Disconnected Rivers

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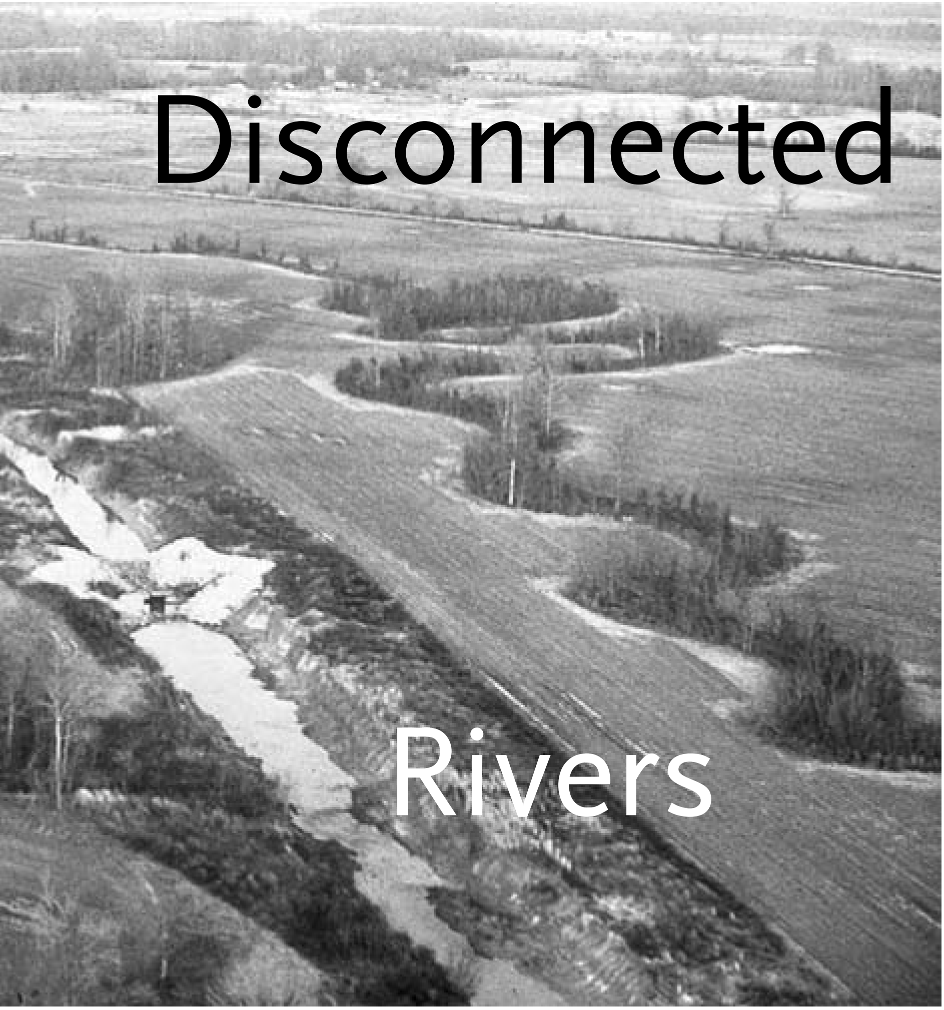

Linking Rivers to Landscapes

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For M, who brought me
to connections beyond science

Contents

Preface

I grew up among rivers. When I was a child, a small creek flowed behind our house in Ohio. Deeply entrenched in a ditch, its quiet waters remained thickly green with algae through the summer. I was forbidden to play in the creek water. Why, I didn't know; somehow the water was unclean.

A half hour's walk from our house lay the Rocky River. True to its name, the river wound between steep cliffs of shale and sandstone and flowed across long, flat bedding planes of rock that were always slick with algae and river slime. Here, too, I was not allowed to enter the river without wearing protective rubber boots. I watched other children swim in the river pools during hot summer days, spouting river water from their mouths, and I wondered whether they would be poisoned.

My parents bought and read Rachel Carson's *Silent Spring* when it came out in 1962, the year of my birth. My father, an environmentalist before the word became widely used, taught biology and chemistry. He knew that during hard rains domestic septic systems commonly overflowed, sending raw sewage into the Rocky River. He also knew what substances industries dumped into the waters and the air. He grew up in Cleveland, where his father worked as a machinist in a tool and dye factory and his mother worked as a seamstress in a garment factory. Those factories were located in the industrial heart of the city along the Cuyahoga River called the Flats. The Flats seemed to me as a child to be a landscape of death with its harsh, angular lines and overlay of black. It was here that the Cuyahoga River caught on fire when I was seven years old, and my home became a source of national embarrassment. Other cities joked that Cleveland was the "Mistake on the Lake."

When he began teaching in the Cleveland public school system, my father devised experiments for his students. For one, he placed the body of a vacuum cleaner in a wooden box fitted with a nozzle. Inside the nozzle he placed a square of gauze. For an hour each day the students ran the machine outside, with its nozzle pointed at the sky, and particulate matter sucked in with the air was left on the gauze. After placing the gauze between two strips of glass, the students positioned a filmstrip projector at a precise distance and shined its light through the gauze, measuring the light's intensity with a light meter at an equally precise distance on the other side of the gauze. Those squares of gauze with their unmistakable dark centers impressed me tremendously. On a good day, the gauze might have a barely discernible circular brown smudge. On a bad day, the circle made from the air near this school surrounded by aircraft and automobile manufacturers could be a vivid orange or a dense black. My father's invention won him a teaching award, and his students did well at regional science fairs.

My father also measured water quality. In some of my earliest science projects with him we measured pH, temperature, and dissolved oxygen and inventoried the species of insects, amphibians, and fish present in the rivers and the vernal ponds. He belonged to a naturalist club and taught me to identify the plants and animals of the eastern deciduous forest. My environmental consciousness took shape during our Sunday morning walks along the Rocky River; one spring I was outraged to see large mounds of disturbed sediment along the river. I assumed the mounds were the work of bulldozers. It was only much later that I realized that the spring floods had been recontouring the riverbanks.

Inexorably, I came to realize that human activities had impoverished the river worlds all around me. Lake Erie was another place I was forbidden to swim, and I could not eat the fish that came from there. It shocked me to read Edwin Way Teale's description in *Journey Into Summer* of the "mayfly storm" on the shores of Lake Erie. Stopping in the town of Sandusky in the late 1950s, Teale described the annual early summer emergence of the aquatic insects. Clouds of insects rising like smoke from the evening waters of the lake moved inland. The weight of thousands of mayflies bent down the leaves of plants. Spent mayfly bodies collected along the waterline in windrows three feet deep, and traffic slowed down on streets slippery with crushed mayflies. There were so many million and billions of mayflies that "numbers lost their meaning." I had never heard of such an occurrence. My parents confirmed that such phenomena used to occur, before the bottom sediments of the lake became so polluted.

Shortly before we moved from Ohio, the second-growth woodlands behind our house were cleared for development. A church replaced the stands of fast-growing maple and oak, and a shopping center obliterated the cattail marsh where the mallards nested. The little creek was directed into a drainage pipe.

We moved to central Arizona, where the rivers now flow only after rain. I attended the university to study geology. I read of the early European American settlers along the Salt River, who used the river's flow to run a flour mill. Malarial mosquitoes had bred in the wetlands along the river. I wandered out from my dormitory for walks along the dry bed of the Salt, observing the skeletal anatomy of the river and growing indignant over environmental change.

I graduated from the university and moved to Colorado, where the rivers still flow. I wandered delightedly up the canyon of the Cache la Poudre River, thinking of it as the pristine mountain river where French fur trappers cached their gunpowder in the 1820s. Then I read early accounts of the river and realized that I could not find the beavers, the lush riverside forests, and the abundant trout that early settlers had described. I wrote my own book, *Virtual Rivers,* to prevent others from mistakenly assuming that the rivers of the Colorado Front Range are pristine.

Along with rivers, I also grew up among books. Rivers I could experience directly gave me only partial insight. I needed the broader and deeper perspective of books to understand how rivers function, how those functions have changed through time, and our role in those changes. As I walk beside a clear-flowing mountain creek, I can see through the water to the texture of the streambed. I can see cobbles green with algae, and tan-colored sand beside the cobbles. A fish darts above the cobbles, creating a swift, dark shadow. Mossy banks and rotting logs overhang the creek. I cannot see the aquatic insects clinging to the cobbles, their delicate nets spread against the current to catch microscopic animals drifting downstream. I cannot see the calcium that dissolved in the water where it flows underground before emerging upstream as a spring. I do not notice the grassy ridge of boulders left when a debris flow completely recontoured the creek thirty years ago, let alone the bedrock knobs smoothed by a glacier during the last glaciation. My direct perceptions are limited to the most obvious features, to the human scale of detail, and to the moment when I observe the creek. And even in that moment, at my own scale, I perceive what my experience has prepared me for; I perceive the arrangement of cobbles and sand on the streambed because I study these phenomena, but I do not perceive the species and ages of the riverside trees. But when I walk the creek with a botanist, she shows me how the river birches are all the same age, having germinated after a flood swept the banks of the creek clean and left fresh sediment for seedlings. An aquatic ecologist brings his collecting net and shows me the astonishing variety of tiny, squirming creatures living out their lives under the cobbles. A historian pulls aside a tangle of saplings to reveal the crumbling foundations of a cabin built during the past century by placer miners working the bed of the creek for gold. As I draw on this knowledge, I build an understanding of the river ecosystem through time and space. Much of that understanding comes from indirect knowledge, from insight gleaned through books. We all owe a huge debt of gratitude to those who care enough to study some part of a river deeply and carefully and then to share their insight through the written word. And so I go back and forth, from river to book to river, trying to understand.

Developing this book has become a personal experience. My perceptions of the world around me changed as I wrote it. Since writing the chapter on water pollution, for instance, I have altered my diet to eat mostly organic, vegetarian foods. If I drive through an agricultural landscape, I no longer perceive benign, pastoral scenery. Instead, I feel an urge to roll up the car windows and hold my breath as I think of the poisons broadcast over the fields. I have become skeptical about the treatment of the food I eat, and of the neatly manicured lawns of my neighbors and my university campus.

Stephen Pyne traced the beginnings of a philosophy of water conservation in the United States to geologists such as John Wesley Powell. Powell's vision of water use was grounded in sustainability and the limits of the understanding of nineteenth-century science. As those scientific limits expanded during the twentieth century, we came to understand more quantitatively what John Muir and others intuited long ago—that everything is interconnected, and sustainable human societies cannot exist apart from sustainable ecosystems.

We all live among rivers. They are the sinews that bind our landscapes together. I have come to feel with increasing urgency that as we unwittingly strain or cut those sinews, we threaten the integrity of the whole environment on which we depend. I grew up in a wet countryside where it was difficult to clean the water enough to drink it. I now live in a dry countryside where it is rapidly becoming difficult to find enough water to drink. We have taken rivers for granted for centuries, and we continue to do so at our peril. I do not think we can continue in this manner for much longer. I hope that we do not try to. This book is an expression of that hope.

Acknowledgments

Writing this book has provided me with both pleasure and an education. The pleasure has come in part from the opportunity to discuss rivers with others who are passionate about rivers, and about writing. Hiroshi Ikeda of Tsukuba University invited me in 1997 to give a talk, “Americans and Rivers,” at an international symposium held on the Kurobe River in Japan. That presentation formed a nucleus that grew into this book when Jean Thomson Black of Yale University Press suggested that I write about rivers. Jean has continued to work with me during all stages of crafting a sketchy idea into a finished book, and I much appreciate her friendship and skill. Several people read drafts of individual chapters: Madeleine Lecocq read the introductory and concluding chapters; L. Allan James read the chapter on pioneer impacts; Brian Bledsoe read the chapter on commercial impacts; Douglas Smith read the chapter on bureaucratic impacts; and Douglas Thompson read the chapter on river restoration. Each of them provided insightful and detailed comments that substantially improved the book. Douglas Thompson, Judy Meyer, and two anonymous reviewers also reviewed the entire book at the request of Yale University Press. Their careful reading and analysis further integrated and strengthened the book. The staff of various government agencies and library collections were very helpful in collecting historical photographs, and I thank those at the Bancroft Library, University of California at Berkeley; the Cleveland Public Library; the Florida Department of State, Division of Library and Information Service; and the South Florida Water Management District. Joe Tomellerie graciously provided the drawing of a paddlefish, Peter LaTourrette provided the photograph of a dipper, and the Missouri Department of Conservation provided the photograph of a hellbender. My parents, Richard and Annette Wohl, were with me each step of the way, telling stories of growing up in Cleveland and gently prompting me with their favorite question, “When is your book going to come out?” Thank you all.

Disconnected Rivers

Chapter 1

Why Should We Care About Rivers?

Rivers reflect a continent's history. Where forces far beneath the Earth's crust force up mountain ranges, rivers flow swift and cold down steep, boulder-strewn channels. Where the Earth is still, rivers meander broadly, depositing thick plains of sand, silt, and clay.

They also reflect a people's history. Where people clear the forests for agriculture, river valleys retain sediments, recording the transitional period when the soil washes down from the hillslopes, and rivers become broad and shallow. Where people mine precious metals from hills or build electronics factories, river valley sediments contain the toxic by-products of these activities. People build canals, roads, and railroads along river corridors, following river passages through dense forests or steep mountains.

River valley sediments record all the changes in a river's drainage basin over thousands of years. The river itself records the most recent changes, steepening its course as it crosses the furthest sediments deposited by a glacier now melted, or dammed where farmers in the 1950s wanted water storage.

The organisms living in and along rivers also reflect history. Along a river downstream from a site where mining occurred in the 1890s, there are fewer individuals and species of aquatic insects and fish in the twenty-first century because toxic metals still leach from the mining site. Where a river repeatedly shifted its course back and forth across the valley bottom during floods spread across 200 years, cottonwood seedlings have sprung up on each new sandbar created by a flood. Now the river has groves of cottonwoods aged 10, 40, 80, and 175 years, and these trees map the changes in the river's course. Where dammed water released from the bottom of a reservoir creates a cold, clear flow, introduced trout thrive, out-competing the native fish adapted to the warm, sediment-laden waters present before the dam was built. And where a dam blocks native fish returning from the sea to spawn, these fish are no longer present at the headwaters of the river.

The physical forms of rivers and river ecosystems are our historical archives, yet these archives are challenging to interpret. Gaps may be present in the physical record where sediments deposited during an earlier period of river history were subsequently eroded. Because of the gaps we can seldom decipher a complete and continuous record of a river's history. But by assembling the records from many rivers we can piece together regional and continental syntheses of history. Organisms living in and along a river also have an evolutionary history, and the unique evolutionary lineages present in different river drainages provide clues to the history of isolation or integration of each drainage.

We owe rivers the respect due to any source of information that helps us to understand our history, and so to understand ourselves. But rivers are also our lifelines. They provide us with the water we drink, the water that helps our crops to grow, and the water that fuels or cools our industries. Water is a universal solvent and is used at some stage in the manufacture of every product we consume. Rivers transport our wastes, and to some extent transform them. If not for this self-purifying function of rivers, many of our estuaries and deltas would be even more polluted. Rivers transport our goods, generate our power, and sustain our recreation. The condition of our rivers, more than any other natural resource, reflects our attitudes toward the world around us, and ultimately our attitudes toward ourselves. The society that does not protect its rivers destroys its own lifelines.

This book draws a connection between lack of respect for rivers and lack of understanding of rivers. We in the United States have not fully appreciated the vital functions that rivers perform.

Human beings have used the natural systems of America as resources since the first people reached this continent. Such use reaches unsustainable levels whenever people deplete a physical resource to the point that the resource is effectively no longer available to them, or whenever they deplete a biological resource to the point that a species can no longer sustain itself or perform its ecological functions. Unsustainable irrigation practices led to the salinization of Hohokam agricultural fields in the southwestern United States by A.D. 1300. Unsustainable hunting, trapping, and fishing by European Americans led to the extinction or near-extinction of beaver in the eastern United States during the 1600s, the bison by 1880, the passenger pigeon in 1914, and commercial fisheries for shad, cod, sturgeon, and other species during the later nineteenth and twentieth centuries. Unsustainable logging practices altered forest ecology and composition in a manner that will require centuries to overcome in regions as diverse as the southern Appalachians (1900s–1930s), the Colorado Rockies (1860s–1890s), and the California coast ranges (1950s). Unsustainable river flow regulation and diversion led to the endangerment of native fish, massive loss of riverside vegetation, erosion of archeological sites, and degraded water quality along the Colorado River as well as to the collapse of salmon populations in the Pacific Northwest.

This long history of resource destruction is partially offset by a developing vision of resource conservation. The environmental movement in the United States has emphasized the conservation of natural resources and the reservation of public lands since the late nineteenth century, when leaders such as John Muir, Gifford Pinchot, and Theodore Roosevelt persuaded the federal government to designate the first forest reserves and national parks. Public support for conservation grew during the succeeding century, along with concerns about how human activities might be affecting the world around us. Development of the modern conceptual framework of ecology during the 1960s and 1970s emphasized that the environmental health of public lands must be assessed in terms of the physical habitats that support communities of interdependent species. With increasing concern over the number of species becoming endangered or extinct, Americans are realizing how closely the species present in any community are linked to the physical landscape and to one another by numerous chemical and physical exchanges. We cannot save an endangered species of trout without also saving the river and floodplain habitat in which that trout evolved, as well as the plants and insects that form the food web in which that trout exists.

At the same time that the federal government reserved public lands, it also invested in land reclamation and engineering, building dams to irrigate agricultural lands and control floods and dredging and straightening rivers that were then confined within levees. While the government created legislation guaranteeing the quality of air and water and protecting endangered species, it also subsidized road building, timber harvesting, mining, and grazing on public lands.

The United States thus has two competing traditions. One tradition emphasizes individual and corporate freedom to optimize short-term profits, with economic growth and increased standards of living based on the excessive exploitation of natural resources. The other tradition emphasizes resource conservation and environmental protection, an interest in natural history, and expectations of outdoor recreation and public access to wilderness areas. These competing traditions together shape the understanding and use of rivers in the United States.

Despite the history of public awareness of environmental issues in this country, many people remain unaware of how substantially human activities have altered rivers across the nation. Human activities affect the movement of both water and sediment along a river—the river's form. Human activities also alter the river's ability to provide habitat and nutrients for diverse species—the river's function. The distinction between form and function is important because it governs public perceptions of rivers.

The form or physical appearance of a river can be readily perceived. People commonly expect a "healthy" river to be "pretty"—to have clear water, stable banks and bed, and perhaps a fringe of trees along its banks or fish in its pools. These expectations of a healthy river's appearance may be misleading in that they ignore loss of function. However, it is difficult to assess a river's function with only a casual examination. River channels are fundamentally conduits for water and sediment, but the specific processes of water and sediment movement vary widely among channels. These processes create unique habitats and processes of nutrient exchange to which the local in-channel and floodplain communities of plants and animals are adapted.

The channel bed of a natural river, for example, is unlikely to be of uniform depth or material for more than a few tens of yards downstream. Most channels have alternating deep pools and shallow riffles. The riffles have coarser sediment and faster and shallower water. Species of aquatic plants, insects, and fish adapted to rapid, shallow water favor riffles, whereas a few yards upstream a different community of species will inhabit the deeper waters of a pool. Because these differences are not readily apparent to an observer, a river with severely impaired function may appear to be healthy. A river with clear water and stable banks

View upstream along the Savage River in Denali National Park, Alaska. This river is fully connected to the surrounding landscape and richly diverse in form and function. Pools and riffles alternate downstream, and riverside vegetation forms a mosaic of different types and ages. During floods, water flows across the floodplain, submerging surfaces such as the cobble bar in the right foreground.

supporting a few mature cottonwood trees meets many people's expectations of a picturesque river. But clearing of wood from the river channel may have destroyed the pools and riffles, changing a diverse in-channel habitat supporting numerous species to a largely uniform channel supporting only a few species. Flow regulation associated with upstream dams may have altered the river's flow such that the banks are more stable and cottonwoods, which germinate on freshly deposited sandbars, are no longer reproducing. Changes in river form have led to an impoverishment of river function and a decrease in biological diversity. If we do not understand how a natural river would really appear or how it would function, however, we will not recognize when a river environment has been altered.

We cannot save trout without saving their river and floodplain habitats. We cannot save river and floodplain habitats—and the plants and insects of the trout's food web—if we do not also maintain the processes controlling water and sediment entering the river corridor from

View upstream along a small river with placer mining in central Alaska. This river has been heavily impacted by increased sediment and reduced streambed and bank stability. Pools and riffles have been buried under sediment, and riverside vegetation has been destroyed. Both form and function have been impoverished.

the surrounding hillslopes and uplands. They go hand in hand. A functional river ecosystem is connected to everything around it: the atmospheric and oceanic circulation patterns that control precipitation over the drainage basin; the soils developed on the hillslopes adjacent to the river during thousands of years of weathering of the underlying bedrock; the plant communities growing on those soils, and the animals that pollinate and consume the plants; the processes by which precipitation filters down to the groundwater and raises or lowers the water table that is intimately connected to most streams; and on and on. By altering our river systems we have, in many cases, severed these vital connections. Dams interrupt the upstream-downstream passage of fish, the downstream flow of seeds that replenish riverside forests, and the downstream movement of water and sediment. Timber harvests short-circuit the gradual downslope flow of rainwater below the ground, instead sending masses of water and sediment quickly into nearby rivers. Artificial levees keep young fish from the rich nursery habitats created by warm, shallow waters spreading across a floodplain during high flows and prevent the pulse of nutrients returned to the channel as floodwaters recede. Disconnected rivers become impoverished in form and function because the processes maintaining form and function no longer operate. We increasingly have discovered that it is enormously expensive and difficult to artificially re-create these processes—to pass salmon through a dam with fish ladders, for example, or to stabilize and revegetate clearcut hillslopes. River corridors function most fully and effectively when they remain connected to the total environment.

Today, the American people are being asked to make decisions regarding rivers from the national level (in relation to the Clean Water Act, the Wild and Scenic Rivers Act, the National Floodplain Insurance Act, the Endangered Species Act, and other federal legislation) to the local level (in relation to wastewater management, nonpoint source pollution, in-stream flow, flood hazards and community zoning, open space and greenbelts, recreation, and dam relicensing and removal). Most people have an instinctive appreciation for flowing water and look to rivers as a source of recreational and esthetic enjoyment. But others still regard rivers as mere conduits for the transport of commodities and wastes or as natural hazards that must be controlled. These conflicting ways of seeing rivers and hence demands on river resources only intensify as both global population and U.S. population and resource use continue to grow. If we are to make informed decisions regarding rivers, it is important that we learn to think of rivers in terms of both form and function. This requires that we look beyond the obvious physical characteristics of a river and think of it as an extensive ecosystem interdependent with and connected to the surrounding floodplains and drainage basin.

Chapter 2

American Rivers

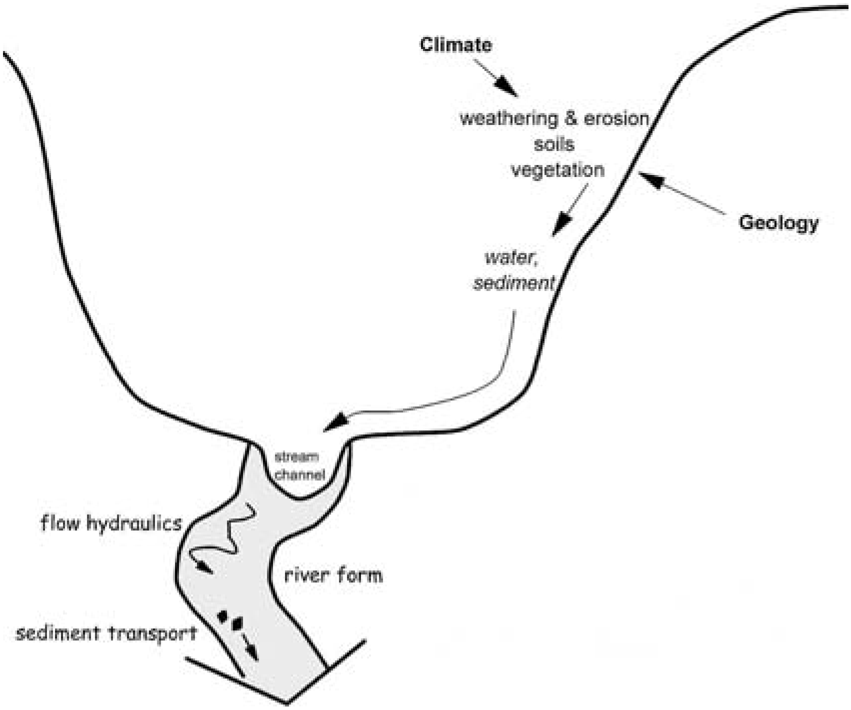
The rivers of the United States are as diverse as the country's people. The rivers meander slowly across marshy plains hazy with heat and humidity. They rush down steep, rocky gorges fed by the melting ice of glaciers. They flow hidden beneath the ground in limestone caves, or they flow only after a thunderstorm has abruptly saturated the desert's surface.

Animals adjust themselves to this diversity. Silvery salmon swim relentlessly up clear, cold waters to lay their eggs among gravels eroded from the jagged Sawtooth Mountains of Idaho. Catfish with barbels sensitive to subtle movements in murky water wait beneath overhanging banks of clay in the lowlands of Louisiana. Mallard ducks call to one another as they land on the gray-green waters of the upper Mississippi. Beavers work steadily with slender branches and saplings, anchoring them among cobbles pushed up into a ridge, and overnight a small mountain stream in Utah is dammed.

Starting at least twelve thousand years ago, humans also adjusted to this rich diversity of river environments and shaped the rivers to their own needs. Human impacts to rivers depend in part on the characteristics of each river ecosystem, and these characteristics reflect the geology, climate, and history of a river basin.

The Physical River System

A river channel conveys water and sediment downstream. Imagine two hypothetical rivers: one flowing from the Rocky Mountains in the southwestern United States, the other flowing from the southern Appala-



The physical river system. Geology and climate together determine how bedrock is broken down into sediment that creates soils and supports vegetation. Water and sediment moving downslope into a river govern the form of the river. River form in turn influences the manner in which water and sediment move downstream.

chians. The contrasts between these rivers illustrate how geology and climate interact to govern the amount of water and sediment supplied to a river, and how the water and sediment supply control river form and process. Both rivers begin in steep terrain where a long history of uplift contorted the bedrock into mountains.

Faulting and the intrusion of large masses of molten rock into the overlying crust during millions of years created the Rockies. Alpine glaciers ground away at their upper valleys until about ten thousand years ago. As the ice widened the valleys, it also deposited huge boulders along them and, when it melted, sent much higher volumes of water and sediment down the rivers. The granite underlying the drainage basin resists weathering and erosion in the relatively dry climate present since the retreat of the glaciers. The tough rock slowly weathers to cobbles and gravel that form steep slopes below the bedrock cliffs. Where softer rock such as shale is present, weathering produces silt and clay that form rounded, gentle slopes.

Summer rains fall with such swift intensity that the rocky, unvegetated ground does not absorb the rainwater, which runs quickly downslope into nearby streams. The water carries large amounts of sediment with it because semiarid regions such as the southern Rockies have enough precipitation to at least periodically move sediment downslope but not enough vegetation to stabilize sediment on hillslopes. The rapid but episodic movement of water and sediment into the river occasionally produces flash floods or debris flows, but even these may not be strong enough to move the large boulders left in the stream channels by the melting glaciers. Floods and debris flows keep the river broad and shallow. In places the river braids into multiple channels. Flow is turbid, with sediment carried in suspension by the water, and only those plants and animals that can withstand such turbidity and rapid fluctuations in flow level live within and along the river. As the river leaves the mountains and enters the broad desert basin beyond, the flow has only enough energy to carry the smaller sediments. The boulders and cobbles of the mountain channel give way to sand and gravel farther downstream. The river may cease to flow on the surface as water percolates into the thick layer of sediment underlying the basin.

The Appalachians are older mountains, created as compression between North America and Africa folded bedrock into tight ridges and valleys. The milder climate supplies abundant rainfall, and the softer sedimentary rocks of the Appalachians weather in this warm, wet climate to thick soils. The soils support dense forests that help to lessen the impact of falling rain, allowing the rainwater to be absorbed by the soils and move downslope more slowly beneath the surface. The Appalachian river has a more constant flow than its counterpart in the Rockies and carries less sediment. The river is narrower and flows in a channel lined with dense riverside forest. Where the river crosses harder rocks, the downstream slope of the valley is steeper and the river has a stair-step configuration. Softer rocks weather to a lower downstream slope, and the river alternates downstream between riffles and pools. As the river leaves the mountains and enters the adjoining foothills, the downstream slope of the valley decreases further, the valley grows wider, and the river meanders across the valley bottom.

View upstream along a meandering river in North Park, Colorado. The river is constantly shifting back and forth across its floodplain as individual meander bends erode along the outside of the bend and fill with sediment along the inside of the bend. Occasionally, the channel will straighten its course across a bend, leaving the abandoned meander as an overflow channel or isolated pond. In this photograph, the band of darker riverside vegetation indicates the width of floodplain across which the river meanders. This width is several times greater than the width of the actual channel.

As geology, climate, and topography change with time or downstream, river form changes in response. A river is thus self-adjusting and variable over time and space. These adjustments may be temporary, as when a river widened by a large flood gradually narrows during the succeeding decade; or the adjustments may be longer-lasting, as when a housing subdivision and its accompanying pavement decrease sediment and increase water supply to a river, causing the river to permanently widen.

Because a river continually responds to changes in its environment,

A closer view of an individual meander bend along a river in the Wind River Range of Wyoming. The outside of the bend, where the flow is swifter and deeper, is eroding. The shallow inside of the bend has a bar of lighter sediment recently deposited by the river.

it is never static. The type of river response depends on the magnitude and persistence of changes in water and sediment entering the river. The movements of water and sediment within a sand-bed channel adjust readily over a period of minutes to hours. As discharge increases during a flood, for example, flow velocity increases, and the greater force of flow exerted against the streambed and banks brings sediment into transport. As the floodwaters recede, much of this sediment is redeposited along the river. If the change in water and sediment entering the river is more dramatic or longer lasting, even a river formed in bedrock can alter its form and downstream slope in response to the change in supply. This adjustability of rivers is at the heart of how rivers respond to human land uses that alter water and sediment supply to stream channels.

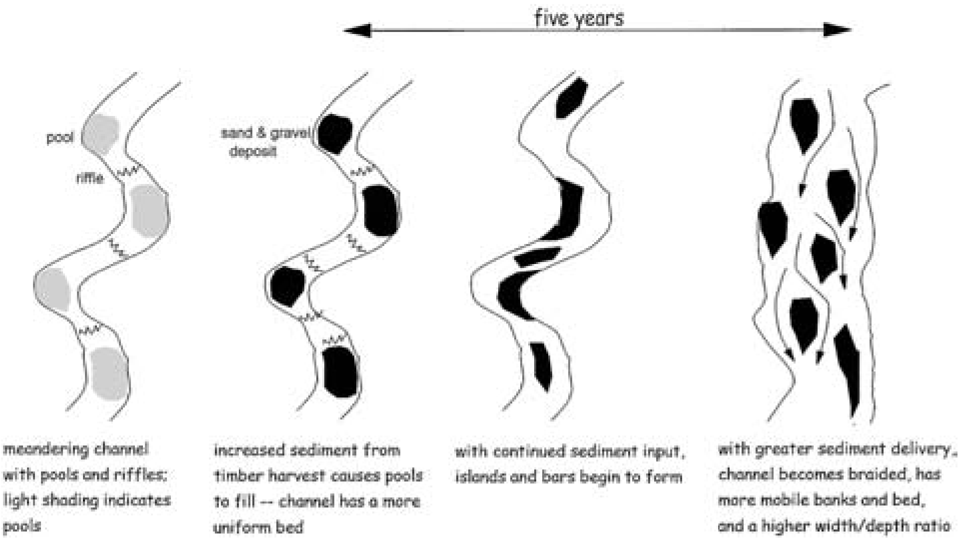
River Regions

The diversity of river forms present in the United States and North America reflects the patterns of geology and climate present across the

View upstream along a mountain river in northwestern Montana. This steeper channel has a stairstep configuration, with steps formed of boulders and small pools alternating downstream. Turbulent mixing in each pool keeps the water highly oxygenated. Such stairstep configuration is characteristic of headwater streams.

continent. The continental United States is drained by five major river systems—the St. Lawrence, the Mississippi, the Columbia, the Colorado, and the Rio Grande—and by numerous smaller river networks. The movement of water and sediment from the continent to the oceans is not evenly distributed among these rivers. Much of the water comes from the wetter regions, and the sediment from the drier regions. The combinations of geology and climate produce six distinctive "river regions" in the United States. River form, flow characteristics, and sediment transport are broadly similar within each region.

A pool formed as flow plunges over logs jammed across a river in Washington. Notice the differences in streambed sediment, from finer gravels at the right to boulders in the pool. Such differences create diverse habitats for aquatic insects and fish.



An example of river adjustment.