Appendix 1

Ecosystem processes in watershed development

1 Rock Creek Watershed as an Ecosystem

The term 'ecosystem' was coined by Tansley (1935) although the concept of a higher level of organization of biological systems was in use since the late 1800s (Pomeroy et al. 1988). The notion of the ecosystem is that "living organisms and their non-living environment are inseparably interrelated and interact upon each other" (Odum 1971). Like watersheds, ecosystems can be large or small. For example, a rotting log in a forest can be considered to be an ecosystem, if there is interaction between the living and non-living components of that log. The Rock Creek watershed is also an ecosystem. Since watersheds have identifiable boundaries, it is convenient to think of watersheds as ecosystems; however, the concepts are not interchangeable. Watersheds are simply areas of the landscape that collect water and drain to a stream, river, bay, lake or ocean. Ecosystems are defined as areas in which living organisms interact (i.e., competition, predation, etc.) with each other and their non-living environment. While watersheds can be ecosystems, not all ecosystems are watersheds!

Ecosystems are open systems, that is, they rely on inputs from other ecosystems and from the sun, and they export materials (i.e., nutrients) and energy (contained in organic materials). Although recycling and storage may help to stabilize ecosystems, energy and materials must constantly be replenished in order to keep ecosystems going (Pomeroy et al. 1988). The storage and recycling of materials and the flow of energy is determined by the ecosystem components (abundance and distribution of organisms) and the way in which the components relate to each other and to their abiotic environment.

2 Flow of energy and materials

The flow of water in the Rock Creek watershed largely dictates how energy and materials move through the ecosystem. A goal of watershed management is to maximize the production of valued resources (i.e., salmon, timber, crabs, etc.) while minimizing loss of desired properties or functions (timber losses due to disease; reductions in water quality; flooding; etc.). An ecosystem approach uses knowledge of energy and material movement to help us evaluate approaches for resource management.

Odum (1971) describes ecosystems as having identifiable trophic structure and material cycles (the movement of materials and energy between living and non-living ecosystem components). He identifies the components of an ecosystem as (1) inorganic substances, (2) organic compounds, (3) climatic regime, (4) producers, (5) microconsumers (transformers), and (6) consumers. Human activities can alter both inorganic and organic components of ecosystems through actions such as burning, fertilization, timber harvest, increasing erosion, etc. Human activities can also affect the types of organisms in the ecosystem (producers and consumers) through such activities as sylvaculture, aquiculture, agriculture, or through the introduction of non-native organisms.

Within ecosystems, food energy is transferred from producers (plants) through a series of consumers and transformers (animals, bacteria, fungi) by eating and being eaten (Odum 1975). A trophic level is a group of organisms that all obtain their nourishment the same number of steps from producers; for example, plants are the first step and constitute the first trophic level. Consumers that eat plants (e.g., cows, caterpillars, Black Brandt geese) are all one step away from the producer (the plant) and all belong to the same trophic level although they are very different organisms. The next trophic level would be composed of organisms that ate cows, caterpillars and Black Brandt. The trophic structure of an ecosystem is a functional description of how organisms interrelate (in this case by eating each other) and how energy moves through the ecosystem.

Energy is lost at each transfer between trophic levels. The trophic structure of Rock Creek cannot be infinitely long: the types of organisms and their interactions (predation, competition, etc.) determine how energy moves into and through the food web. Therefore, expectations of desired management action outcomes must occur within certain limits. For example, although it may be desirable to have higher trophic level organisms (e.g., salmon) in the watershed, if food web support is not present, consumers cannot exist.

Ecosystems can be structured by the interactions between living and non-living components. Inorganic substances are ecosystem components (Odum 1971). Several of these inorganic substances, phosphorus (P), nitrogen (N), oxygen (O), carbon (C), carbon dioxide (CO_2), and water (H_2O) are essential to living organisms. Of these substances, N and P most often limit plant growth in aquatic and marine ecosystems (Hutchinson 1973; Wetzel 1983; Schelske et al. 1974). Inorganic substances are taken up by organisms directly from their environment (often through the action of bacteria or fungi) or as food. Inorganic substances are used by organisms as building blocks for proteins, carbohydrates, lipids, or other organic compounds. Organic compounds (another ecosystem component) provide an important structural ecosystem component, as well function to store materials in the bodies of the plants and animals that live in the Rock Creek watershed. In a sense, a resource-based economy depends on maximizing the flow of organic materials into the bodies of desirable species such as salmon, Douglas-fir and oysters. Watershed management is the process of ensuring that human actions upon all components of the ecosystem have the desired effect of increasing target resource production, without excess negative impact to other, nontarget resources.

3 Land cover

Vegetation, both living and dead, provides structure to the terrestrial ecosystem. For example, trees form a substrate for epiphytic plants, slow the wind, reduce rainfall impact to the soil surface, provide shade to the forest floor and streams, bind soils to slow erosion, and provide obstacles to slow the overland flow of water. Undisturbed old growth forests are stable and conservative in terms of sediment movement; root systems, protective canopy and a highly organic soil layer mitigate the effect of intense precipitation in the area (Proctor 1980). The structure of unmowed fields and riparian areas can also slow soil loss. Alterations to slope and to vegetation can accelerate erosion (see Proctor 1980 for discussion).

Vegetation slows down the movement of water. The pool of organic material in forest, shrublands, and agricultural fields holds moisture during dry periods by slowing down evaporation. The importance of large woody debris is recognized in Pacific Northwest forests. Woody debris acts as a food source for some organisms. In addition, woody debris and other organic material slows down water velocities over the forest floor and in streams, thereby decreasing the flushing of materials from the watershed and establishing the complex in-stream environments favorable for many organisms such as salmon. Of all the structural components in the terrestrial ecosystem, woody debris is one of the slowest components of the forest ecosystem to recover after disturbance (Spies et al. 1988).

Terrestrial ecosystems, forests, are the upper end of a continuum that extends from the ridge tops to the sea. Most of the materials and energy move down the elevational gradient. The time that it takes for materials to move depends on how land cover has been modified. Energy and materials leave the terrestrial subsystem when resources are harvested, as animals migrate out of the area or when dissolved and particulate organic materials are transported into the stream network.

4 Sediment Transport: A Conceptual Model

Sediments are produced through various types of erosion, including sheet and rill, gully, road, trail, streambank, and roadside erosion; landslides; and debris flows. Humans influence sediment production rates in many ways, such as vegetation removal for agriculture, timber harvest, roadbuilding, stream channel modifications, and gravel mining.

Landslides (mass wasting) are one source of upper watershed sediments. Landslides occur naturally due to instability of soils and geologic formations. The frequency of landslides may also be influenced by human-induced land use changes. Soil and organic debris that break loose from the hillside may be temporarily stopped by vegetation (trees and riparian areas) before entering into the stream. For any point on a stream course, sediments entering at that point are a combination of those sediments entering from upstream and those that enter from sources on the hillside. Land use practices can dramatically affect the frequency and phasing (timing of pulses of sediments) that enter the stream by exacerbating slumping and removing vegetation which may promote hillside sediment deposition. Sediments can be temporarily removed from a stream by deposition. Sediments may also enter the stream *via* bank erosion. Precipitation patterns and geomorphology determine the quantity and timing of sediment movement.

As sediments are transported down gradient, they eventually enter Siletz Bay. Once in the bay, sediments can be permanently lost from the system as deep sediments (those sediments that do not interact with the water column under normal circumstances) or lost to the ocean. Sediments can also be temporarily removed from the water column by settling to shallow sediments; however, resuspension of shallow sediments can occur under a variety of circumstances (wind, heavy precipitation events, etc.). Sediments that end up as deep sediments remain within the bay and may change processes which occur within the bay. For example, as sediments accrete, deep water habitat may be replaced by mudflats and water circulation patterns and temperature can be altered.

4.1 Erosion and Sedimentation

Erosion is the detachment and transport of material from a surface.

Surface erosion is characterized by lack of channels or rills. Consequences of erosion are many and are not confined to source areas. Much of the concern about steepland erosion is not so much over the loss of soil but over the degradation of stream resources. Steepland erosion is the result of numerous interactions between climate, soil, geology, topography and vegetation. There are also interactions between different types of erosion, that is, one type of erosion can increase or decrease the rate of another type (after Ziemer undated). For example, high rates of runoff and erosion on steep, cleared slopes with roads can result in areas of **mass wasting** (Reckendorf 1994).

In undisturbed forested areas, surface erosion is usually insignificant due to the high infiltration rates of soil (Ziemer undated) and because living and dead plant material intercepts and dissipates raindrop and wind energy (Pimentel et al. 1995). However, logging, road construction, wildfires or mass erosion can expose mineral soil or otherwise decrease soil permeability (Ziemer undated).

Immediate effects of erosion by water and wind include loss of soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrient and organic content, soil biota and soil depth. Vegetation regenerates poorly on these low-quality soils, creating a cycle in which eroded areas remain prone to further erosion due to poor vegetation establishment and the consequent higher runoff rates (Pimentel et al. 1995).

4.2 Mass erosion

Mass erosion (or mass wasting) is the downslope movement of soil or rock in response to gravitational stress. This movement can be slow and subtle to rapid failures of hillsides and stream channels: in undisturbed forested areas, mass erosion is the dominant mechanism by which soil gets into stream channels (Ziemer undated).
Debris flows, **debris avalanches** or **debris torrents** (mass erosion) are generally found in shallow noncohesive soils on steep slopes. Debris flows can be a significant source of sediments and woody debris to streams and rivers. Plant roots can reduce the frequency of these shallow failures. In marginally stable areas, debris avalanches frequency can increase after trees are cut and their roots decompose. Road building activities can also increase the frequency of debris avalanches because road cuts can undercut shallow failure surfaces and road fills can increase the weight of overburden on slope surfaces.
Creep, a type of mass erosion, is the slow downslope movement of soil. In Pacific Northwest forests annual creep rates are generally less than 10 mm yr^{-1};
Earthflow, also a type of mass erosion, can be considered to be accelerated creep where shear stress exceeds the strength of the soil mantle resulting in discrete failures. The movement of overburden during earthflow can be imperceptibly slow or it can exceed a meter day^{-1}. Failures due to earthflow can range in size from less than a hectare to square kilometers.

Mass wasting, such as debris flows, can be responsible for large inputs of sediment into stream systems. Mass wasting can result from natural disturbances, such as floods and fires, but is exacerbated by human land use activities. High rates of runoff and erosion on steep cleared slopes with roads are a prime source of mass wasting. Forest road building and maintenance failures make the most significant contribution to the mass wasting process and sediment (especially gravel) production. On United States Department of Agriculture Bureau of Land Management (BLM) lands, sediment production and delivery are primarily a result of past timber harvest and road construction activities.
Debris flows are a major source of disturbance to riparian vegetation in humid mountainous areas (Swantson 1978, Veblen and Ashton 1978). Landslides, debris flow, and erosion are ultimately the source of terrestrial sediments that arrive in the bay. In addition to supplying organic material and sediments to streams and rivers, these types of disturbances can have a profound effect on the structure and function of ecosystems.

Intense debris flows can remove all vegetation and remove soils down to bedrock (Costa 1984). Lack of upland forest cover and riparian vegetation can lead to chronic sedimentation problems. For example, in areas where vegetation, which would have trapped sediment movement, is no longer present even small rainfall events can lead to significant sediment movement. Surface deposit characteristics and earth flow intensity are the most important influences on revegetation (Gecy and Wilson 1990). Mass movement of earth can also alter landscape successional patterns by promoting the growth of disturbance adapted species. For example, in Oregon streams, red alder (Alnus rubra) seedlings can quickly become established in debris flow zones (Gecy and Wilson 1990).

In addition to removing vegetation and increasing the potential for chronic sedimentation, debris flows can quickly move woody debris from the forest into aquatic ecosystems. Once in aquatic ecosystems, and depending on the stream, woody debris can either become trapped in the stream where it can reduce erosion by dissipating energy in flowing water, store moisture, serve as a seedbed or provide energy, nutrients and structure to the stream channel that can be used by a variety of aquatic organisms (Franklin et al. 1981, Harmon and Hua 1991) or woody debris can be quickly exported from the stream. Dead trees trapped in streams can persist for centuries (Triska and Cromack 1980); therefore, the influence of the dead tree upon the forest-stream ecosystem can be as long-lasting as the live tree (Harmon and Hua 1991), provided the tree stays in the stream.

4.3 Sediments and Stream Channels

The morphology or physical form of a stream channel at any point is a dynamic expression of the climate (as it affects stream flows) and the geology (as it affects sedimentation) of a stream basin. Other variables, such as resistance to flow (friction) and bed particle size, also influence important channel variables, such as width, depth, velocity, slope, and pattern. Perturbations (both human and natural) to a fluvial (river) system can result in site-specific channel changes (e.g., changes in cross-sectional geometry at the point of disturbance) and/or channel morphology adjustments longitudinally over an area of stream downstream or upstream from the point of disturbance (after M. Reiter, 1995).

Human modifications of channels can cause an array of effects depending on the inherent characteristics of a system. In larger river systems these modifications rarely occur in isolation, but interact with other upstream and downstream alterations to channel morphology.

Channel erosion is the detachment and transport of material from a gully or stream channel. The material may be derived from the channel itself or material that has been deposited within the channel by surface or mass erosion. The size, complexity (sinuosity) and transport capability of channels is determined by the energy of the water which flows through the channel. High gradients, low friction and unimpeded water flow characterize high energy channel systems.

Channels are unique; therefore their responses to natural factors and human-induced modifications are also unique. Changes in channel form and process occur longitudinally along a stream. In the downstream direction, the gradient decreases, sinuosity ("curviness") increases, the ratio of **bedload** to **total sediment load** decreases, the grain size of material which can be transported decreases, and the total **discharge** or **streamflow** increases. Large-scale determinants of channel morphology include the following factors; climate, geology/topography, vegetation and soils, land use practices, and in-channel modifications.

Fluvial processes are structured by hydrology, sediment load and movement, and the resistance of the channel to flow and sediment movement. Components of hydrology include the type of flow (baseflow, **bankfull flow**, and highflow), **stream power**, and the hydrological disturbance regime. Sediments can differ in their source, type (suspended load, bedload, turbidity), and size. Changes in sediment load that occur through land use practices can result in sediment accumulation (**aggradation)** or loss (**degradation**) in portions of the stream. Channel resistance is determined by the bank and bed material, vegetation (large wood, riparian vegetation, and roots), and physical form of the channel. Adjustments of channels include a number of factors. Channels have four degrees of freedom or ways in which the form can change: 1) **the longitudinal profile**, 2) **channel sinuosity**, 3) roughness of bed or bank, and 4) **the hydraulic radius**.

5 Aquatic and riparian habitats

There are several models used to describe and inventory riverine areas. These models are useful to resource managers because models promote an understanding of factors that control the abundance and distribution of organisms. First, the River Continuum Concept (Vannote et al. 1980) recognized that there are predictable patterns in the physical characters of stream channels to which organisms adapt. Briefly, the River Continuum Concept (summarized in Table 2.3) can provide resource managers with expectations and an understanding for certain stream reaches. For example, insectivorous fish distribution in the watershed may be controlled by fish passage issues alone, but also by the availability of prey items in the upper reaches of the stream network. Different species of salmonids have specific requirements for current, stream bed substrate and temperature. The Oregon Department of Fish & Wildlife recognizes the relationship between salmonids and Oregon streams and has spent considerable effort to inventory salmonid habitats (ODFW 1994). Indeed, management actions aimed at increasing salmonid populations in Oregon target instream areas. For example, the lack of off-channel alcoves and deep dam pools are thought to limit coho salmon production (Solazzi 1995).

Stream velocity also structures riverine ecosystems. The stream network in the Rock Creek basin occurs along a steep elevational gradient, reaching from the peaks of the Coast Range to the Siletz River. Water velocity in the stream channel is a primary organizing factor for the riverine ecosystem, both the abiotic components (Hynes 1970, Cummins 1988) and the biotic components (Hynes 1970, Merritt and Cummins 1984). At high velocities, water is capable of eroding away the stream substrate and carrying away suspended solids. As the water slows, suspended solids settle; therefore, water velocity affects the stream bed depth (pools), patterns in stream meander, the distribution of sediment sizes along the stream bed (boulders, gravel bars, silt or clay deposits) and the type of organic material (coarse vs. fine). Suspended sediments in turn affect the amount of light reaching the stream bed (important for algal production) and the availability of some nutrients (phosphorus sorbs to particulates). Fast moving, turbulent water has the potential to have more dissolved oxygen than still water due to mixing. Since different types of organisms have different ecological requirements for current, light, temperature, oxygen, food particle size and substrate, it is easy to see that water velocity can be important in structuring the biological communities within riverine ecosystems.

Following the River Continuum Concept, aquatic macroinvertebrates may be used as indicators for instream conditions. Since these organisms may have specific ecological requirements for temperature, dissolved oxygen concentration, current and food particle size , the presence and abundance of these organisms can be related to environmental conditions within a stream. Table 2.3 shows how the composition of the invertebrate community (by feeding / functional group) is expected to change along the river continuum. At higher elevations, in lower order streams, the invertebrate community is dominated by organisms that use coarse particulate organic material (shredders, such as caddisflies [family *Phyrganeidae*]. In higher order streams, shredders are eventually replaced by organisms that use fine particulate organic material in streams (such as freshwater mussels). This demonstrates that the stream network functions to transform organic materials: coarse material is degraded into fine or dissolved materials by biological (invertebrate) and abiotic (i.e., fragmentation, leaching) mechanisms. The processing of organic material within the stream network is fundamental to the biological productivity of the stream.

Table 2.3. General characteristics of streams along the River Continuum of Stream Order (after Cummins 1988).

Stream Order	Description	Width (m)	P/R ratio	light	Organic Material*	Invert. Func. Group	Fish
0	intermittent	0.5-1	hetero or autotrophic	with or without	CPOM periphyton	shredders, collectors, scrapers	none
1-3	headwater	0.5-8	heterotrophic	shading	riparian CPOM & derived FPOM	shredders (25-50%); collectors (50-60%); scrapers (< 10%)	eat invert
4-6	mid size river	10-50	autotrophic	open; low sed load	transported FPOM periphyton CPOM	shredders (<5%); collectors (50-75%); scrapers (25-50%)	eat invert. and other fish
7-12	large river	75-500	heterotrophic	heavy sed load	transported FPOM	collectors (75-90%);	eat plankton and inverts

* CPOM: coarse particulate organic material; FPOM: fine particulate organic material