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Distance Learning Modules on Watershed Management

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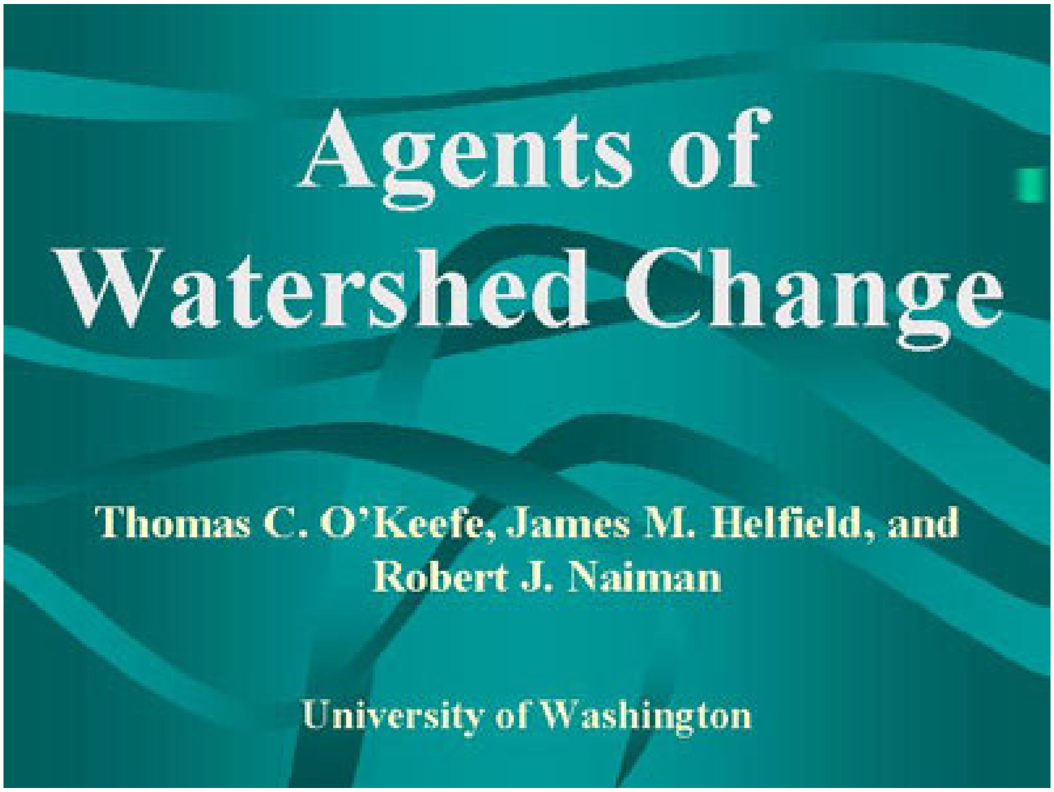

Agents of Watershed Change

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Introduction

This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections (Figure 1):

Watershed Change

Watershed Change Concepts
Natural Change
Human-made Change
How Change Affects Watersheds

Figure 1

- an introduction to the role of change in the watershed,
- descriptions of specific natural agents of change and their ecological effects,
- descriptions of specific human-made agents of change and their ecological effects, and
- a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, ***Introduction to Watershed Ecology*** at http://www.epa.gov/watertrain/ecology.

The training goals of this unit are to:

1) Introduce basic characteristics of watershed change
2) Describe the different sources and effects of natural and human-made watershed change
3) Provide examples of how these changes affect watershed condition

The Concept of Change

Watershed Change

Watershed Change Concepts

Natural Change

Human-made Change

How Change Affects Watersheds

Figure 2

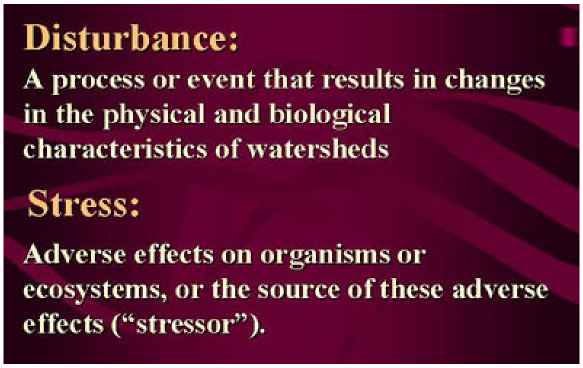
Flowing water is a source of continual change in river corridors

Figure 3

Change is an integral component of the watershed (Figure 2). The wide variations in river and stream flow regularly change shorelines, stream channels and stream corridors (Figure 3). Upland areas of watersheds also undergo changes due to ecological succession, disease, competition, human activity and other factors. Even when virtually undisturbed by man, the physical and biological characteristics of ecosystems do not remain constant over time, as plant and animal communities are continually altered in response to changes in each other and in the watershed's physiographic and climatic conditions. Natural changes do cause adverse effects on some components of the ecosystem, while benefiting others with new opportunities.

The processes and events that cause these changes are generally called **disturbance** or sometimes **stress** (Figure 4). The former term implies any change to a watershed's physical or biological characteristics, and the latter term is a more value-laden word that implies the adverse effects that change usually has on some part of the ecosystem.

Terms like **dynamic equilibrium** (Figure 5) are used to describe the state of existence in which ecological communities exist through and are modified by change. In many cases, periodic disturbance is required to foster ecological processes (e.g., flooding promotes nutrient cycling in riparian soils), or to complete the life cycles of various organisms (e.g., many coniferous trees rely on fire for seed release and dispersal). A certain amount of change is therefore unavoidable, essential and desirable in watershed ecosystems. For this reason, a key element in any concept of ecosystem health is an ecosystem's ability to evolve over time and to self-regulate following disturbance (Steedman and Regier 1990).



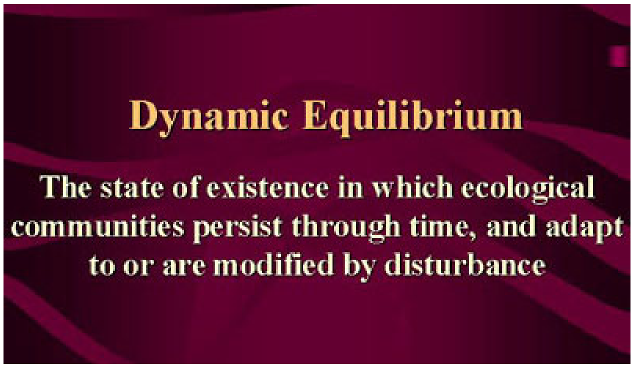
Disturbance:

A process or event that results in changes in the physical and biological characteristics of watersheds

Stress:

Adverse effects on organisms or ecosystems, or the source of these adverse effects ("stressor").

Figure 4



Dynamic Equilibrium

The state of existence in which ecological communities persist through time, and adapt to or are modified by disturbance

Figure 5

> ***Take a moment:*** *Think about the main types of change occurring in your watershed. What changes mostly involve natural components of the watershed ecosystem? What changes in the human community are occurring in your watershed? Are these changes or their magnitude new or unprecedented? What do you think is the outlook for your watershed's human and natural changes, in terms of dynamic equilibrium? You may wish to revisit these questions after completing this module.*

Scale Concepts

Environmental change is caused by a wide range of processes occurring through space and over time (Figure 6). As a basic conceptual framework, think of a watershed as a system incorporating a series of subsystems at smaller spatial scales (e.g., watershed > river corridor > tributary > reach > pool/riffle habitat > microhabitat spaces among cobblestones), each of which are affected by disturbances occurring at time intervals and spatial scales that are (as a very general rule) proportionally related to the magnitude of the subsystem (Table 1). Scale is essential to evaluating change because the significance of a given change is very different from scale to scale. For example, channel form and streamside vegetation may seem constant when viewed over a time frame of months or a few years, but may be highly variable when viewed over a time scale of decades or longer. Similarly, a forest fire may be considered a rare and catastrophic event within the lifetime of a stand of trees, but the same fire may be a natural part of a larger cycle of recurrent fires when considered over a geological time scale.

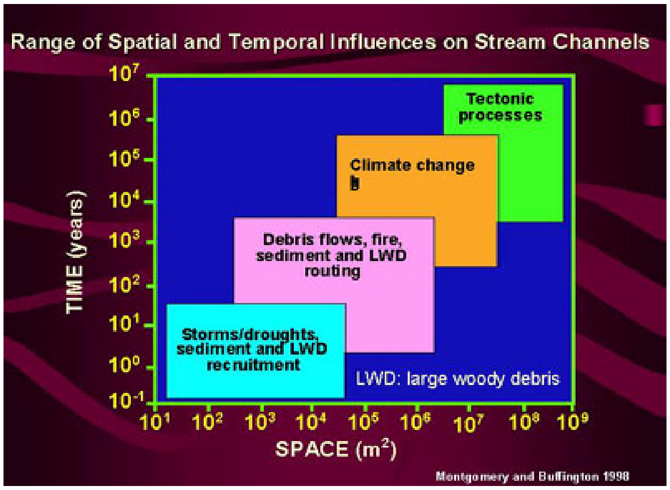


Figure 6

Some events or processes controlling stream habitat on different spatiotemporal scales (from Frissell et al. 1986).

Stream System	**Linear Spatial Scale (m)**	**Evolutionary Events**	**Developmental Processes**	**Time Scale of Potential Persistence (years)**
Stream	10^3	Tectonic uplift, subsidence; catastrophic volcanism; sea level changes; glaciation, climatic shifts	Planation; denudation; drainage network development	10^6-10^5
Segment	10^2	Minor glaciation, volcanism; earthquakes; very large landslides; alluvial or colluvial valley infilling	Migration of tributary junctions and bedrock nickpoints; channel floor downcutting; development of new first order channels	10^4-10^3
Reach	10^1	Debris torrents; landslides; log input or washout; channel shifts, cutoffs; channelization, diversion or damming by man	Aggradation/degradation associated with large sediment-storing structures; bank erosion; riparian vegetation succession	10^2-10^1
Pool/ Riffle System	10^0	Input or washout of wood, boulders, etc.; small bank failures; flood scour or deposition; thalweg shifts; numerous human activities	Small-scale lateral or elevational changes in bedforms; minor bedload resorting	10^1-10^0
Micro-habitat system	10^{-1}	Annual sediment, organic matter transport; scour of stationary substrates; seasonal macrophyte growth and cropping	Seasonal depth, velocity changes; accumulation of fines; microbial breakdown of organics; periphyton growth	10^0-10^{-1}

Table 1

Evolutionary Events

Intrinsic forces that create and destroy systems at a given scale

Developmental Processes

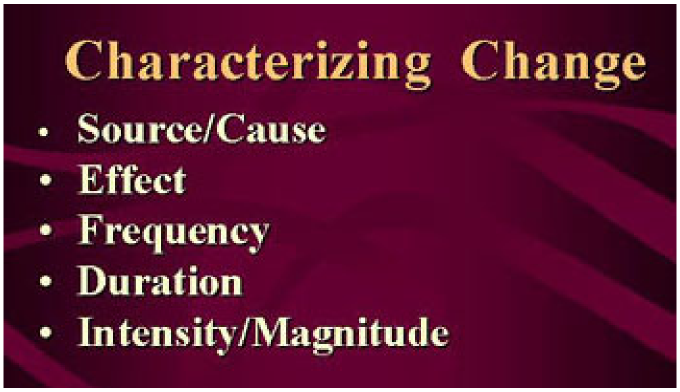
Intrinsic, progressive changes following a system's change as a result of an evolutionary event

Figure 7

There is a distinction to be made between **evolutionary events** (Figure 7), which are extrinsic forces that create, significantly modify, and destroy systems at a given scale, and developmental processes, which are intrinsic, progressive changes following a system or subsystem's genesis or change as a result of an evolutionary event (Frissell et al. 1986). For example, global climate change may result in a shift in the distribution of a various tree species. In this case, climate change represents a large-scale evolutionary event resulting in a predictable set of developmental processes (i.e., shifts in forest community composition) at smaller scales. Similarly, a 100-year flood may be seen as an evolutionary event that scours away and destroys floodplain vegetation communities, giving rise to developmental processes such as forest succession in affected habitats.

Characterizing Change

Different types of changes are usually described in terms of the **sources** or **causes** of change and the **effects** they bring about in the watershed ecosystem (Figure 8). In addition to the type of change that occurs, disturbance processes are typically characterized according to the **frequency** of occurrence, as well as the **duration** of their effects. In general, geological processes and climate cause the primary natural changes affecting higher levels of organization (i.e., the larger-scale watersheds) over long periods of time. Within the context of these larger-scale and long-term processes, ongoing frequent and smaller-scale processes also produce change.



Characterizing Change

- Source/Cause
- Effect
- Frequency
- Duration
- Intensity/Magnitude

Figure 8

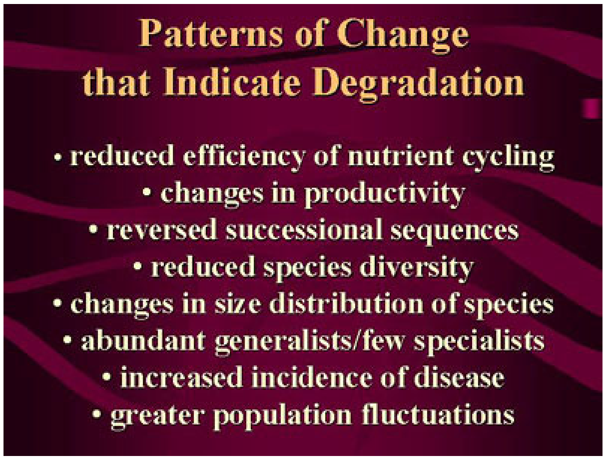
Change processes may also be characterized according to the **intensity** or **magnitude** of their effects. Intensity of disturbance is typically defined according to the magnitude of effects on biotic communities, but can imply physical effects as well (e.g., magnitude of a flood or the quantity of sediments it has moved).

Frequency and intensity of change can highly influence plant and animal communities; species associated with frequently disturbed habitats tend to develop adaptations that allow them to persist or even thrive under those conditions. For example, trees growing in low floodplains subjected to frequent flooding often produce adventitious roots that allow for oxygenation following burial by water and sediment. In dry, upland forests, species such as ponderosa pine withstand frequent fires through such adaptations as the development of thick, fire-resistant bark and dropping of lower limbs to minimize the spread of fire to the crown. Within many watersheds, upper reaches are often prone to infrequent, high-intensity events (e.g., landslides, debris flows), whereas lower reaches tend to be affected by frequent, low-intensity events (e.g. sediment transport and redeposition).

The frequency and intensity of such changes as flooding, windstorms, hurricanes, and brush fires also heavily influence land use planning decisions for many communities, who are often placed in a position of continually evaluating and managing risks versus potential benefits. Examples include southeastern US coastal communities' interactions with hurricanes, and the recurrent flood management decisions of many US towns located on river floodplains. Thorough understanding of all aspects of potential changes can help these communities make sound decisions.

Changes of Concern (Figure 9)

Environmental changes almost always benefit some species to the detriment of others. Accordingly, **environmental degradation** is a subjective, value-laden concept influenced by different ideas of desired environmental conditions. Changes that markedly decrease populations of favored wildlife or plant species, or limit a watershed's ability to provide resources for human communities (e.g., potable water, food/fiber, aesthetics) are widely seen as degradation especially by affected people.

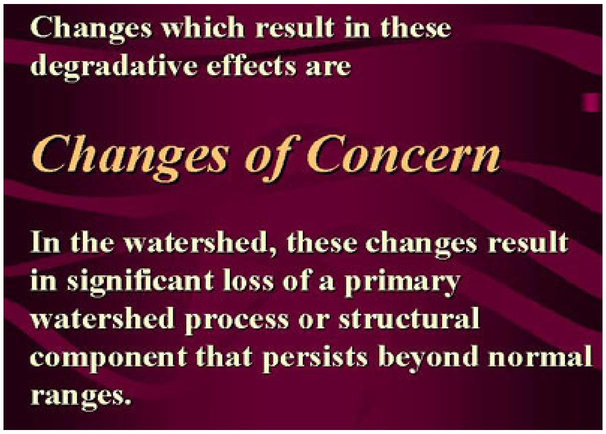

Patterns of Change
that Indicate Degradation

- reduced efficiency of nutrient cycling
- changes in productivity
- reversed successional sequences
- reduced species diversity
- changes in size distribution of species
- abundant generalists/few specialists
- increased incidence of disease
- greater population fluctuations

Figure 9

But, besides these human examples, other patterns of significant change are also symptomatic of degradation; these types of change are not necessarily related to human values or perceptions, but adversely affect ecosystems in ways beyond what is immediately useful to man. These changes include reduced efficiency of nutrient cycling, changes in productivity, reversed successional sequences, reduced species diversity, changes in size distribution of species, increased abundance of tolerant "generalist species" relative to "specialists", increased incidence of disease, and greater population fluctuations (Steedman and Regier 1987).

Changes that produce significant, widespread and/or long-term degradation are **changes of concern** (Figure 10). These types of changes alter the ways in which ecosystems organize, remain functional, and evolve over time, and threaten the abilities of ecological communities to recover and persist following periodic disturbance. Change of concern in the watershed may be defined as the significant alteration or loss of a primary watershed process or structural component that persists beyond normal cyclical change (e.g., seasonal change).


Changes which result in these degradative effects are

Changes of Concern

In the watershed, these changes result in significant loss of a primary watershed process or structural component that persists beyond normal ranges.

Figure 10

Changes of concern are most often related to a human-made cause or to the high-magnitude, cumulative effects of human-made plus natural agents acting together. Except for major evolutionary events discussed earlier, purely natural changes are often not permanently degrading to whole ecosystems because these ecosystems developed in adaptation to these very same changes. As human-made changes are very recent and often very intensive changes, they have not been easily accommodated by ecosystems and thus can lead to more significant and long-lasting degradation.

Nevertheless, it is also possible to consider any change as a change of concern if its "temporary" disruption is unacceptable on human time scales (e.g., duration in human rather than geologic terms) – consider, for example, earthquakes at the San Andreas fault, or a forest fire near a residential community that treasures its nearby woods. Although many natural changes can reach magnitudes often called “natural disasters,” still they represent changes from which watersheds can and do eventually recover, often with different ecological features than before. Human evaluation of the seriousness of natural disasters relates closely to the time scales necessary for recovery of the ecosystem components valued by people.

It is very important to note that many human-made changes of concern are not unavoidable, and considerable progress has been made in understanding human influence on change and how to manage our impacts. Rather, one of the biggest problems is limited awareness of the necessary remedies and a related unwillingness to use them. A major challenge for the watershed manager is to recognize when a change – or the risk of a future change – represents a potentially damaging change of concern rather than a temporary, recoverable change that will leave ecological processes and valued attributes of the watershed intact and functional. When an environmental change proceeds past a certain threshold level, it often results in a change of state at which previous relationships within the ecosystem no longer hold.

Take a moment: *Earlier you were asked to think about changes of all kinds in your own watershed. Do you now feel that any of these changes are changes of concern? To whom or what are they of particular concern? Is your judgment based on these changes causing losses of things valued by people, based on losses of key ecosystem features or functions, or based on both?*

Agents of Natural Change in Watersheds

Agents of change may be naturally occurring or anthropogenic (Figure 11). In many cases, change involves interactions between human and natural processes. First, this module will provide brief descriptions of several agents of natural change processes, along with their general effects on watersheds. Then in the next section, a series of human-made agents of change will be discussed.

Watershed Change

Watershed Change Concepts
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Figure 11

Natural Change Processes

The natural agents of change listed in Figure 12 all have had important direct impacts on watershed ecosystems and their evolution over countless centuries. There are many additional natural change agents beyond those listed and discussed here.

Natural Agents of Change

- Flooding
- Drought
- Fire
- Windstorms
- Erosion/sediment deposition
- Climate change
- Glacial movement
- Tectonic activity
- Volcanic eruption

Figure 12

Natural Change Processes: Flooding

In rivers and streams, floods are critical for several reasons (Figure 13). They redistribute organic material and living organisms downstream and create an opportunity for exchange of sediment and nutrients with the floodplains. Major structural elements of the channel are redistributed during floods and new surfaces are exposed. During particularly intense floods entirely new channels can form, riparian forests can be displaced, and major landslides and debris torrents can be triggered, leading to a more extensive ecological recolonization and recovery period.

Major flooding effects on a Virginia river (left) included the flattening of riparian forest trees; the most visible effect on a nearby small stream (right) was soil erosion.

Figure 13

Variation in flow on a seasonal and interannual basis is a primary selective force for organisms living in rivers and their associated watersheds. Floodwaters also play a major role in shaping the physical environment of the stream channel and floodplains. For example, the bankfull flood stage (a flood level which fills the main channel and just begins to spill onto the floodplain), which is a flood level that recurs approximately every 1.5 years on average, is recognized as the primary force in determining the shape of the channel and the location of its floodplains. The amount and velocity of streamflow and the shape of the channel affect the size of materials transported and the stability of the streambed, which in turn affect the density and composition of benthic organisms. Across much of North America, seasonal floods are associated with the spring snowmelt. In other parts of the country, floods occur during extreme weather events such as hurricanes (southeast coastal areas) or periods of extended rain.

Natural Change Processes: Drought

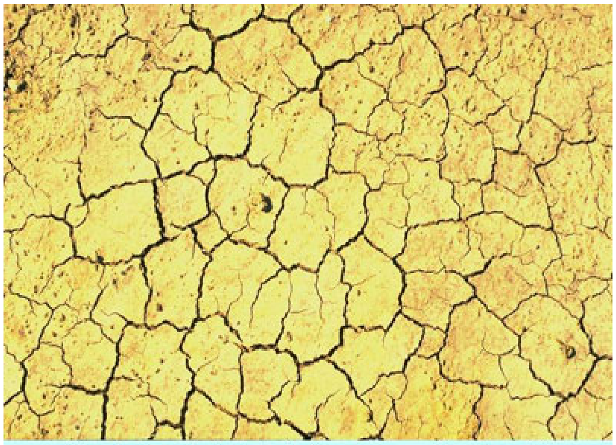

Cracked mud of a lake bottom exposed by drought

Figure 14

In addition to its obvious adverse effect of significantly reducing overall water volume or flow, drought can have a major impact on water chemistry by altering the relative contribution of groundwater versus surface water (Figure 14). This can in turn result in changes in the water chemistry, transparency, light regime, and thermal characteristics of lakes and rivers. Drought also may totally dry up temporary water bodies such as woodland ephemeral pools, small streams with marginal flow, or seasonal, pothole-type wetlands. Many organisms are uniquely dependent upon these ephemeral waters that are absent from the landscape during periods of drought. For several species of birds and amphibians, the disappearance of seasonal water bodies during times of drought can have a detrimental effect on the population due to temporary elimination of breeding or feeding grounds. Many years of depressed population numbers in these species can follow droughts. Other species, including most microcrustaceans, many other amphibians, and even some species of fish can wait out periods of drought by going through a stage of dormancy that, in the case of some crustaceans, can last up to hundreds of years.

Beyond affecting the water body and its aquatic organisms, drought significantly affects upland areas of watersheds. Severe drought can cause dieback of less-tolerant tree and shrub species and lead to shifts in dominant vegetation. Crop failures from sustained droughts can eventually lead to abandonment of some areas' agricultural land uses and communities. As witnessed in the "dust bowl" years, droughts can also liberate huge volumes of topsoil that is no longer stabilized by crops or natural vegetation. This may have severe effects on water quality and on productivity of the topsoil-deprived lands as well as the new sites of deposition.

Natural Change Processes: Fire


Crown fires burn hotter and can cause stand replacement, unlike surface fires which consume leaf litter and promote germination and growth of more conifers.

Figure 15

Fire frequencies and intensities are controlled by soil moisture, ignition sources (e.g., lightning) and fuel buildup (i.e., amounts and combustibility of litter) (Figure 15). In North America, fires in coniferous forests typically occur during dry summer periods, and dry upland areas are generally more prone to fire than riparian areas. Longer intervals between fires entail greater fuel buildups and correspondingly more intense fires when they do occur. There is a distinction to be made between surface fires, which tend to occur at frequent intervals (1 to 10 years) and burn at low intensities (200 to 800 kW/m), and crown fires, which occur less frequently (100 to 1,000 years) and burn at high intensities (>50,000 kW/m). Crown fires tend to do more damage to trees and are more likely to initiate stand replacement by other, pioneer species.

Fires in and around Yellowstone National Park (Figure 16) burned over 250,000 ha in 1988, a major disturbance event which likely occurs on intervals of 100-300 years (Turner et al. 1997). The spatial pattern of fires on the landscape could not be predicted by landscape characteristics. Instead, fire spread was determined largely by wind speed and direction. Although the Yellowstone fires are often thought of as a single event, individual burns created a heterogeneous mosaic across the landscape. Low intensity surface burns occurred in some areas while high intensity crown fires occurred in other areas.

Frequent low-intensity fires play an important role in shaping various forest associations. Species such as lodgepole pine and jack pine rely on heat from fires to open cones and allow seeds to disperse, while exposed mineral soils following fire encourages germination of pine seeds. In some areas, fire resistance adaptations (e.g., thick bark, dropping of lower limbs to prevent fire ladder effects) allow species like ponderosa pine and red pine to withstand periodic low-intensity fires, maintaining open stands with minimal shading and competition for soil resources from other species. More intense fires kill off mature trees, creating open conditions for early successional species such as alder, which fixes nitrogen to contribute to soil and litter pools. Small, patchy fires (Figure 17) help maintain a mosaic of different seral communities within a given watershed, thereby increasing habitat complexity and diversity.

Wildfire effects on water quality can vary widely. Very intense fire can volatilize important nutrients needed by terrestrial plants, but less intense fires can mobilize nutrients for rapid uptake and growth (FISRWG, 1998). Large-scale fires in a watershed with steep slopes can accelerate erosion and runoff, raise water temperatures due to removal of riparian cover, and leave a watershed more vulnerable to other disturbances for a period of years.

Regrowth of pines following the Yellowstone National Park wildfires of 1988

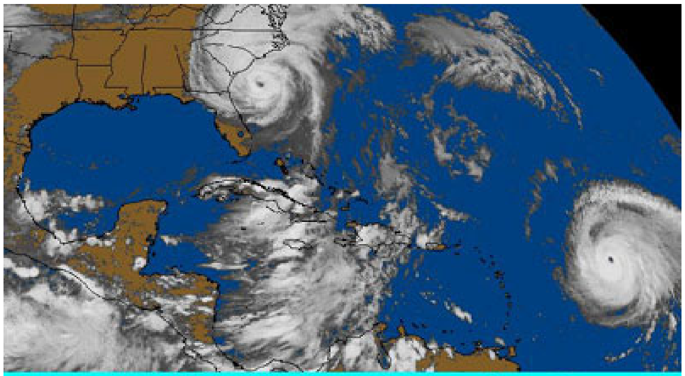
Figure 16

Small fires like this one in Wenatchee, WA help maintain a mosaic of different plant communities within a given watershed, thereby increasing habitat complexity.

Figure 17

Natural Change Processes: Windstorms

Windstorms are one of the many factors responsible for maintaining the spatial mosaic of different vegetation communities that exists across the landscape (Figure 18). Extreme windstorms, such as tornadoes in the Central US and hurricanes in the Southeastern US, occur regularly. In the Pacific Northwest, ten known storms with hurricane force winds have hit the coast in the last 200 years. Two of these storms had winds in excess of 150 mph. Many hurricanes, as well as simply high winds over sustained periods of time, have deforested areas of hundreds to thousands of square miles. In 1999, for example, 25% of the Boundary Waters Canoe Area of Minnesota was deforested in a massive blowdown not associated with a hurricane.



A September 1999 satellite image shows two large, Category 4 hurricanes (Floyd and Gert: up to 155 mph winds) approaching the US coast. Wind and rain damages from Floyd extended from the Carolinas through New England.

Figure 18

The effects of a windstorm can depend greatly on the local topography and the vegetation present (Figure 19). Disturbance associated with wind can thus be quite patchy. The ability of a given tree to withstand a windstorm depends on not only the energy of the wind, but the exposed surface area of the tree, its root mass, and the characteristics of the soil it is rooted in. Small groves of old-growth trees found in second growth forests can be especially susceptible to windstorms. Blowdown patches form open areas that become habitat for edge-preferring plant and animal species. Synergy between windstorms and pest outbreaks is evident when a disease weakens a stand of trees that later become victims of high winds. There can also be interactions between human land use and the effects of windstorms, as when removing natural windbreaks makes remaining vegetation more susceptible to windthrow.

Substantial damage to mature trees occurs during hurricanes, but regrowth can be rapid

Figure 19

Wind can affect water quality and aquatic ecosystem health, for example, by adding significant quantities of windblown soil to the water. Wind events are often responsible for transporting debris and in some cases organisms to different areas of the lake. Even non-extreme winds play an important role in determining when a lake stratifies or destratifies and the length of time that it retains an ice cover. The timing of lake turnover in the fall, for example, depends on the relative strengths of wind energy and the water's buoyant resistance to mixing.

Natural Change Processes: Erosion and Sediment Deposition

Despite the fact that erosion can dramatically affect water quality, it is a natural process (Figure 20). Sediment erosion, transport and redeposition are among the most essential natural processes occurring in watersheds. In fact, cutting off sediment supply (as when an impoundment intercepts cobbles, gravels and smaller particle sizes normally transported downstream as a stream's bedload) can lead to dramatic shifts in streambed composition and stream downcutting, among other effects.

Sediment eroded from a wilderness area upstream enters a California river; the natural balance of erosion and deposition replaces sediments carried downstream with sediments of similar quantity and particle size from upstream.

Figure 20

Although sediment may enter a river from adjacent banks, most is transported from upstream sources. Sediment supply can be a major factor in determining channel morphology, which in turn determines many of the primary physical and biological characteristics of a river. During the 1964 floods of Northern California and Southern Oregon, for example, channel widths doubled and channel beds aggraded up to 4 meters in response to increased sediment loads. Sediment transport depends on the interaction between upland topography, which represents the source of sediments, and discharge regime, which supplies the kinetic energy for their distribution in the river channel. The vegetation cover, climate, soil type, and slope gradient can all influence the location and nature of erosion. Dramatic changes can occur, for example, when intense rainstorms cause landslides or when a stand-replacing fire changes the vegetation cover on a hill slope. It is important to note that in most parts of the watershed erosion, transport and deposition do not occur at constant rates, but are highly active during events such as flooding, windstorms, ice scour, and seasonal or drought-induced exposure of soils.

The relationship of transport capacity to sediment supply determines the channel response to inputs of sediment. Widening and aggradation of the channel, pool filling, and braiding can all occur when sediment supply overwhelms the ability of the river to transport it. Channels with too-high sediment supply tend to be unstable and have multiple active channels separated by bars.

Natural Change Processes: Climate Change

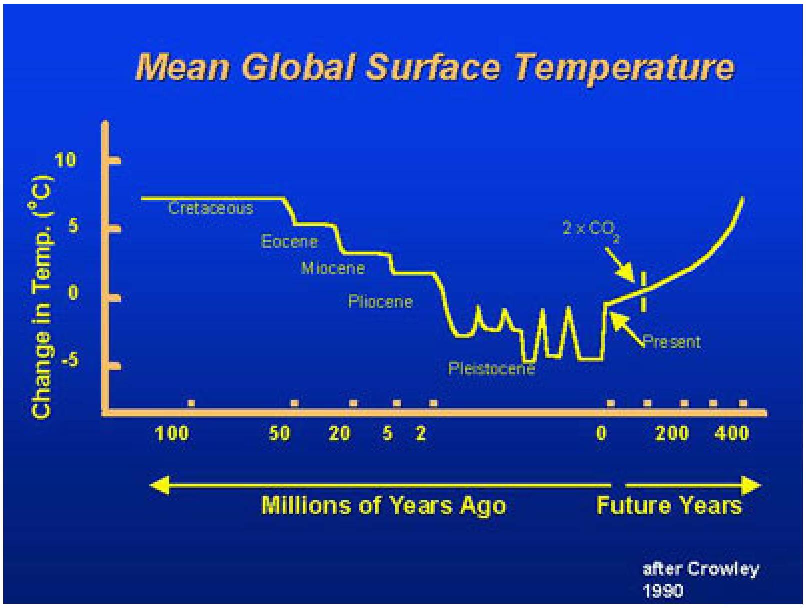


Figure 21

Although there is strong evidence of human-induced climate change effects, climate change has long been a natural agent of change occurring gradually over broad spatial scales (Figure 21). Climatic conditions and atmospheric CO_2 concentrations have been variable on a scale of glacial-interglacial cycles, as evidenced by analyses of gas bubbles in Antarctic ice, simulations by atmospheric circulation models, estimates of global ice volume, and paleolimnological analyses of pollen grains in lake and bog sediments. These paleo-records of climate clearly indicate that climate has varied due to natural causes on time scales from decades to millions of years. The present warm period began approximately 10,000 years ago with the end of the last ice age. Within this time, minor fluctuations have occurred in climate. The Medieval Warm Period reached its peak in the 12th and 13th centuries. This was followed by considerably colder climate that lasted until about 1890 referred to as the “Little Ice Age”. During this period mean global temperatures were approximately 0.5-1.0°C cooler than today. On even shorter time scales (years to decades), the El Niño phenomenon has widespread effects on global climate. In general, the dominant tree species in North America today have probably become common only within the past 10,000 years, and have likely attained their current distribution within the last 3,000 - 5,000 years (Brubaker 1988).

This process has potentially important implications for long-term watershed management, particularly in parks and wilderness areas that have been established to preserve certain species or communities. Over the life span of long-lived species, climate may change to the extent that subsequent generations will not reproduce effectively in protected areas. For example, the oldest populations of giant sequoia in California national parks experience generally drier conditions relative to when they were established, 2,000 - 3,000 years ago. As a result, seedling establishment may be hampered and populations may be in decline. Vegetation responds to climate at the level of the individual species rather than as an intact assemblage of species. As climate changes in the future, we should therefore expect the formation of new communities rather than the simple displacement of existing communities to new locations (Crowley 1996).

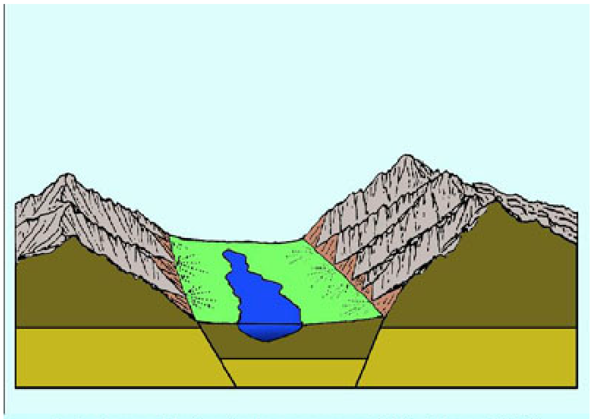
Natural Change Processes: Glacial Movement

Glaciers have transported sediment, carved the landscape, modified vegetation, and redistributed fish and wildlife.

Figure 22

On the time scale of human lives, lakes and river valleys appear to be relatively permanent features on the landscape (Figure 22). On a geological time scale, however, they are ephemeral. Pleistocene glaciation (12,000-15,000 years ago) was responsible for forming the majority of lakes we find in North America, particularly those in the northern latitudes. Glaciers slowly moved across the landscape creating lakes by a variety of processes. Basins are created by active ice scouring that carves them out, dams composed of either of glacial debris or ice, or depressions that are left behind as the glacier retreats. Despite the slow pace associated with glacial activity, historically spectacular floods have occurred when glacial dams have failed. During the last ice age, ice dams across the Clarks Fork River in Montana formed glacial Lake Missoula. At its maximum filling, the lake was 2,000 feet deep and contained 480 cubic miles of water, which is comparable to Lake Erie and Ontario. The ice dams would fail catastrophically when they began to float, and the waters poured across western Washington and drained into the Columbia River Gorge. The estimated discharge from the greatest flood is approximately 9 cubic miles of water per hour, which is 450 times the maximum recorded for the Mississippi River. The resulting flood was of dramatic proportion and rushed through the Columbia gap in less than one week, scouring the Columbia River Gorge to its present day configuration. Rocks that originated from the Rocky Mountains can be found over 1000 feet above the present river level along the Columbia River in western Oregon (sources: Alt and Hyndman 1995).

On a much smaller spatial scale, ice is an important agent of change in many northern watersheds. Ice jam-induced floods at “ice-out time” in early spring can significantly modify channels and floodplains, and the plant and animal communities that inhabit them.



Lake formed by tectonic processes (Hutchinson 1957)

Figure 23

Natural Change Processes: Tectonic Activity

Tectonic activity has formed lakes and altered the course of rivers over long periods of geologic time associated with uplifting and over the short events associated with earthquake activity (Figure 23). Slow movements of the earth’s crust have exposed the Florida peninsula which was once covered by the sea. Irregularities in the land surface created by former ocean currents created basins that are now lakes, an example being Lake Okechobee. By a different tectonic process, the irregular tilting of fault blocks creates depressions such as the basin where Lake Tahoe is located. In contrast to these slower processes, movements of the earth's crust associated with earthquakes can form basins and domes over very short periods of time. The New Madrid Earthquake of 1811 formed several of the lake basins of Tennessee and Missouri while a dome reversed the flow of the Mississippi River for a short time before it cut a new course to the sea. Local subsidence along fault lines such as the San Andreas forms depressions that become lakes. Earthquakes can also cause landslides that dam rivers or alter their courses (sources: Hutchinson 1957).

Natural Change Processes: Volcanic eruption

Volcanic eruptions can alter watersheds with tremendous force and over time periods as brief as hours or minutes (Figure 24). New lake basins are formed while old ones fill in. Changes in local topography create new routes for water that result in mountain streams where they had not existed before. Lava flows can cross stream channels either damming them to form lakes or diverting flow towards a new course. On Mt. St. Helens, the eruption of 1980 resulted in huge mudslides that formed a dam resulting in a much-enlarged Spirit Lake. Extensive areas of upland forest were incinerated and/or buried, and numerous nearby streams and rivers underwent fish kills due to heavy sediment loads in the water, primarily due to deposited ash. The gradual recolonization of the upland areas and water bodies has provided an excellent laboratory for observing recovery.

Mt. Hood, one of several volcanic peaks in the Pacific Northwestern US.

Figure 24

Volcanic events have a dramatic impact on upland forests, by destroying and modifying existing vegetation and creating new substrate. Primary impacts of volcanoes on forests are caused by the mechanical destruction of vegetation by lava flows or pyroclastic flows and associated fires, debris avalanches that occur with partial collapse of a volcano, mudflows which often follow existing stream channels and can transport debris, burial from ash deposits, and blowdowns from shockwaves. Secondary impacts can include soil changes and even climate changes. The ash from the Krakatoa eruption of 1883 encircled the globe and limited sunlight penetration reducing growing seasons as far away as North America. The species of vegetation most affected and their recovery from a volcano are determined by their ability to survive the eruption, their distance from and characteristics of the eruption, and the time since the eruption occurred.

Human-Made Changes

Change through anthropogenic factors is often closely tied to, and interactive with, natural change. A common form of human influence on watershed change is that the same **type** of change may occur, but at a very different **magnitude** or **frequency** (Figure 25, next page). You will note in the following discussion of human-induced changes that many of the same effects on the ecosystem are evident, but at magnitudes or frequencies that watershed ecosystems have not become adapted to over time. As mentioned, when these intensified changes exceed certain thresholds, recovery is no longer certain and significant loss of natural resources, goods and services can result, to the detriment of human and ecological communities alike.

Given that some change is natural, could human-induced changes really be that harmful, or would ecosystems simply adapt to our modifications? The capacity of the human race to adversely influence the natural environment is best illustrated by our influence on the rate of biological species extinctions. In 1999, a working group of the world's leading evolutionary biologists ranked the brief period of human presence on earth as among the top 4 sources of mass biological extinctions in the planet's history. Recovery from the previous mass extinction period did take place, but it required 10 million years to occur.

Watershed Change

Watershed Change Concepts
Natural Change
Human-made Change
How Change Affects Watersheds

Figure 25

Human-Made Agents of Change

- Modification of river flow
- Agriculture
- Timber harvest
- Urbanization
- Fire suppression
- Mining
- Harvesting of fish and wildlife
- Introduction of exotic species
- Accelerated climate change

Figure 26

Human-induced changes (Figure 26) include those major agents of change listed at left, plus a large number of minor and indirect effects too numerous to include in this discussion. While many management measures to avoid, minimize or otherwise remediate human-made changes have been developed, these management remedies are covered in other Academy 2000 modules rather than here, due to module length.

Human-induced Change Processes: Modification of River Flow

Land uses such as urbanization, agriculture and timber harvest in watersheds change runoff and flow in significant indirect ways, but this section specifically addresses how river flow is modified directly when water is impounded or diverted (Figure 27). In many cases, impoundment and water withdrawal occur together with the result that

Grandfather Falls Dam, Wisconsin has had a visible effect on reducing flow volume and changing sediment characteristics downstream, with resultant changes in aquatic habitat quality.

Figure 27

flow amplitude is reduced, baseflow variation increases, temperature regime is altered, and mass transport of materials declines. When these things occur, overall connectivity between upstream and downstream reaches and between the river and its floodplain are compromised. This has a detrimental effect on biodiversity and ecological processes. These effects are significant across much of North America. Approximately 3,500,000 river miles were once free flowing; of this, 500,00 to 600,000 miles (14 to 17% of total) are now behind dams. 1,523 hydropower projects are currently operating under FERC license or exemption but approximately 60,000 dams are found in the United States (source: FERC). Although many of these dams are small they do have an impact on the flow regime of rivers and streams. Only 312 significant streams in the lower 48 States (0.4% of the total U.S. river mileage) are still free flowing and undeveloped in their entirety. None of the 15 large rivers in the continental United States (mean annual discharges > 350 m3/sec.) are unaffected by human impoundment and diversions.

Even where dams exist, they can often be operated in a manner to that more closely mimics natural flow regimes. For more on this topic, visit the Academy module ***Protecting Instream Flows: How Much Water Does a River Need?*** (http://www.epa.gov/watertrain/river); Although it is unlikely that it will be possible or desirable to operate a dam in a manner *entirely* consistent with a natural flow regime, measures can be taken to both stabilize base flows and ensure flows necessary to reconfigure channels and transport and exchange sediment. Lack of periodic high flows in the Colorado River's Grand Canyon justified a carefully planned "flushing flow" water release, designed to restore habitat types that had been affected by the altered sediment dynamics caused by the dam.

Flow regime, however, is not the only aspect of a river affected by dams. Dissolved oxygen, sediment transport and habitat are also affected.

Downstream temperature can also experience significant changes in response to dam operation. Reservoirs in temperate latitudes typically stratify as lakes do, with a warm surface epilimnion layer and a cold, dense hypolimnion in the depths. Dams that release surface water tend to increase annual temperature variation whereas dams that release deep water will tend to decrease annual temperature variation. Substantial biological consequences can result from altered temperature regimes and related changes in dissolved oxygen. Dams also act as sediment traps that limit downstream sediment delivery, with mixed effects on downstream habitat. In the arid Southwest, for example, non-native trout fisheries are now present at the base of dams that release cold clear water into river channels that were once filled with warm, sediment-laden water.

Human-induced Change Processes: Agriculture

Agricultural practices can affect watersheds through several different means (Figure 28). Primary changes of concern result from streamside vegetation removal and soil tillage, application of fertilizers and pesticides and their subsequent export into water, grazing practices that can shift grassland vegetation to dominance by inedible species, and irrigation practices that dewater streams to levels that harm aquatic communities.

Figure 28

The clearing of forested watersheds for crop and pasture lands has often resulted in degraded water quality and modification of natural flow regimes (i.e., increased erosion, turbidity, fluctuations in discharge and temperature), compounded by such practices as soil tillage and application of fertilizers and pesticides. Under agricultural development, crops generally represent sparser ground cover than indigenous vegetation, allowing greater erosion and soil loss. Lands are ploughed and smoothed to create planting surfaces, while use of heavy machinery for tilling and threshing compacts soil. In temperate watersheds, soils are often ploughed in fall for spring planting, and are left bare throughout the winter and spring months during peak flow season, a practice which makes for increased runoff and vulnerability to surface erosion. Of the approximately 650,000 tons of suspended sediment delivered annually to the Great Lakes from agricultural watersheds, an estimated 0-30% are from bank erosion and 70-100% are from cropland and sheet erosion (Wall et al. 1982).

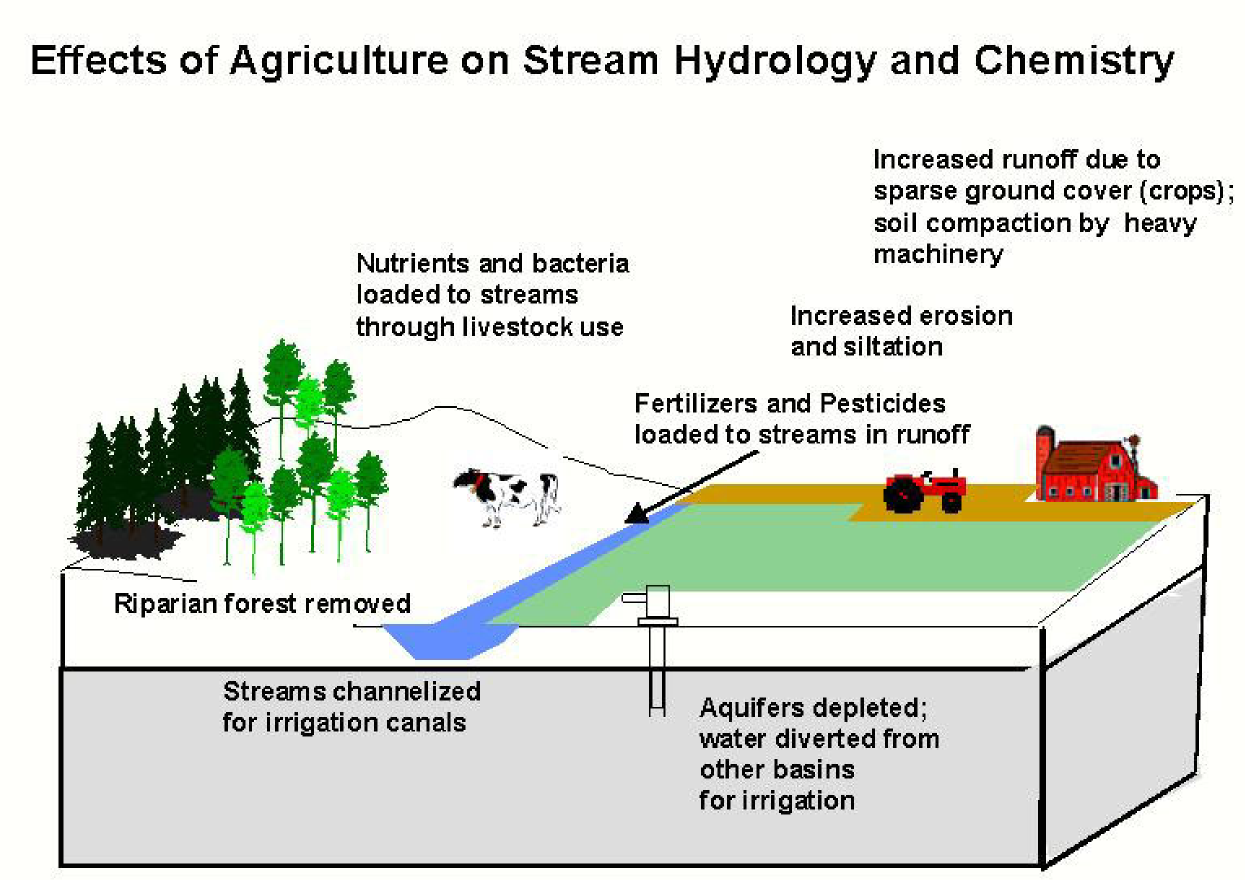


Figure 29

In addition to altered hydrologic regimes, streams through agricultural lands typically feature high exports of dissolved nutrients (e.g., NO3, PO4) as a result of fertilizer applications and loss of forest cover (Figure 29). A typical result in agricultural streams and lakes is increased primary production (i.e., eutrophication) and depletion of dissolved oxygen as excess organic matter decomposes. Organochlorine compounds associated with pesticide use are also found in some agricultural waters. Although pesticides typically occur during a limited spray season, some compounds persist long enough in soils to load continually throughout the year via suspended sediments in surface runoff. In many cases, toxic effects may persist for several years after pesticide use has stopped. The pesticide DDT, for example, was banned in 1972 for most uses in the United States, but it continues to be found in trace amounts in soil, sediment, and tissue samples from agricultural watersheds across North America.

In some areas of the United States, particularly in the arid and semi-arid lands of the West, livestock grazing with unlimited access to the stream channel and banks can cause degraded water quality and is one of the most significant rural sources of non-industrial pollution (Figure 30). Although they often make up a small percentage of grazing areas by surface area, riparian zones (vegetated stream corridors) are particularly attractive to cattle that prefer the cooler environment and lush vegetation found alongside rivers and streams. This can result in increased sediment and debris input into streams due to “hoof shear,” trampling of bank vegetation, downcutting by the destabilized stream with resultant drop in the water table, loss of fisheries, and direct deposition of wastes into waterways. Ironically, despite livestock’s preference for frequent water access, farm veterinarians have reported that cows whose stream access is limited are healthier.

A field crew measures downcutting by a creek whose banks were trampled and destabilized by cattle. A lowered water table has reduced forage grasses in the adjacent pastures. Resident trout populations have also vanished.

Figure 30

Pivot irrigation (left) in a subhumid climatic region loses water to evaporation; drip irrigation (right) is water-efficient, but still risks overusing groundwater reserves in some areas.

Figure 31

Irrigation of agricultural fields has had dramatic impacts on watershed hydrology through the diversion and detention of running waters and overutilization of groundwater reserves (Figure 31). In many cases, impacts are felt over broad regions encompassing several watersheds. Agriculture represents the heaviest demand for water in most parts of the United States, and accounts for more than 2/3 of global water use, but irrigation is a largely inefficient process, and less than half of all diverted water actually reaches the intended crops. Much of this loss is due to evaporation from reservoirs and seepage from canals. Because there is not widespread awareness of this loss, and because different political bodies have jurisdiction over parts of what is really a connected system, water rights for many river basins are oversubscribed. The Colorado River, for example, flows through seven U.S. states and Mexico, and these jurisdictions together have legal rights to withdraw more water annually than the river actually contains.

There are countless opportunities for reducing the adverse effects on aquatic systems from agriculture and grazing by following well-documented and publicized Best Management Practices (BMPs). Probably the best-known and most widely useful category of BMP is the retention of naturally vegetated buffer strips along streams (Figure 32). Streamside buffers serve many functions including nutrient filtering, bank stabilization, reduction of soil loss and land loss, moderating water temperature (which helps dissolved oxygen and hence fisheries), and terrestrial wildlife habitat and corridors for movement. Two challenges -- informing everyone who might be able to use BMPs, and overcoming resistance to changing established habits -- face watershed managers who hope to improve water quality in agricultural areas. CORE-4, a targeted public information program designed for the farmer and rancher, is a national outreach effort of the US Department of Agriculture's Conservation Technology Information Center, which promotes the four best practices to minimize agricultural impacts on water quality: buffers, conservation tillage, crop nutrient management, and weed and pest management.

Natural riparian vegetation buffers and farmlands in the North Fork Shenandoah River valley of Virginia.

Figure 32

Human-induced Change Processes: Timber Harvest

Many watershed effects of timber harvest are similar to agriculture's effects (Figure 33). Aquatic impacts such as altered runoff and streamflow, increased sedimentation, and addition of nutrients can result from silvicultural operations. The most obvious terrestrial change associated with timber harvest is that of removal of vegetation, but other common changes involve habitat alteration, altered species diversity and stand age. There are also numerous indirect effects.

Large clearcuts in the Oregon Cascades comprise a greater proportion than forests of the landscape visible here.

Figure 33

Under commercial forestry, mature, multi-aged, mixed-species forests are often replaced with young monoculture stands of commercially valuable species. In many cases, harvested lands are left denuded of live vegetation for long periods of time. These changes in forest habitat have different effects on different species. Species which rely on old-growth conditions for parts of their life cycle (e.g., northern spotted owl) may be adversely impacted, whereas species which use edge habitats (e.g., white-tailed deer) may increase in population. Intensity of disturbance generally corresponds with the spatial scale of the area cut, whereas rotation lengths control frequency. Accordingly, there is a distinction to be made between clearcutting (Figure 34), in which all trees harvested from a given area and replaced with an even-aged stand, and selective harvesting (i.e., some trees removed, others remain, resulting in a mixed-age stand). Whereas clearcutting results in drastic change over large areas of forest habitat, selective cutting may also produce significant impacts, as rotation lengths are typically shorter, and sites are therefore disturbed more frequently.

A Cascades clear cut within the first few years of regrowth after timber harvest.

Figure 34

In addition to terrestrial impacts, timber harvesting may have significant effects on stream discharge and water quality. Loss of mature vegetative cover leads to decreased evapotranspiration and correspondingly increased peak flows. These effects are compounded by road construction, which creates permanently bare surfaces and compacts soil, resulting in decreased infiltration and increased surface runoff (Figure 35). Logging roads also fragment and isolate habitat patches from smaller, less mobile animals such as salamander species, and roads' stream crossings and culverts sometimes become barriers to fish passage. Surface runoff on or near logging roads effectively increases stream density in logged watersheds, resulting in more rapid drainage and higher fluctuations between peak flows and base flow. Increased surface runoff, along with fewer trees for bank stabilization, generally causes increased erosion and siltation, while road construction on steep slopes often results in slope failure and excess sediment delivery to streams (Figure 36). Overall effects can also include elevated and more variable water temperature, increased turbidity, and higher uniformity of substrates, which generally impair habitat for a number of fish and invertebrate species.

Many watershed and water quality impacts associated with timber harvest arise in connection with roads built to transport the lumber.

Figure 35

This improperly sited and maintained logging road has eroded badly and essentially functions as a new intermittent stream. Drainage ditches of properly maintained roads also can increase stream density and reduce groundwater recharge.

Figure 36

Riparian buffers are required in many jurisdictions, but these have not always been successful in mitigating effects on streams. In general, it should be recognized that the effects of logging on stream discharge and temperature are caused by watershed-level processes and, as such, are unlikely to be completely mitigated by riparian buffers alone. *(Harr 1986, Murphy 1995, Jones and Grant 1996)* A major change in federal land management policy in the 1990s has begun integrating watershed analysis into timber management and multi-purpose land management on federal lands across the US.

Human-induced Change Processes: Urbanization


Lake Union's watershed in Seattle, WA has become heavily urbanized and faces many management challenges related to the effects of urban impervious surfaces

Figure 37

Urbanization often has more severe hydrologic effects than timber harvesting or agriculture, as watershed vegetation is replaced with impervious surfaces in the form of paved roads and parking lots. Accordingly, urbanization results in increased surface runoff and correspondingly earlier and higher peak flows following storms, as plotted on a hydrograph (Figure 37). Flooding frequency is also increased. These effects are compounded by channelization of small streams and use of storm sewers designed for rapid downstream transport of drainage waters, both of which are intended as flood control measures but in fact can contribute to rapid water rise and flooding downstream, often still within the urban area. There is a direct relationship between urbanization (i.e. % watershed imperviousness) and the number of bankfull flows occurring annually (Leopold 1968). It has been estimated that a watershed with 25% impervious surfaces is subjected once every five years to an event of peak volume equivalent to the 100-year storm under completely forested conditions. At 38% imperviousness, this same event occurs every 2.5 years, and at 65% imperviousness it occurs annually (Klein 1979).

Bank scour from frequent high flow events tends to enlarge urban streams and result in increased turbidity and uniformity of substrates. Structural complexity is then further reduced by bank armoring, and channelization designed to limit the damage to streamside property resulting from increased flooding and erosion (Figure 38). In many cases, however, channelization results in increased flow velocities and subsequently increased flooding and erosive power downstream.


Urban channelized and "hardened" streams (left) are poor habitat but route stormflows quickly. Natural streams below urban areas (right) retain some habitat features but become heavily eroded by flows from increased urban runoff.

Figure 38

These physical impacts of urbanization are compounded by contaminant inputs from a variety of sources. Urban contaminants may be loaded directly to streams and lakes (Figure 39, next page) from point sources (e.g., sewage, industrial effluents), or they may originate from nonpoint sources (e.g., atmospheric deposition and/or street litter washed off impervious surfaces and incorporated in storm runoff). Individual nonpoint source loadings are generally of small volumes, but these tend to be ubiquitous in urban watersheds and collectively represent an important contribution to overall pollution. Whereas quantification of point source pollution is relatively straightforward, assessment and control of nonpoint source loadings are made difficult by the fact that contaminants originate over broad areas and the processes by which they are carried are often not easily modeled or measured.

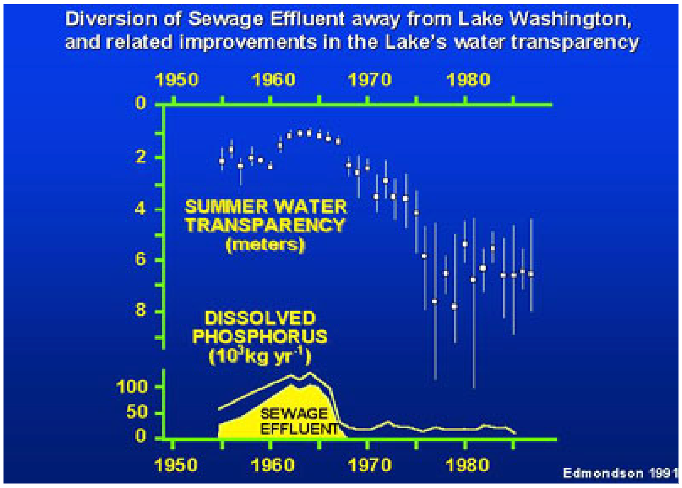


Figure 39

As a result of these effects, a direct inverse relationship may be demonstrated between the diversity of stream communities and the degree of urbanization. Klein (1979) reported reduced fish and invertebrate diversity at 12% watershed imperviousness (10% for areas supporting self-sustaining salmonid populations), and severe degradation in the form of reduced benthic populations and absence of fish life at 30% imperviousness. The presence of an intact riparian buffer and/or wetlands, which unfortunately have not been conserved in most urbanized areas, can lessen these impacts.

In many cases, the effects of urbanization extend far beyond the urbanized watershed. As urban growth increases, water must be pumped in from increasingly great distances to meet sewage and drinking water requirements of urban populations. For example, pumping water from the Sacramento and Colorado Rivers over hundreds of miles and hundreds of feet in elevation in aqueducts and canals facilitated the growth of urban centers in southern California. These diversions and impoundments have resulted in widespread hydrologic and ecological changes, as well as significant economic and political conflicts (Reisner 1986).

Human-induced Change Processes: Fire Suppression

In the years following European settlement, forest management policies related to fire suppression have had a profound impact on forest community structure (Figure 40). Since the turn of the century, suppression has been the primary goal of fire policy in mixed conifer forests of the Pacific Northwest, the overall effects of which have been an increase in fuel accumulation and a shift in composition toward shade-tolerant species and away from fire-dependent conifers (Huff et al. 1995, Kimmins 1997). Effects have generally been more profound in areas where fires were historically frequent as opposed to where fires occurred at longer return intervals.

An airplane releases fire retardant chemicals to suppress an active forest fire.

Figure 40

These changes increase potential for high-intensity crown fires, not only by providing more available energy but also by creating pathways for flames to reach the forest canopy. Such crown fires usually exceed our control and kill all species present, including those resistant to fires of moderate to low intensities. For example, fuel buildup due to fire suppression is in part responsible for the catastrophic fires in 1988 that burned almost half of Yellowstone National Park. The accumulation of fuel is one of the biggest concerns of land managers today, who now fear that when fires occur they will be extremely difficult to control, although the implications of fire suppression extend beyond increased potential for catastrophic fires. Fire represents an important component of forest ecology, as fires increase the availability of soil nutrients, while periodic disturbance results in a mixture of seral stages and increased biodiversity. Recognizing this, forest managers in U.S. national parks have adopted a fire management policy that combines a let-burn approach with active monitoring and prescribed burns (Figure 41).

A forest manager carries out a prescribed burn using a drip torch.

Figure 41

In trying to determine the effects of fire or fire suppression on forest community composition, note that plant succession is not always predictable. In addition to variables such as many species' responses to disturbance or life history traits which affect patterns of vegetation change, random factors may come into play. This presents difficulties in determining whether or not fires should be suppressed on public lands. Such decisions are further complicated by the fact that forest conservation has become a management imperative to many, given the decline of forested lands in North America and worldwide. If forest fires are allowed to burn without intervention, entire regions may be deprived of forest resources for long periods of time. Long-term goals related to the preservation of ecological processes and relationships must therefore be weighed against shorter-term goals of resource use, aesthetics and recreation when local management decisions are made.

Human-induced Change Processes: Mining

Mining and mineral development result in a series of environmental changes which may occur over several decades. The actual mine site is just one point in a long line of activity before and after the digging starts. A mine is also at the center of a geographical web of transportation routes (e.g., roads, barges, air access routes) and energy infrastructure (e.g., dams, power lines), as well as processing plants, tailings ponds and waste rock piles. The basic stages of mineral development are: (1) preliminary and advanced exploration, (2) mining and milling, (3) smelting and refining, and (4) mine closure. Each of these stages entails specific activities and environmental impacts. Activities and impacts also vary with different mining procedures and environmental settings. Historically before more recent environmental controls, mining left a legacy of severe impacts on watersheds and the rivers and streams of western federal lands, as well as in eastern coal mining areas. Restoration after mining remains a significant challenge in many parts of the US.

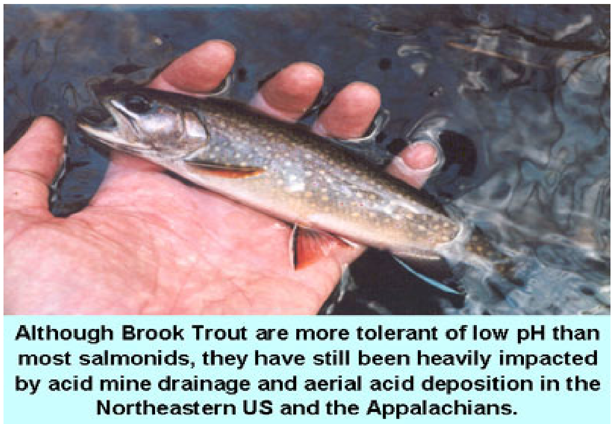
Without proper restoration, mining can have severe impacts upon stream hydrology, morphology, biota and water quality.

Figure 42

Mining operations remove significant amounts of soil and rock. The Bingham Canyon copper mine in Utah has removed a piece of earth seven times the weight of all the material dug for the Panama Canal (Goudie 1990). Worldwide, mining operations extract approximately 24 billion tons of non-fuel minerals from the Earth each year. Taking into account overburden (soil and rock above the ore), the total is 28 billion tons of material disturbed annually. This amounts to approximately 1.7 times the estimated amount of sediment carried by all of the world's rivers each year (Skinner 1989). Even if chemically inert, erosion of exposed overburden can result in excessive siltation affecting stream and lake ecosystems (Figure 42).

After being removed, waste rock is usually stored above ground in freestanding piles. When rocks containing sulfide minerals are excavated, they react with water and oxygen to form sulfuric acid. The resulting leachate is known as acid mine drainage (AMD). AMD will continue to be produced in source rock exposed to air and water until all of the sulfides are leached out, a process that can last hundreds and even thousands of years. During this process, there is a constant risk of water pollution, as AMD is transported from mine sites in surface drainage to receiving streams, lakes and groundwater.

Further effects stem from extraction of the ore itself and from disposal of tailings (i.e., residues from ore concentration). Up to 90 percent of metal ore ends up as tailings, which are commonly dumped in large piles or ponds near the mine. Tailings usually contain residues of toxic organic chemicals used in ore concentrators (e.g., toluene, a solvent damaging to human respiratory, circulatory and nervous systems). The finely ground tailings material makes metals that were formerly bound up in solid rock (e.g., arsenic, cadmium, copper, lead and zinc) accessible to water, increasing potential for heavy metal contamination in aquatic communities. These effects are exacerbated by AMD, which creates low pH conditions, thereby increasing the mobility of many heavy metal species. Ponds full of tailings cover at least 3500 hectares in the Clark Fork area of Montana, and 2100 hectares at the Bingham Canyon copper mine in Utah (Young 1992).



Although Brook Trout are more tolerant of low pH than most salmonids, they have still been heavily impacted by acid mine drainage and aerial acid deposition in the Northeastern US and the Appalachians.

Figure 43

Smelting can produce significant quantities of air pollutants. Worldwide, smelting of copper and other non-ferrous metals releases large quantities of metals such as As, Pb and Cd, as well as an estimated 6 million tons of sulfur dioxide into the atmosphere each year. Smelting produces approximately 8 percent of total emissions of the sulfur compound that is a primary cause of acid rain (Moller 1984), well-known in the Northeastern US for its heavy impacts upon the fish and invertebrate populations of headwaters streams and lakes (Figure 43). Mining and smelting operations also consume significant amounts of energy. Although data are sparse, the mineral industry probably accounts for 5 - 10 percent of global energy use (Young 1992).

Human-induced Change Processes: Harvesting of Fish and Wildlife

Figure 44

Commercial and recreational harvesting of fish and wildlife may have significant impacts on community composition and trophic (food web) interactions, well beyond the removal of the target species (Figure 44). These effects have been most pronounced in commercial fisheries, where harvest pressures have resulted in a gradual shift from large, long-lived, high trophic level species to smaller, shorter-lived, planktivorous and insectivorous species. Recent studies have reported a steady mean decline of approximately 0.1 trophic levels per decade in worldwide catches over the past 45 years. These changes in decreased abundance of one trophic level lead to trophic cascades where perturbations at higher trophic levels cascade down to lower trophic levels. This is because piscivores determine the size and species composition of planktivorous fish, which in turn affect the zooplankton community composition, that determines the kinds of phytoplankton that compete for nutrients (Carpenter and Kitchell 1993).

Placing a moratorium on certain species such as the striped bass in the Chesapeake Bay (Figure 45, next page) is a management technique that has successfully brought about significant changes in numbers and sizes of fish, after a combination of overharvest and habitat decline pressures had seriously reduced populations of this game and recreational fish. Management techniques like the moratorium represent the kinds of sacrifices in natural resource use that can become necessary, in part, due to changes of concern in the watershed. Rebounding numbers of fish have occurred simultaneously with increases in submerged vegetation beds, a key habitat whose decline and subsequent resurgence was related to several aspects of watershed management.


Figure 45

Human-induced Change Processes: Introduction of Exotic Species

Human mobility has resulted in significant exchanges of biota, occurring at global and local scales. Exotic species, or invasive non-native species, may be introduced to a given region intentionally, as with ornamental plants or popular game fish species, but in many cases they are transported and introduced unintentionally. For example, zebra mussels have become abundant in the aquatic ecosystems of the Great Lakes, having been transported in ballast waters of large ships arriving from Europe, and are spreading rapidly to other systems (Figure 46). Once an invasive plant species is established near a river or stream (Figure 47) , the flowing water of streams and rivers and the contiguity of river corridors has helped many exotic species spread far and wide. Similarly, a study by Schmidt (1989) found viable seeds from 124 different plant species in sludge washed off the mudguards of a car that had driven approximately 15,000 km in the area surrounding Gottingen, Germany. These findings suggest that plants growing in roadside areas may be readily dispersed by moving vehicles. As human mobility increases as a result of extensive international trade and worldwide travel opportunities, more and more regions are likely to be affected by introductions of exotic species.


The Zebra Mussel, *Dreissena polymorpha*, an invasive non-native species significantly altering many US waters.

Figure 46

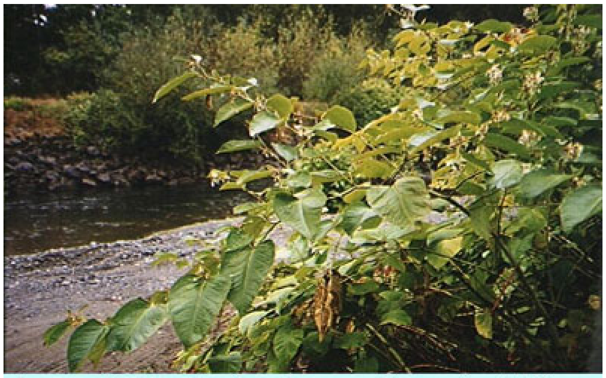

Japanese Knotweed, an invasive non-native species that forms dense monocultures and displaces native plants along stream and highway corridors across the US.

Figure 47

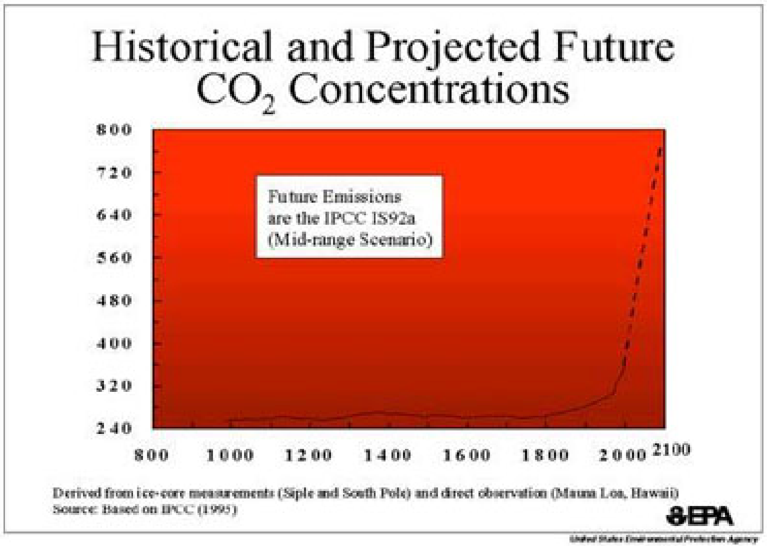
In some cases, introduced species do not prosper because they lack adaptations to local environments, but in many cases introduced plants and animals outcompete native species through prolific reproductive strategies and a lack of natural predators. Establishment of exotic species often results in significant changes in food webs and community composition. For example, introduced honeybees have had adverse impacts on indigenous flowering plants in Australia, South America and North America. Several studies have indicated that introduced honeybees outcompete native pollinators, but they may be ineffective in pollinating native flowers.

As a result, the reproductive success of native plants is hampered by reduced seed sets, and offspring are less vigorous due to reduced genetic diversity as a result of increased self-pollination (Kearns and Inouye 1997). Resulting changes in plant abundance and species composition may have further direct and indirect effects on herbivore and carnivore populations.

The effects of exotic species have been particularly devastating to the Great Lakes basin, which is a site of several invasions and a source for the spread of invaders across North America. The Great Lakes are now inhabited by at least 139 nonindigenous species that have been transported by human activity. These reported exotics are mostly fish, vascular plants and some of the larger (> 0.5 mm) plankton species. Intensive management efforts have been directed toward controlling the most pervasive and visible exotics (e.g. sea lamprey), although it is likely that many smaller exotics exist for which the taxonomy is less well known. Some exotic species have had significant effects on Great Lakes ecosystems. For example, recent changes in the trophic status of Lake Erie (i.e., shift from eutrophic to mesotrophic conditions) have been attributed in part to the introduction of filter feeding zebra mussels. With each individual capable of filtering 10 - 100 ml of water per hour, zebra mussels may be highly effective in removing phosphorus and other aquatic contaminants from the water column (Mackie and Wright 1994). These seemingly positive effects, however, are counterbalanced by the displacement of native filter feeders that are better integrated into the ecosystem's food webs and natural processes.

Exotics are thought to have been involved in 70% of this century's extinctions of native aquatic species. The U.S. Fish and Wildlife Service declared invasive exotic species control one of their top four priorities for 1999 and beyond; futhermore, 500 scientists signed a letter to the Vice President asking to make control of aquatic nuisance species a priority program. For more information on this subject, see the Academy module on invasive non-native species (http://www.epa.gov/watertrain/invasive.html).

Human-induced Change Processes: Accelerated Climate Change

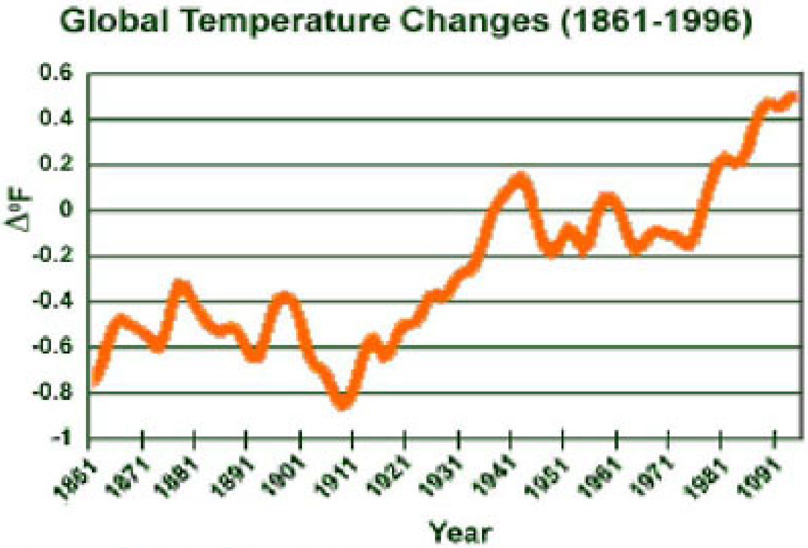


Derived from ice-core measurements (Siple and South Pole) and direct observation (Mauna Loa, Hawaii)
Source: Based on IPCC (1995)

Figure 48

A major difference between natural and anthropogenic climate change is the rate at which it occurs (Figure 48). With industrialization and population growth proceeding at a rapid pace over the last century, greenhouse gases from human activities have consistently increased in the atmosphere. Although it is not the only greenhouse gas, CO_2 clearly illustrates the trend where levels since 1860 have increased from 280 ppm to 360 ppm. Measurements from ice cores extending back 160,000 years show that CO_2 levels and global temperature are strongly correlated. If current emissions trends continue, CO_2 and temperature will rise to their highest levels in the past 50 million years. Current predictions indicate that we can expect an increase of 3.5°F over the next century with this continued release of CO_2 into the atmosphere.

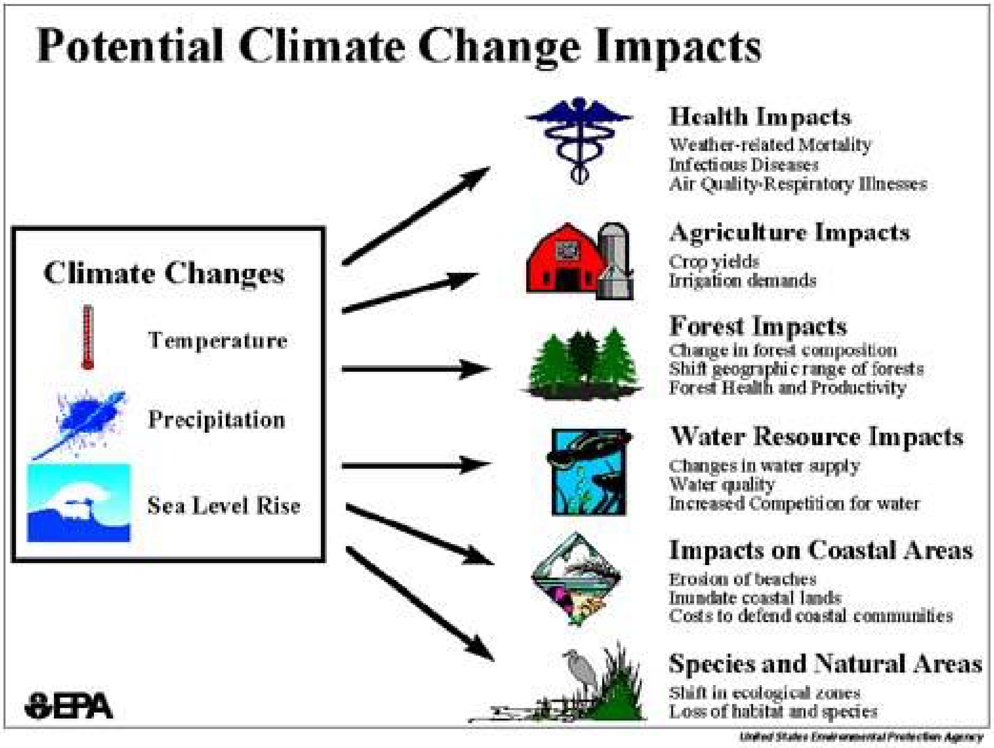
Over the last century the average surface temperature of the earth has warmed by approximately 1.0°F (Figure 49). The higher latitudes have warmed more than equatorial regions. These changes may seem small and some have argued that over geologic time our planet has experienced changes in global temperature (during the Cretaceous period temperature is estimated to have been 8.5°F higher than at present).



Source: IPCC (1995), updated.

Figure 49

Despite these apparently small increases in temperature, however, we can expect major impacts on the global hydrologic cycle and other natural processes (Figure 50). When air temperature increases just 1°F, the air can hold 6% more water. This warming trend tends to speed up the exchange of water among oceans, land, and atmosphere. Longer droughts punctuated by heavy bursts of rain and flash flooding are a consequence. These effects can determine the water supply available to plants and the hydrologic regime of streams and rivers. Species composition of upland plant communities will also undergo major changes. For more information on climate change, visit the EPA website on Global Warming (http://www.epa.gov/globalwarming).



Potential Climate Change Impacts

Climate Changes

- Temperature
- Precipitation
- Sea Level Rise

Health Impacts
Weather-related Mortality
Infectious Diseases
Air Quality-Respiratory Illnesses

Agriculture Impacts
Crop yields
Irrigation demands

Forest Impacts
Change in forest composition
Shift geographic range of forests
Forest Health and Productivity

Water Resource Impacts
Changes in water supply
Water quality
Increased Competition for water

Impacts on Coastal Areas
Erosion of beaches
Inundate coastal lands
Costs to defend coastal communities

Species and Natural Areas
Shift in ecological zones
Loss of habitat and species

EPA
United States Environmental Protection Agency

Figure 50

How Change Affects Watershed Processes

In many cases, watershed change occurs as a result of several agents of change that act together (Figure 51). Changes of concern often result from interactions of natural and human-induced disturbances. Even where individual stresses are relatively insignificant, ecological processes and relationships may be significantly influenced by the cumulative impacts of multiple stresses. Change is also not a single-step phenomenon, in that the original disturbance may lead first to direct effects that then bring about additional indirect effects (Figure 52, next page).

Watershed Change

Watershed Change Concepts
Natural Change
Human-made Change
How Change Affects Watersheds

Figure 51

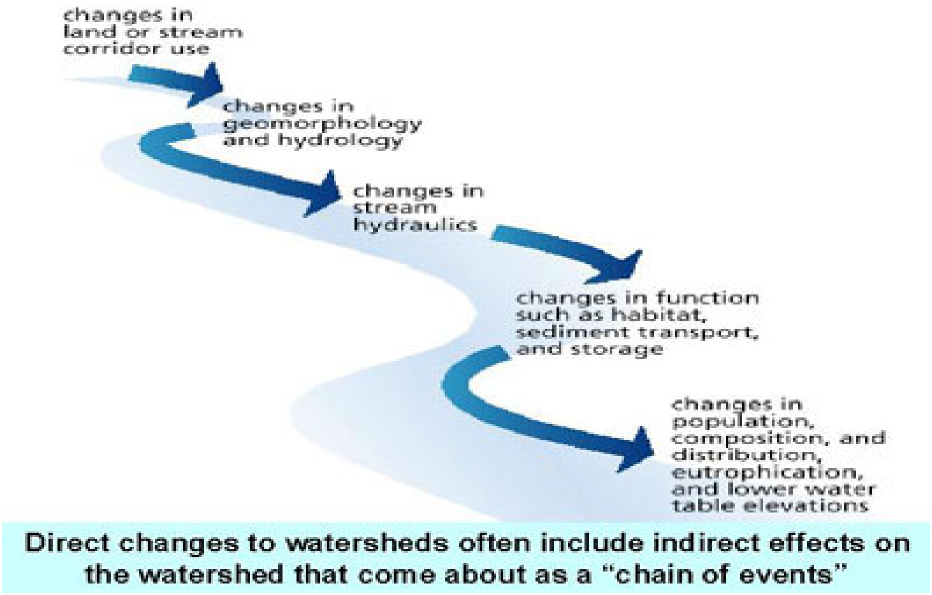


Figure 52

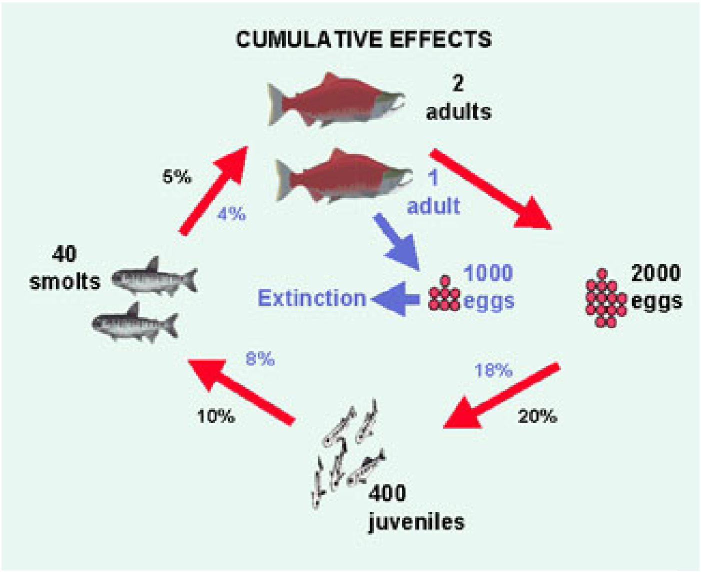
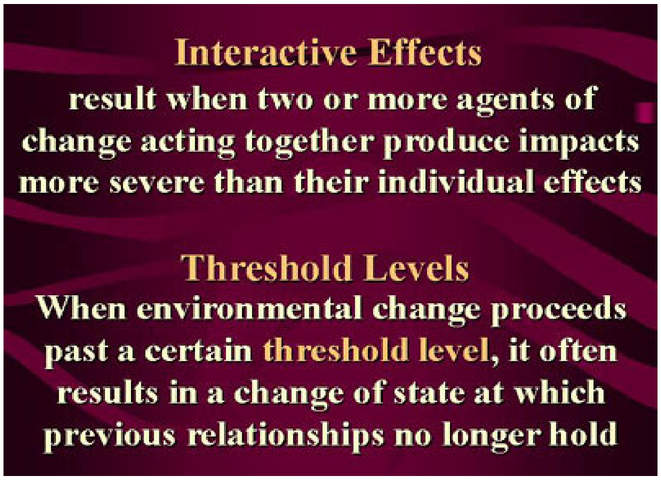


Figure 53

For example, overall reproductive success of Pacific salmon populations may be significantly affected by the cumulative impacts of relatively minor stresses at various life history stages (Figure 53). Under average environmental conditions (e.g., gravel size, flow, temperature), and in the absence of human influences, survival rates may be as low as 10% for incubating pink salmon eggs, even in relatively productive streams (Groot and Margolis 1991). Of those eggs which survive to emergence, as few as 1% may survive juvenile and smolt stages, oceanic life and upstream migration to spawn successfully themselves (i.e., total survival on the order of 1/1,000). Given that the average pink female lays approximately 2,000 eggs, some populations may only just replace themselves with each subsequent generation. Accordingly, these populations may decline rapidly or even become extinct as a result of relatively small increases in mortality at different life history stages due to various anthropogenic stresses (e.g., increased peak flows and bed scour during winter egg incubation, increased commercial harvests at sea, or physical barriers to upstream migration and spawning).

In addition to cumulative impacts, significant change may occur as a result of the **interactive effects** of different agents of change (Figure 54)). Two or more agents of change acting together may produce more severe or entirely different impacts than would result from each change in itself. For example, climatic changes typically entail changes in disturbance regime (e.g., fire frequency) which may alter plant species composition. Another example of interactive change is the way metals toxicity in lakes may result from changes in pH due to acid precipitation. Metals behave differently at different pH levels. At specific critical pH levels (pHzpc) different metals become less soluble and precipitate out of the water column, and become available to the aquatic food web. Aluminum (Al) for example has a pHzpc of approximately 5.3. In areas with high concentrations of Al in underlying substrates, or where Al is a constituent of urban and industrial pollution, fish may be more likely to die of Al toxicity than acid toxicity as pH values decrease and approach a pH of 5.3.



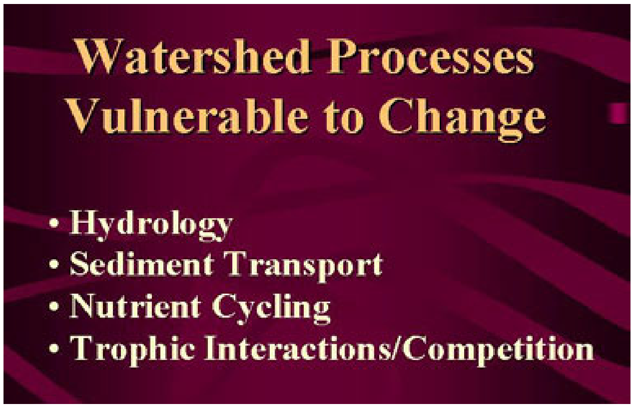
Interactive Effects
result when two or more agents of change acting together produce impacts more severe than their individual effects

Threshold Levels
When environmental change proceeds past a certain threshold level, it often results in a change of state at which previous relationships no longer hold

Figure 54

Another important concept is that of **threshold levels** of change. When environmental change proceeds past a certain threshold level, it often results in a change of state at which previous relationships no longer hold and entirely new influences come to bear on ecological communities. For example, microbial activity generally increases with temperature, but will drop off due to increased mortality once temperatures reach a given threshold. Similarly, increased algal productivity may result in increased productivity in zooplankton and planktivorous fishes in lakes, but this relationship ends at a certain threshold level of algal production. When a superabundance of algal cells die and decompose before they can be eaten by zooplanktors, resulting increases in oxygen demand may entail decreased productivity at higher trophic levels. This common eutrophication scenario may result in rapid declines in populations of fishes with high oxygen requirements (e.g., salmonids), particularly when lakes are stratified and deep-water oxygen inputs are minimal.

As you may have noticed while reading the summaries of different change agents and their effects, some watershed processes are particularly vulnerable to change (Figure 55). Four major watershed processes and the ways in which they are influenced by the cumulative and interactive effects of multiple stresses are reviewed in the coming pages. The processes are:



Watershed Processes Vulnerable to Change

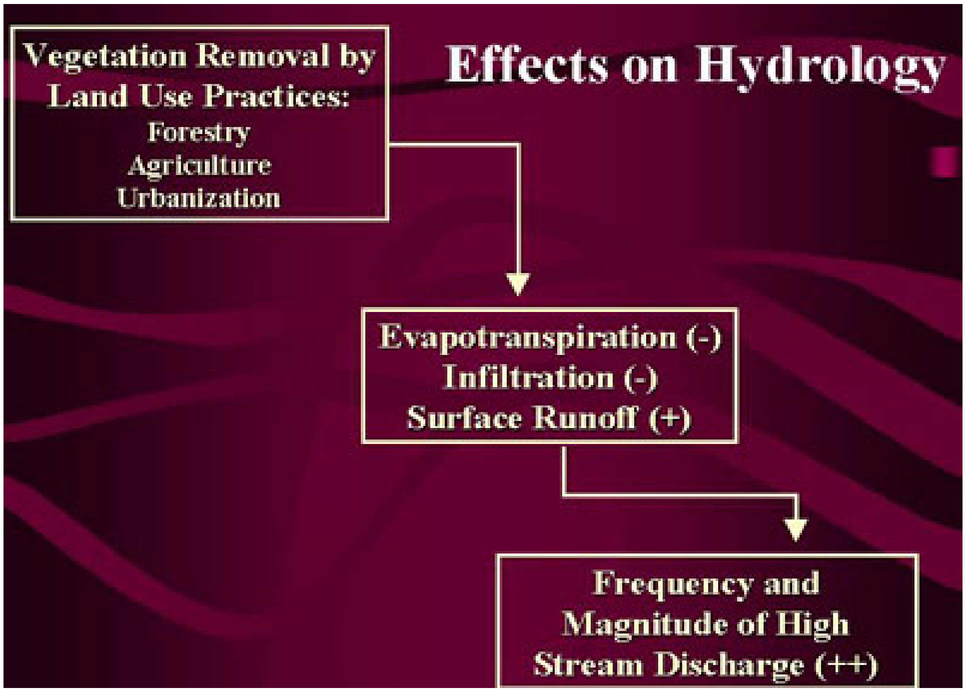
- Hydrology
- Sediment Transport
- Nutrient Cycling
- Trophic Interactions/Competition

Figure 55

- Hydrology
- Sediment Transport
- Nutrient Cycling
- Trophic Interactions/Competition

Hydrology

Land use practices such as forestry, agriculture and urbanization affect amounts and rates of evapotranspiration, infiltration and surface runoff within the watershed, which in turn have significant impacts on the timing and magnitude of stream discharge events (Figure 56). As discussed, the general hydrologic symptoms of forest clearing, agriculture and urbanization are increased peak flows and decreased base flows, resulting in more frequent flooding, increased bank erosion and siltation, and other effects (Figure 57, next page). These effects are often exacerbated by measures designed to mitigate flooding and erosion (e.g., culverts, bank armoring, channelization of streams), which further increase drainage efficiency and flow velocities, resulting in increased flooding and erosion downstream. As a result, urban and logged streams tend to be wider, warmer and more turbid than their forested counterparts, and floods and spates tend to occur more frequently at intensities beyond the abilities of fish and invertebrate communities to adapt.



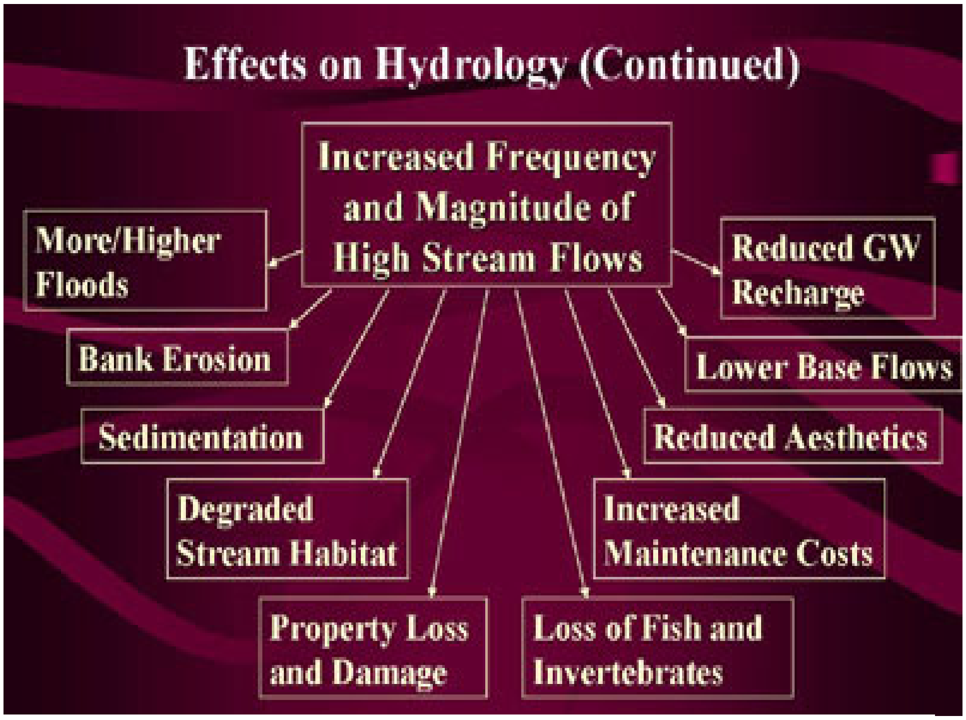
Effects on Hydrology

Vegetation Removal by Land Use Practices:
Forestry
Agriculture
Urbanization

Evapotranspiration (-)
Infiltration (-)
Surface Runoff (+)

Frequency and Magnitude of High Stream Discharge (++)

Figure 56



Effects on Hydrology (Continued)

Increased Frequency and Magnitude of High Stream Flows

More/Higher Floods

Reduced GW Recharge

Bank Erosion

Lower Base Flows

Sedimentation

Reduced Aesthetics

Degraded Stream Habitat

Increased Maintenance Costs

Property Loss and Damage

Loss of Fish and Invertebrates

Figure 57

Sediment Transport

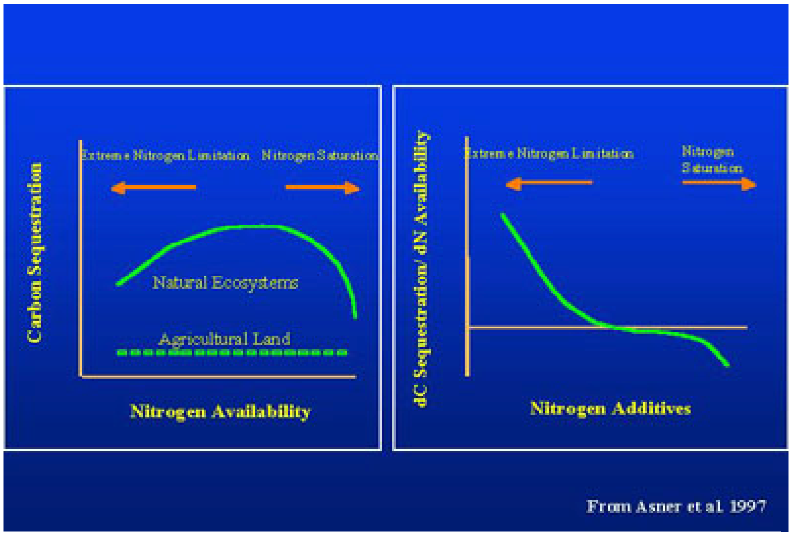
Erosion and sedimentation typically increase as a consequence of the hydrologic impacts of land use practices (Figure 58). Streams and lakes in urbanized, agricultural and logged watersheds are therefore characterized by increased levels of turbidity, relatively uniform substrates and high proportions of fine particles. These conditions may be detrimental to aquatic life in themselves: For example, suspended sediments can clog the gills of fish, while increased fines in spawning beds impede water flow and hamper oxygenation of incubating salmon eggs. Increased sedimentation may also have indirect and/or interactive effects, such as increased contaminant loadings. Human land uses tend to produce organic contaminants (e.g., petroleum byproducts, pesticides, industrial solvents), which are highly sorptive and partition strongly to fine particles with high ratios of surface area to volume. Increased siltation may therefore result in increased contaminant loadings and correspondingly increased toxic effects in impacted watersheds.

Figure 58

Conversely, dams and other modifications of river flow may decrease sediment delivery, which create large reservoirs where suspended materials settle easily. Inordinate reductions in sedimentation may also have detrimental impacts on aquatic life downstream of dams. Moreover, lack of sediment loads may result in carrying less sediment and correspondingly increased erosive potential downstream (i.e., a river unencumbered by sediment loads will have a greater capacity to pick up and move materials). As a result, areas downstream of large reservoirs may be scoured to create bedrock channels or armored substrates offering little structural habitat for aquatic life.

Nutrient Cycling

Human activities tend to remove nutrients from soils (e.g., in form of agricultural crops, timber harvested) to be transported to cities and towns (e.g., in form of food, wood products) and ultimately loaded to aquatic systems in other watersheds (e.g., in form of municipal sewage). At one end of this process, soil nutrient cycles are disrupted by loss of detritus and litter pools (Figure 59). At the other end, nutrient cycling and trophic interactions in rivers and lakes are altered by excess nutrient inputs. Productivity in freshwater systems is often limited by phosphorus, but in some cases nitrogen. Municipal sewage generally contains high amounts of both NO_3 and PO_4, which may stimulate algal productivity to the point where other organisms are affected by oxygen depletion (Edmondson 1991). Depletion of nutrients from agricultural soils often necessitates addition of fertilizers, which are often easily washed off fields to receiving waterbodies, exacerbating eutrophication effects. The annual replacement cost, in fertilizer, for nutrients discarded in U.S. sewage has been calculated at almost $1 billion (Shaeffer and Stevens 1983).



From Asner et al. 1997

Figure 59

Over the past century, inputs of nitrogen to the Earth's atmosphere, soils and aquatic ecosystems have doubled as a result of the cumulative impacts of human activities (Vitousek et al. 1997). The combustion of fossil fuels results in atmospheric emissions of N_2O, an important greenhouse gas, as well other oxides of nitrogen (e.g., NO) which drive the formation of photochemical smog. Inputs to soils have been as a result of fertilizer applications and increased atmospheric deposition, while freshwater ecosystems have been affected by runoff from nitrogen-enriched soils, as well as direct inputs (e.g., sewage). As NH4 builds up in soils, it is increasingly converted to NO_3 by microbial activity. This process releases hydrogen ions and acidifies soil. As negatively charged NO_3 molecules leach out into streams and groundwater, they carry with them positively charged nutrients such as calcium, magnesium and potassium. In affected watersheds, acidification and loss of cations degrade soils, while aquatic communities are affected by eutrophication.

Trophic Interactions/Competition

Harvesting of fish and wildlife and introductions of exotic species have direct impacts on species composition, while habitat alterations (e.g., as a result of urbanization, timber harvest) have indirect effects (Figure 60, next page). As different species are displaced, fragment or extirpated in response to habitat changes, new species expand to occupy niche vacancies. In general, anthropogenic influences favor generalist taxa capable of withstanding a wide range of environmental conditions, while populations of more sensitive or specialized taxa tend to decline. The cumulative effects of anthropogenic activities also tend to work against organisms of high trophic levels. While commercial fisheries eliminate top predators from the aquatic food web, these organisms are also affected by biomagnification of contaminants (i.e., concentrations of bioaccumulative contaminants are magnified by up to several orders of magnitude at each successive trophic level). Although concentrations of contaminants such as PCB's are so low in the Great Lakes that they can not be measured with standard water tests, they exponentially accumulate as they move up the food chain and are incorporated into animal tissue. Through this process the concentration of PCB's in a top predator can be 25 million times that of the surrounding water. In general, top predators are especially vulnerable to environmental change because they rely on all subordinate trophic levels for sustenance.

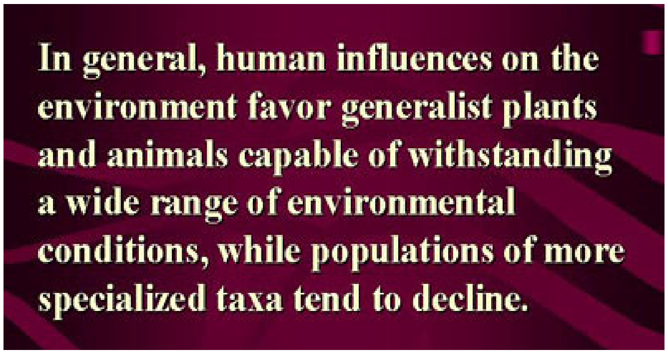

In general, human influences on the environment favor generalist plants and animals capable of withstanding a wide range of environmental conditions, while populations of more specialized taxa tend to decline.

Figure 60

Summary

Change is both unavoidable and essential in the watershed, as plant and animal communities are continually altered in response to changes in physiographic and climatic conditions (Figure 61). Environmental change or disturbance occurs at varying spatiotemporal scales. Disturbance processes are typically characterized according to the frequencies and intensities with which they occur. Changes of concern are defined as disturbances resulting in significant long-term alteration or loss of primary watershed processes or structural components.

Figure 61

Natural agents of change in the watershed discussed here include:

- climate change
- glacial movement
- tectonic activity

- volcanic eruption
- drought/flood
- fire
- windstorms
- erosion and sediment deposition
- disease outbreaks

Human-made agents of change in the watershed discussed here include:

- accelerated climate change
- timber harvest
- agriculture
- urbanization
- modification of river flow
- mining
- fire suppression
- harvesting of fish and wildlife
- introduction of exotic species
- air pollution

In many cases, watershed change occurs as a result of cumulative and interactive effects of more than one agent of change. Changes of concern often result from the interactions of natural and anthropogenic disturbances. These cumulative and interactive effects have resulted in widespread changes in watershed processes such as hydrology, sediment transport, nutrient cycling, and trophic interactions.

A self-test to assess your comprehension is included on page 44 of this module.

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SELF TEST FOR AGENTS OF WATERSHED CHANGE MODULE

After you've completed the quiz, check your answers with the ones provided on page 49 of this document. A passing grade is 14 of 20 correct, or 70%.

1. Which of the following is most accurate?

☐ A. Most human-made changes to watersheds are inevitable and cannot be controlled.

☐ B. Most human-made changes to watersheds could be controlled if we knew technical solutions for the problems they create.

☐ C. Most human-made changes to watersheds can be controlled but occur due to limited awareness of the remedies or willingness to use them.

☐ D. Most human-made changes to watersheds are not of concern.

2. Which of the following is most accurate?

☐ A. Watershed ecosystems don't change permanently from the influence of natural disturbances alone.

☐ B. Watershed ecosystems can be changed permanently by natural evolutionary events.

☐ C. Natural changes do cause adverse effects on some components of the ecosystem, while benefiting others.

☐ D. A and B

☐ E. B and C

☐ F. A and C

☐ G. All of the above

3. Grazing with unlimited access to all parts of a stream by livestock can create which of the following adverse impacts?

☐ A. Downcutting streams and eroding banks.

☐ B. Siltation in the streambed, nutrients and pathogens in the water.

☐ C. Degradation of fish populations.

☐ D. Lowering the water table

☐ E. Less healthy cattle

☐ F. None of the above

☐ G. A through C

☐ H. A through E

4. A change of concern is:

☐ A. Any change that takes a long time to recover, in terms of human life spans and time scales.

☐ B. Any change that involves human-made agents of change.

☐ C. Any change that results in the loss of a beneficial functional or structural characteristic of the watershed.

☐ D. Any change that results in a different type of ecosystem than what had been there before.

5. Cumulative impacts from multiple agents of change are potentially more of a challenge to watershed management because:

☐ A. watershed managers cannot do anything about natural impacts.

☐ B. different agents of change are contributing impacts at a variety of spatial and temporal scales.

☐ C. it is often difficult to identify the amount of adverse impact that comes from each agent of change, when planning a remedy.

☐ D. A and C

☐ E. B and C

☐ F. A and B

☐ G. A through C

☐ H. none of the above

6. For many changes of concern, there are known solutions but the awareness of the people responsible has been limited.

☐ A. True

☐ B. False

7. 100-year or larger floods are the primary force that determines what a stream channel is shaped like.

☐ A. True

☐ B. False

8. When native species can no longer survive, it is a wise policy to introduce a similar non-native species.

☐ A. True

☐ B. False

9. The period of modern man is one of the greatest periods of mass species extinctions the planet has ever seen.

☐ A. True

☐ B. False

10. Natural changes cause stress to some plants and animals while benefiting others.

☐ A. True

☐ B. False

11. Urbanization can cause stream channels to become wider and deeper.

☐ A. True

☐ B. False

12. With the absence of human intervention, a totally natural disturbance to an ecosystem will eventually result in the same ecosystem after a full recovery.

☐ A. True

☐ B. False

13. Most suspended sediment in streams and rivers comes from the erosion of streambanks rather than from overland flow across croplands.

☐ A. True

☐ B. False

14. A watershed with 25% impervious surface is likely to have increased runoff and higher peak streamflows, but probably no other problems.

☐ A. True

☐ B. False

15. A large percentage of irrigation water withdrawn from rivers and streams never makes it to the point of watering the crops due to inefficient water handling.

☐ A. True

☐ B. False

16. An urban watershed with 25% impervious surface will probably experience 100-year flood levels once every five years, on average.

☐ A. True

☐ B. False

17. Fire is an important, beneficial agent of change to western deciduous forest species.

☐ A. True

☐ B. False

18. Dynamic equilibrium implies that a watershed can undergo changes in physical form or biological communities, and still maintain stability and function as long as the changes occur within a normal range of magnitude and frequency.

☐ A. True

☐ B. False

19. Buffer strips along streambanks are part of the remedy for most of the water quality problems that arise from agriculture and timber harvest.

☐ A. True

☐ B. False

20. Agriculture represents the heaviest demand for water in most parts of the United States, and accounts for more than 2/3 of global water use.

☐ A. True

☐ B. False

ANSWERS

Q1: C Q2: E Q3: H Q4: C Q5: E Q6: A Q7: B Q8: B
Q9: A Q10: A Q11: A Q12: B Q13: B Q14: B Q15: A Q16: A
Q17: B Q18: A Q19: A Q20: A