TOO MUCH OR TOO LITTLE: SUSTAINING WATERSHEDS AND THE PEOPLE WHO NEED THEM

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ABSTRACT

Around the world, decreasing water availability and increasing costs of water purification serve as an indicator of our struggle between human demands and the maintenance of ecological functions and processes of natural resources. But while much has been written on the degradation of natural areas, and growing concerns for human health, little has been done to address their connections. While inherently we know that there is a connection between how we use our water resources and the resources available to us, the challenge has been to define this connection in terms that are considered valid, and to apply this knowledge in a strategy for action. This work outlines the similarities and interactions between ecological and human needs; serving as a basis for the identification and development of effective risk assessment and management alternatives that focus on an increased awareness of the tradeoffs inherent in every resource decision. By exploring the connections between water quantity and quantity in land use, water quality and human health, we can gain a better understanding of how human effects on ecological processes do, in fact, affect our quality of life.

Key Words: watershed management, hydrologic system, ecological processes, environmental health, environmental planning, water to drink, ecosystem hydrology, land use, water quality

INTRODUCTION

"Most disasters can be prevented simply by not creating them." (Toch, 2003)

Around the world, decreasing water availability and increasing costs of water purification serve as an indicator of our struggle between human demands and the maintenance of ecological functions and processes of natural resources. Land use activities have been known to affect rates of river flows, soil infiltration characteristics and storage capacities (U.C. Water Resources Center, 1991), and decline of water quality has been correlated with the influx of disease (World Health Organization, 1984) But while much has been written on the degradation of natural areas, and growing concerns for human health, little has been done to address their connections. The conventional approach to the over-exploitation of vulnerable ecosystems has been to focus on the "lacks and needs" (Falkenmark et al., 1990), rather than the potential to improve and protect the mechanisms that allow these resources to exist. This has been evidenced by emerging water-borne pathogens, and the increasing costs in water supply development and purification.

Specifically referring to the drainage of wetlands, soil erosion and deforestation, habitat alteration and the degradation of watersheds has been targeted as the "highest risk to human health and quality of life" (US EPA, 1990). These risks ranked higher than any other impact, due to the scale that they encompass, the length of time required for mitigation and the fact that many effects are irreversible. While most land use activities can be associated with ecosystem change, resource use does not necessarily comprise a contamination source. It is the methods by which human activities occur on a watershed that has the potential to promote or reduce mechanisms for human illness. The degree and extent of specific land use practices can also be identified and controlled.

An investigation into land use as it relates to the impact on hydrologic processes can serve as a basis for the identification and development of effective management alternatives addressing water quality and thus, quantity. The focus should be on an increased awareness of the tradeoffs inherent in every resource decision. By exploring the connections between land use, water quality and human health, we can gain a better understanding of how human effects on ecological processes do, in fact, affect our quality of life.

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CONTAMINATION OF POTABLE SUPPLIES

From 1971 to 1990, over 140,000 people are known to have become ill in over 570 documented disease outbreaks in the U.S. linked to contaminated drinking water. In addition, EPA data reveals that about 100 large water systems-serving cities from Boston to San Francisco do not filter and are technically breaking laws designed to protect water quality (NRDC, 1993). More and more stringent regulations have been the response to water quality deterioration. In 1986, Congress passed amendments to the Safe Drinking Water Act (SDWA) requiring EPA to regulate 83 individual contaminants (compared to 14 previously regulated) and to add 25 contaminants to the regulated list every three years, indefinitely. These amendments required all public water systems that rely on surface water, to have in place by the end of June, 1993, either filtration systems or watershed protection measures. While increasing protection measures, these SDWA standards have also increased the possibility of detecting potential pathogens in areas not previously thought to contain them. The additional concerns for disinfectant byproducts like trihalomethanes (THM's) do not allow for chlorine or other disinfectants to be the sole solution.

In order to comply with SDWA regulations, the San Francisco Water Department (SFWD) was required to construct a 300-mgd filtration plant, estimated at $500 million, in 1993. Along with the already growing financial problems of the City, this amount had the potential to double current water bills for all water users. With the headwaters of their potable supply within National Park boundaries, the City sought an exemption from the filtration requirement based on the "quality of the natural source". They opted for the "watershed protection measures". The Tuolumne River Watershed and the San Francisco water supply was the first filtration exemption that was established in the State of California, granted by the California Department of Health and the EPA to the San Francisco Water Department in 1993. Components of the Sanitary Survey that documented water quality issues are used here to demonstrate how the ecological assessment of resource use can be related to public health concerns (Toch, 1994). This information identifies watershed management as a viable and necessary means to water quality control.

THE TUOLUMNE RIVER WATERSHED AND THE SAN FRANCISCO WATER SUPPLY

The Tuolumne River is a major Sierra Nevada watershed which has its source within the boundaries of Yosemite National Park. Since passage of the Raker Act in 1914, San Francisco County has depended on the Tuolumne River Basin for much of its domestic water and electrical power. Approximately 85 percent of the City's water supply is derived from the Hetch Hetchy system, a series of watersheds connected along the Tuolumne River. Land use varies from the wilderness areas of Yosemite Park and the Stanislaus National Forest, to the more developed areas in Tuolumne Meadows, Big Oak Flats, and Moccasin.

The Hetch Hetchy watershed was chosen as a site for the San Francisco water supply, in part because of its location; that is, one that was far away from the City's development conflicts. The "pristine nature" of the source is attributed to the fact that the majority of the watershed is under federal protection, with limited development. The quality of the supply thus demonstrated the value of resource preservation. Ecological functions of the natural environment that included intact soil structure and indigenous vegetation cover could serve as natural purification devices. Human impact was minimal in sensitive meadows, fragile soils, or riparian zones. However, federal mandates requiring resource preservation decrease as one moves downstream, with increased development and resource use occurring on leased and private land. These watersheds are considered more risky relative to current EPA Safe Drinking Water parameters for human health.

WATER QUALITY

There are four constituents of primary interest in maintaining current potable standards for water supplies, and they are discussed below. Indicators of potential pathogenic agents transmitted by water include Coliform and turbidity. The flagellate Giardia lamblia and the sporozoan Cryptosporidium sp. are the intestinal parasites that are most prevalent in the United States.

Coliform bacteria are indicators of the presence of disease-causing (pathogenic) bacteria in drinking water. Waters free of Coliform can be considered to be free of pathogens. There are also known to be at least four types of infections that originate with the ingestion of E-coli. These range form gastroenteritis to severe diarrhea. Some bacteria are commonly found in organic, decaying matter and in soil and water. Potential contaminant sources are generally related to fecal matter and urine.

The occurrence of turbidity in a water supply has been related to the shielding of potential pathogens from disinfection. It has also been associated with the need for increased chlorination, and as a transport mechanism for pollutants. Contaminated sources have been associated with land use practices that impact soil characteristics. Giardia and Cryptosporidium are enteric protozoa which cause waterborne diseases. Both are transmitted by the fecal-oral route, with the infected individual excreting Cryptosporidium oocysts or Giardia cysts. Animals as well as humans may serve as sources of environmental contamination and human infection. Parasites and Coliform may be found along the watershed and transmitted to the water supply via hydrologic pathways. They may be transmitted by mammals and are commonly found in streams and rivers.

The Role of Land Use In Water Quality

Certain land use practices serve as a specific threat to water quality and greatly influence the potential for the above mentioned parameters. These include inadequate human or animal waste disposal, frequency of occurrence and density of domestic and/or wild animal's occurrence, the type and duration of soil impacts and runoff potential, and land use activities that initiate a pollutant source, or create pathways for pollutant transport.

The location of these practices in relation to specific watershed characteristics are of significance, as an activity (re: sewage discharge) may be of concern on an environmentally sensitive area (re: highly permeable, erodible soils), while not causing degradation in another area (re: clay soils). The cumulative effects of land use activities may not be directly associated with source pollutants. However, these may also contribute to water quality degradation. For example, logging practices that initiate soil erosion, a physical process associated with increased turbidity, may alter water quality. However, that same activity may be performed in an ecologically sustainable fashion. Vegetation serves to stabilize soil structure. Often indigenous species have specific characteristics suitable to the native soil. By maintaining suitable herbaceous cover, it is possible to reduce both resource degradation, and potential contamination of the water supply. Watershed management is a strategy to deal with current trends of resource use that threaten to impair water quality, and as an economically viable alternative to technological advancement.

Land Use Related to Ecological Process and Water Quality

Lindeman (1942) defined "ecosystem" as: "A system composed of physical-chemical-biological processes active within a space-time unit of any magnitude." Ecological integrity can be defined as a combination of Chemical, Physical, and Biological influences (EPA, 1990). Specific land use practices can also be analyzed with respect to their impact on biological, physical and chemical functions of the hydrologic environment. The American Waterworks Association (AWWA, 1993) recommends guidelines for water quality assessment that include a list of potential contaminant sources. These originate with specific land use practices. Table 1 describes these land use practices within three drainage basins in the Hetch Hetchy water supply.

Table 2 describes some of the biological, physical and chemical processes which in turn affect water quality. These are associated with potential identified land use impacts in the Tuolumne River Watershed. The relationship of these land use impacts on specific water quality parameters, and ultimately human health, is described in Table 3.

Table 1. Land Use Activity by Watershed In the Hetch Hetchy and Tuolumne River Basin			
Land Use Activity	**Watersheds**		
	Hetch Hetchy	**Moccasin**	**Priest**
Agriculture/crops	N/A	S,I	I
Grazing	N/A	S,I	S,I
Logging	N/A	I	I
Mine runoff	N/A	S,I	S,I
Fire	S	S	S
Concentrated animal facilities	S	I	I
Wildlife	S	I	S
Chemical use	S	S	S
Urban runoff	N/A	N/A	N/A
Recreational/Visitor use	S	N/A	N/A
Undeveloped land	N/A	N/A	N/A
Unauthorized activity	S	S,I	S,I
Groundwater discharges	I	I	I
Industrial facilities	N/A	N/A	N/A
Solid waste disposal facilities	N/A	S	
Hazardous waste disposal facilities	N/A	N/A	N/A
Roads	S	S	S
Hazardous material transport	S	S	S
Commercial	S	S	S
I=Insufficient information, N/A=Not applicable, S=Source present(Revised from Hetch Hetchy Sanitary Survey, 1993)			

Table 2. Land Use Activity Related to Potential Source Contaminant		
Land Use Activity	**Process**	**Potential Source**
Agriculture/Crop	B,P,C	poor tillage practices: erosion, soil compaction
Grazing	B,P	cattle affect riparian growth, erosion/compaction sewage directly in water supply
Logging	B,P	roads, impacts on riparian stability, erosion
Mine runoff	P,C	abandoned mines, chemicals
Fire	B,P,	erosion, wildlife
Concentrated Animal Facilities	B,P	sewage runoff, erosion
Wildlife	B,P	compaction, sewage runoff (though it is often sporadic enough to be dispersed)
Chemical Use	C	depletes natural environmental defenses
Urban Runoff	B	inadequate septic
Visitor/Recreational Use	B,P	improper trail maintenance, lack of septic facilities in ESA's
Unauthorized Activity	B,P, C	unregulated use; erosion, runoff
Ground Water Discharge	B,P,C	carries pollutants into surface supply
Undeveloped Land		important as reference baseline for ecosystem maintenance
Population Growth	B,P	concentrated facilities on ESA's
Wastewater Treatment Facility	B	inadequate construction maintenance; sewage runoff
Industrial Facilities	B,P,C	inadequate facilities for ecological site criteria
Solid Waste Disposal Facilities	B,P,C	concentrated sewage
Roads	P,C	transports waste, erosion
Hazardous Material Transport	C	potential accidents
Commercial	B,P,C	inadequate maintenance for sites

B= Biological P=Physical C=Chemical

Table 3. Significance of Land Use Impacts to Primary Water Quality Parameters in the Tuolumne River Watershed

Land Use Activity	**Water Quality Parameters**			
	Coliform	**Turbidity**	**Giardia**	**Cryptosporidium**
Agriculture/crop	_	_	_	_
Grazing	_	_	_	_
Logging	-	_	-	-
Mine runoff	-	_	-	-
Fire	_	_	-	-
Concentrated animal facilities	_	_	_	_
Wildlife	_	-	_	_
Chemical use	-	-	-	-
Urban runoff	N/A	N/A	N/A	N/A
Recreational /Visitor use	_	_	_	_
Undeveloped land	N/A	N/A	N/A	N/A
Unauthorized activity	_	_	_	_
Groundwater discharges	N/A	N/A	N/A	N/A
Industrial facilities	N/A	N/A	N/A	N/A
Solid waste disposal facilities	N/A	N/A	N/A	N/A
Hazardous waste disposal facilities	N/A	N/A	N/A	N/A
Roads	_	_	-	-
Hazardous material transport	-	-	-	-
Commercial	_	_	-	-

N/A = Not applicable (Revised from Hetch Hetchy Sanitary Survey, 1993)

THE POLLUTION PROCESS

Data collection strategies have often focused on specific point source pollutants such as sewage discharge facilities, rather than in the mechanisms that initiate or perpetuate pollutants. Rather than focus on individual constituents or indicator species, it is possible to assess the process through which pollution occurs. A comprehensive analysis of pollutant sources and the attendant land use impacts can thus identify the potential for water quality degradation. The components of such an analysis should include geographic correlations of water quality parameters within the watershed as a whole. With a base map of the hydrologic system, ecological characteristics of the watershed can be defined: precipitation (for input), tributaries and flow patterns (for transport mechanisms), and geology, soils and vegetation (for storage and filtration). An overlay of land use activities can include concentrations of animals, sewage discharge, grazing, or mining. By connecting the ecological characteristics of a watershed with the land use activity, a specific location point is defined. Sample points can be identified along the watershed to coincide with these processes. Water quality data can thus be associated with a specific land use practice and the location where it occurs, identifying the mechanisms for impact.

Mechanisms -----> Location ------> Indicators

By associating potential pollutant processes with specific land use practices, inconsistent policies can also be targeted. For example, the Taylor Grazing Act, Section 15, permits open range rights on utilities and public water supplies. Grazing has been associated with the physical impacts of compaction and erosion. Giardia, Cryptosporidium and Coliform are known to come from cattle manure.

The potential for grazing to be a contaminant source can be correlated with the geographic location where it occurs. By allowing grazing along the riparian zone (an environmentally sensitive area), or within the water supply, itself, the ecological integrity of the system is altered. Impacts include the resulting compaction that would decrease herbaceous cover and the natural filtration capacity of the soil. This would leave the area more vulnerable to insult. Biological pollutants are more easily transported by erosion. With fewer natural purification mechanisms, the accumulation of these insults can more easily alter water quality parameters and increase potential for illness. The occurrence of disease can then be related to human contact and susceptibility. Grazing, as a form of land use thus directly conflicts with objectives stated in the Clean Water Act and SDWA criteria, if impacts are incurred without regard to the hydrologic system (Toch, 1994).

BEST MANAGEMENT PRACTICES

With data collection that integrates ecological processes with points of impact, management strategies can be used to promote natural mechanisms for water quality maintenance and control, as well as reduce undesirable land use effects. A hydrologic buffer zone should be established based on the geographic drainage area. Mechanisms for water quality maintenance or impacts to hydrological processes can be targeted. From this information, a flow chart and a table can be constructed that focus on processes of water quality impacts and natural mechanisms for water quality control. These can list land use practices, geographic location, effects of land use practices on the physical, biological and chemical ecosystem processes, and resulting impact on water quality parameters; in this case, Coliform, Turbidity, Giardia, and Cryptosporidium.

The flow chart (described in Figure 1) can focus on ecological characteristics that serve to protect and maintain water quality. The table below identifies mechanisms for water quality degradation (Table 4).

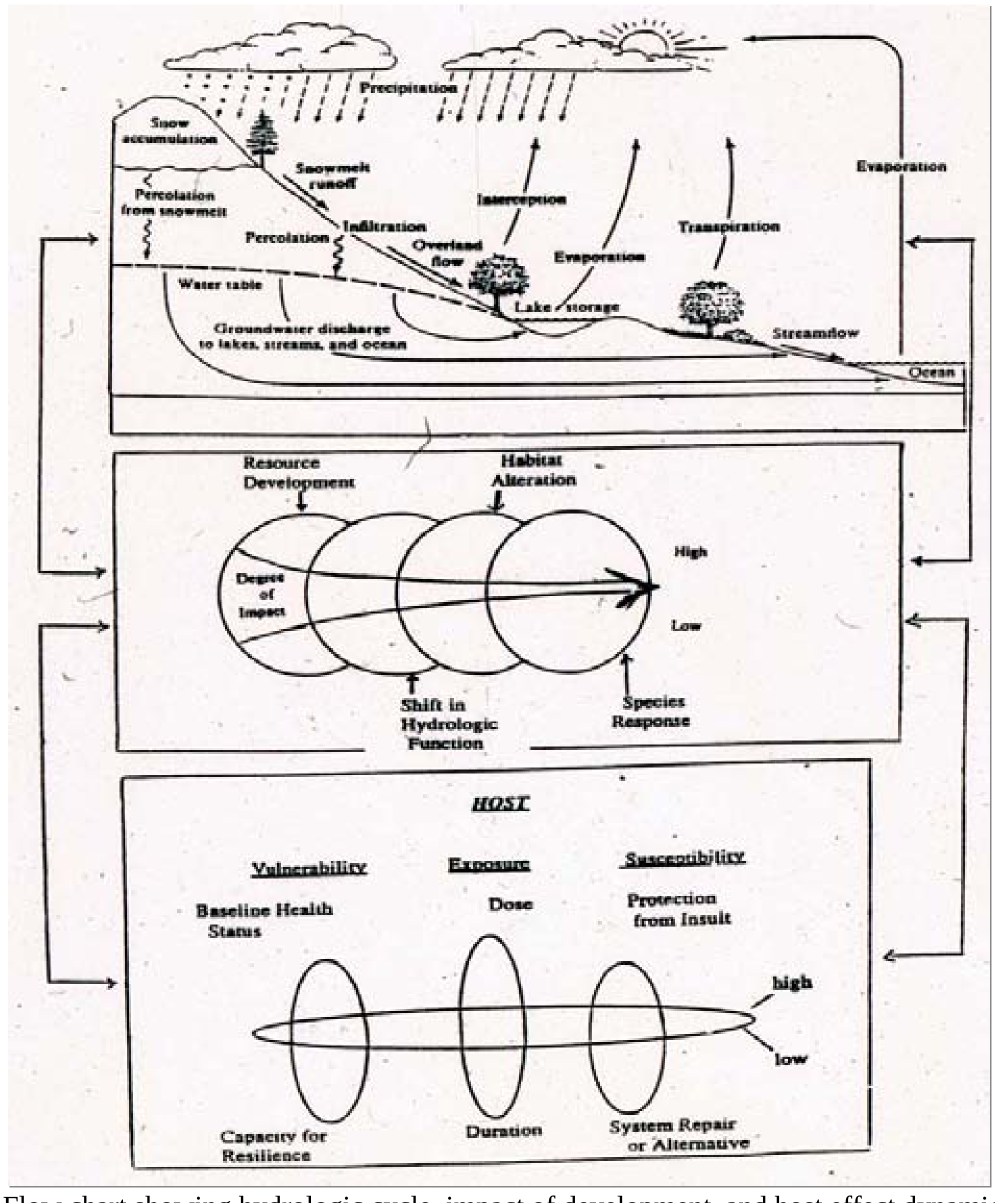

Figure 1. Flow chart showing hydrologic cycle, impact of development, and host effect dynamics

Table 4. Mechanisms for Water Quality Degradation

Land Use Practice	Location	Effect	Resulting Water Quality Effect (T, G, C, Cry)
Construction/Access Roads	Steep Slopes	Erosion/Compaction	Increase Turbidity
Septic System Siting	Fractured Hardrock	Waste Discharge	Increase Coliform, Giardia, & Cryptosporidium
Culverts	Tributaries/Wetlands near Roads	Pollution Transport	Increase Turbidity, Coliform, & Cryptosporidium
Elevated Water Levels for Hydropower	Hetch Hetchy, Priest, and Moccasin Reservoirs	Erosion	Increase Turbidity

CONCLUSION

Quality assurance means a combined approach aimed at the preservation and maintenance of hydrologic processes within a specific watershed. Directives should be geared towards the enhancement of viable ecological functions of purification and filtration; mechanisms for "natural water quality control", as well as the management of land use practices to prevent the adverse impacts to the ecosystem.

Goals for best management practices in water quality control should thus include the preservation of wetlands, protection of riparian habitat, and promotion of native vegetation and maintenance of soil integrity. These criteria should be complimented by an additional set of guidelines that aim to reduce the mechanisms of water quality impact through appropriate land use practices in sensitive areas. By linking biological, physical or chemical processes to an activity source, those agencies responsible for the monitoring and control of these activities can also be coordinated. Management strategies and policy directives can then be geared to the protection and maintenance of hydrologic processes.

By incorporating a methodology that considers resource and health criteria, human welfare concerns can be managed in accordance with hydrologic constraints. The connections between land use, water quality and human health place the preservation of hydrologic processes in the context of human health and well-being.

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