicking on the ‘Source’ button in RStudio, or by setting the working directory and then typing source(‘lakeSalt.R’)). Take a look at the graphic output. I have initially set the parameter values to mimic a scenario in which the citizens do not attempt to flush the lake with spring water, but do reduce slightly the application of road salt in the watershed. What happens to the mass of chloride in the lake under this scenario?
2. Now take a closer look at the lakeSalt.R script. With your lab partner(s), talk through what the script is doing.
3. Try some experiments with the model. What happens to chloride in the lake if road salt application ceases completely (cLand <- 0)? What happens if a volume of spring water equal to the volume of natural runoff that the lake receives is pumped into the lake (vFlush <- 1.03e+4)? Try to develop some intuition about how the different management options, and the strength of those actions (such as how high the flushing volume is set) affects the mass of chloride.
4. You have seen by now that the chloride concentration seems to “settle” at some value in the long run after a management change alters conditions in the lake. This is known as the “steady state” or “equilibrium” value. At the steady state, dM/dt equals 0 (think about why that makes sense).

What is the steady state value of M if vFlush is 0 and cLand is 0?

What is the steady state value of M if vFlush is 0 but cLand is 10?

**Feedback**

Towards the end of class we will discuss as a group some of the assumptions of this chloride model. Relax one of those assumptions and then re-draw and re-write the model that we used in this class. Submit a document that identifies the assumption you relaxed and shows your model in pictorial and equation form.