Systems Theory

This discussion of systems theory is taken primarily from Christopherson, pp. 4-9.
Systems are difficult to define but at its most fundamental, a system is “an ordered, interrelated set of items linked by flows of energy and matter as distinct from their surrounding environment.” Thus, most systems are composed of sub-systems, which operate and interact in a (more-or-less) coherent way and make the larger system separate from the environment in which it operates.

An important distinction between types of systems is the open system versus the closed system. **Closed systems** gain no energy or mass from beyond the system boundaries. **Open Systems** may get energy and/or mass from the surrounding environment. Note that some systems, like the **earth**, have elements of both open and closed systems. The earth receives energy from beyond the earth system, the sun, and it returns energy to space after it has driven processes on the earth. So the earth is an open system with respect to transfers of energy. Sometimes this is called an energy **cascade**. However, the earth does not gain mass from space, nor does it send mass to space (not usually anyway). Thus, the earth acts as a closed system with respect to transfers of mass.

One curious and interesting attribute of many systems is that they are **self regulating**. This is also known as **homeostasis.** The interaction of the sub-systems within the larger system is governed by **feedback loops.** As the system operates, it generates outputs that influence its own operations. These outputs represent a kind of “**information**” that is sent or returned to various points in the system via pathways called feedback loops. Feedback information can control (or guide) subsequent system operations through **positive and negative feedbacks**. If feedback information encourages increased response in the system, it is called positive feedback. The rate of change accelerates causing even more change. Further production in the system stimulates growth of the system. Unchecked positive feedback in a system can create a runaway (“Snowballing”) condition. In natural systems, such unchecked growth will reach a critical limit, leading to instability and disintegration. However, most systems maintain their structure and character over time. If the flows of energy and material through the system remain balanced over time, it is called a **steady state system**. More often systems will show a trend in increasing outputs for a time and then decreasing outputs for a time. However, the ups balance the downs and the system continues to operate. This can only occur through negative feedback that dampens out the change that has started. Some negative feedbacks operate immediately; others take longer to have an effect. The speed with which negative feedbacks operate, determines how much the system fluctuates around an average value. A system exhibiting such **dynamic equilibrium** fluctuates more than a steady state system. Most systems resist abrupt change. However the system may reach a **threshold** at which it can no longer maintain its character, so it lurches to a new operational level. This abrupt change places the system in a **metastable equilibrium**.

Types of Systems

A **model** is a simplifed, idealized representation of some part (or system) of the real world. The model makes the system easier to understand. Adjusting one variable in the model produces a system response and allows prediction of possible changes in outputs. Models are designed with varying degrees of abstraction. Types of models range from conceptual to physical, to computer (mathematical) models. To understand system models, one must first understand various types of systems.

There are many different types of systems , and ther are many different ways to model them. We are going to apply **systems theory** to **river systems**. Rivers are prominent features on the landscape, and, therefore on maps. They are not only agents of erosion, but also the means by which the product of erosion (sediment) is carried off and deposited elsewhere. River systems are very dynamic. Sometimes they carry tremendous amounts of water, other times they are almost dry. They are linked as networks. Two or three rivers join to make a larger river and so on. A river system may be thought of as several types of systems.

Morphological Systems. These are defined only by their structural relationships. A map shows the structure of a place. A topographic map is a model of the landforms in a give place. An organizational chart tells you make up and structure of an organization. These can perhaps show how items are linked but have little idea as to the flow or dynamics of the system. In the context of streams and rivers, defining its morphological system wold involve analysis of **stream orders** and other measurable characteristics of the **drainage basin**. These might be slope of the channel, number of channels, perimeter, shape, etc.

Cascading Systems. In these systems, the subsystems are functionally linked so that the output of one becomes the input for another. The flow or progression of mass and energy through several subsystems is known as a **cascade**. Rivers are classic **open, cascading systems**.

Process Response Systems. The focus here is on the total dynamics of the system not simply the flow. Both mass (water and sediment) and energy (moving water) flow downward through the system. However these flows vary tremendously and the response will be different in different river systems or in streams of different age. How large are the flows of mass and energy and when? What is the system response to high flow or low flow? In the context of river systems, a mature river will be in a **graded condition**. This means the river has attained an equilibrium with the amounts of water and sediments typically supplied to it. A young river is attempting to attain grade through the erosional process and will have a different response than a mature river. The young river also has a steeper slope/profile and different morphological measures.

Intelligent Systems. This is where the people who came up with systems theory really blew it. Their idea was that any system that is (largely) under human-control would be called an intelligent system because human intelligence directed the dynamics and outcome. However, in the context of river system, some control is more intelligent than others. Building dams for flood mitigation might be viewed as good and therefore intelligent. However, stripping the land of vegetation, so that floods occur more often and the soil is eroded away more quickly is not exactly an intelligent thing to do. Both are a result of human intelligence (well, at least human activity), but that does not mean the result is good. Nevertheless, many river systems, especially in modern, developed countries can be viewed as an intelligently controlled cascading, process-response systems.

Biological (eco)systems. Finally we need to mention **biological systems**. A river is not a biological system in the sense that the Amazon rainforest is a biological system. Any organism is, in fact, a system maintained with flows of mass and energy. That is true of micro-organisms, and it is true of humans. When many groups of organisms form functioning ecological system it is called an **ecosystem**. Finally, the earth can be viewed as one, single living organism. This is the **Gaia theory of James Lovelock**. He argues that life on the earth regulates many other systems on the plant by affecting (if not controlling) the composition of gasses in the atmosphere, and through that regulating the temperature of the planet. Life on the earth is not simply a passenger on a pile of rocks but rather contributes to homeostasis of subsystems which comprise all the earth system processes.