

PROFILE

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An Ecological Perspective on In-Stream Temperature: Natural Heat Dynamics and Mechanisms of Human-Caused Thermal Degradation

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ABSTRACT / While external factors (drivers) determine the net heat energy and water delivered to a stream, the internal structure of a stream determines how heat and water will be distributed within and exchanged among a stream's components (channel, alluvial aquifer, and riparian zone/floodplain). Therefore, the interaction between external drivers of stream temperature and the internal structure of integrated stream systems ultimately determines channel water temperature. This paper presents a synoptic, ecologically based discussion

of the external drivers of stream temperature, the internal structures and processes that insulate and buffer stream temperatures, and the mechanisms of human influence on stream temperature. It provides a holistic perspective on the diversity of natural dynamics and human activities that influence stream temperature, including discussions of the role of the hyporheic zone. Key management implications include: (1) Protecting or reestablishing in-stream flow is critical for restoring desirable thermal regimes in streams. (2) Modified riparian vegetation, groundwater dynamics, and channel morphology are all important pathways of human influence on channel-water temperature and each pathway should be addressed in management plans. (3) Stream temperature research and monitoring programs will be jeopardized by an inaccurate or incomplete conceptual understanding of complex temporal and spatial stream temperature response patterns to anthropogenic influences. (4) Analyses of land-use history and the historical vs contemporary structure of the stream channel, riparian zone, and alluvial aquifer are important prerequisites for applying mechanistic temperature models to develop management prescriptions to meet in-channel temperature goals.

Stream temperature directly influences the metabolic rates, physiology, and life-history traits of aquatic species and helps to determine rates of important community processes such as nutrient cycling and productivity (Allen 1995). Fluctuations in water temperature induce behavioral and physiological responses in aquatic organisms and permanent shifts in stream temperature regimes can render formerly suitable habitat unusable for native species (Holtby 1988, Quigley and Arbelbide 1997, Wissmar and others 1994b). Because of the ecological importance of stream temperature, preventing or mitigating anthropogenic thermal degrada-

tion is a common concern for resource managers (Coutant 1999).

Perhaps because of the widespread use of quantitative models (and associated simplifying assumptions), management actions seldom consider the multitude of interacting environmental processes that determine stream temperature regimes or the wide variety of pathways by which humans may affect stream temperature. In this paper, we attempt to succinctly describe a number of these important processes and pathways. Our most detailed discussions focus on heat energy exchange and transport within stream systems because, in our opinion, these processes provide great promise for successful stream temperature management, yet are most often overlooked during the development of management plans. Although the discussion and examples in this paper focus on the Pacific Northwest, USA, the ecological principles and processes discussed are applicable to lotic systems in general.

KEY WORDS: Stream temperature management; Shade; Hyporheic zone; Groundwater; Channel morphology; Riparian vegetation; Anthropogenic influences

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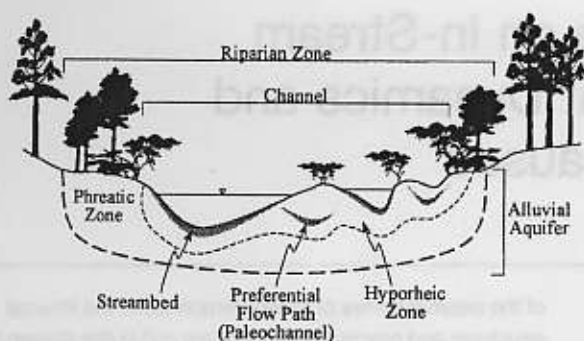


Figure 1. Structural components of a stream system (not all features exist in all streams.)

Fluvial System Structure

At least three integrated and interdependent components determine stream structure: the channel, riparian zone, and alluvial aquifer (Findlay 1995, Gibert and others 1994, Stanford and Ward 1988, 1993, Ward 1989, 1998a,b). Thus, the edge of a river is not its channel margin, but the edge of the riparian zone (Gregory and others 1991). Similarly, the bottom of a river is not the streambed, but the bottom of the alluvial aquifer (Ward 1998b) (Figure 1). Interactions between external drivers of stream temperature and the internal structure of the integrated stream system ultimately determine channel water temperature. The relative importance of various drivers and structures varies spatially. Together, drivers and structures interact to produce heterogeneity in stream temperature at a variety of spatial and temporal scales.

Although other factors also affect stream temperature, the primary determinants of stream temperature are climatic drivers (such as solar radiation, air temperature, and windspeed), stream morphology, groundwater influences, and riparian canopy condition (Sullivan and Adams 1991). Therefore, this paper focuses on the importance of stream morphology, groundwater influences, and riparian canopy conditions as factors that markedly influence stream temperature and that are substantially altered by various human activities.

The stream channel is the portion of a stream system that transports water across the earth's surface. The channel boundary is approximately the typical annual high water level on each streambank. Stream channels may be discontinuous in cross section and comprised of the main channel, side channels, and channels that are active seasonally during high flow. On floodplains, the locations of channels change over time (Leopold and others 1964, Naiman and others 1992). Changes occur gradually over decades (as in meandering systems) or

suddenly as streams cut new channels or recapture previously abandoned channels during floods (as in anastomosed systems) (Nanson and Knighton 1996). Dynamic channels create and maintain floodplain complexity and habitat diversity, thus directly influencing important in-stream dynamics (e.g., nutrient and carbon cycles, natural floodwater storage, and water temperature buffers) and enhancing biological diversity (Abbe and Montgomery 1996, Creuzé des Châtelliers and others 1994, Harvey and Bencala 1993, Sedell and Froggatt 1984).

The riparian zone is the land area influenced by stream-derived moisture. For small streams, it extends a short distance (from meters to tens of meters) laterally from the channel margin. However, for large streams, the riparian zone extends further (from tens to thousands of meters), at least to the edge of the active floodplain (Gregory and others 1991). For rivers like the Mississippi and Amazon, the riparian zone may extend even further (from kilometers to hundreds of kilometers) (Salo and others 1986). Periodic flooding of the riparian zone encourages the exchange of water, nutrients, sediments, and energy between the stream channel and riparian zone, creating unique habitats, enhancing natural productivity, and driving biological processes that contribute to the ecological integrity of streams (Ward 1998a).

A stream's alluvium (sediments that have been deposited by the stream) along with the groundwater contained therein form the alluvial aquifer (Creuzé des Châtelliers and others 1994). The alluvial aquifer underlies both the stream channel and the riparian zone (or floodplain). In streams flowing across bedrock, the alluvial aquifer may consist of pockets of sediment trapped in bedrock depressions. In most large rivers, however, the upper substrate of the floodplain is built entirely from alluvial deposits that can be meters thick. Stream channels and their alluvial aquifers may rapidly and frequently exchange substantial amounts of water and in both directions (Gibert and others 1994). Hyporheic groundwater is water that enters the alluvial aquifer from the stream, travels along localized subsurface flow pathways for relatively short periods of time (perhaps from minutes to months), and reemerges into the stream channel downstream without leaving the alluvial aquifer. The portion of the alluvial aquifer that contains at least some hyporheic groundwater (White 1993) is referred to as the hyporheic zone (Brunke and Gonser 1997, Jones and Holmes 1996, Stanford and Ward 1988). Therefore, two types of groundwater influence streams: hyporheic groundwater and phreatic groundwater (water derived from the catchment aquifer). Phreatic groundwater feeding a river enters the