CONTENTS

1

Of Vernal Pools & Burning Rivers

I grew up in a country of water. Rain and snow fell abundantly, the hydrologic cycle on the southern shore of Lake Erie fueled by the "lake effect" of winds migrating south from Canada, picking up plenty of moisture as they crossed the Great Lakes, and dropping the moisture as a gift for lakeshore communities such as Cleveland. We had a dehumidifier in the basement that had to be emptied regularly during summer. Vegetation grew easily and abundantly. The nearest creek was a short walk from my house. Spring snowmelt saturated patches of the second-growth woodlands behind the house, giving rise to vernal pools. Chilly evenings reverberated with the calls of thousands of spring peepers.

My dad taught junior-high biology and chemistry, and I was keen to be a scientist. We set up a lab in the basement, complete with a dissecting kit and microscope. I waded into the vernal pools and collected water that revealed invisibles like the tiny animalcules that Antonie van Leeuwenhoek marveled at when he built the first microscope. I drew and learned to identify *Daphnia*, the fat-bodied, small-headed, translucent creatures known as water fleas, as well as rotifers, copepods, ostracods, and planaria.

Salamanders and frogs were the charismatic megafauna of the pools. We watched them and the invisibles reach abundance as the pools grew in size, then disappear to places unknown as the pools shrank and eventually vanished with the advance of summer.

Every week we hiked in the nearby natural area. The waters marked the seasons. An oxbow lake that froze for skating in winter nearly disappeared beneath a continuous surface of duckweed in summer. The ducks and frogs left slender trails of open water when they moved across the lake. The Rocky River cut slowly down through cliffs of black shale and buff or gray sandstone. Winter floods reshaped the gravel bars in ways that initially left me suspicious someone had been working in the river with a bulldozer.

I considered human intervention a given. The river looked natural, but I wore rubber boots to wade into the river when I caught stickleback minnows with a dipnet in summer. The rule was to wash any skin that touched the water—septic tanks in the area regularly overflowed during heavy rains. That was the Rocky River; never mind the Cuyahoga, which caught on fire (for the third time) when I was 6.

I suppose we never fully know how childhood experiences shape our subsequent lives. Certainly, I loved being outdoors in a world as natural as I could find in northern Ohio during the 1960s and '70s. And I liked knowing things: I wanted to identify what I saw and understand how the plants and animals lived their lives. Decades later, the same desires drive my choices in life. I want to see, to experience, and to understand—but mostly the natural world. I am content to let my computer and my new, electronics-dominated car remain mysteries, although I regularly grumble at each.

I grew up a naturalist—someone fascinated by the entire natural world—and I remain a naturalist at heart, but I am also a professional scientist with the narrower focus that implies. I've been lucky enough to make a good life and career out of knowing a lot about a little and a little about a lot. This is a roundabout way of saying that I study the details of how moving water and sediment create river channels and floodplains, but I think about those channels and floodplains in relation to climate, geology, chemical reactions, plants, animals, and little invisibles—and, inevitably, people.

I came to the study of rivers without any premeditated design. When I started college in Arizona, I had a hard time deciding between geology and biology. I chose geology during my freshman year, with some longing looks over my shoulder at ecology. My first geology class introduced me to the idea of using rocks to understand environments long vanished from Earth's surface, and to the realization that a professional geologist could travel around the world studying amazing places. I was entranced by slide shows of mountains and ice sheets in Antarctica and by regular field trips to the Grand Canyon. I liked most of the courses within geology, but a course in geomorphology—the study of Earth's surface processes and landforms—came relatively late in my class sequence, and the topic "stuck." The choice of rivers as a specialty within geomorphology was easy.

About the time I was trying to decide what kind of geomorphologist I wanted to be, I took a hike along the canyon of the Hassayampa River in central Arizona. I remember looking at the sandbars along the basalt canyon and feeling a quiet pride—and wonder—that I now understood how those sandbars got there and why they were located exactly there. I've always had trouble turning back rather than following just one more bend of the river to see what's ahead. Contemplating those sandbars, I realized I could spend my life following the next bend and the one after that—and the choice was made.

I like natural environments. Cities and rural areas, not so much. I also like to read history and biography and tend to make note of relevant river tidbits I come across, such as descriptions of big logjams or abundant beaver dams that travelers described a century ago on rivers that no longer have those features. And I enjoy traveling and seeing new natural places. I've been lucky. I've been to be able to do field research in deserts, tropical savannas and rainforests, arctic tundra and boreal forest, dry steppes, temperate forests, high mountains and lowland swamps, and coastal regions. Everywhere, pretty much, except Antarctica, which is not really known for its rivers.

Recognizing the history of human manipulations of landscapes and rivers in places I have worked, and reading of this history elsewhere, I have come to understand that human legacies are difficult to escape. I like to work in the most natural rivers I can find, but people have influenced rivers even in the most remote portions of arctic Alaska or the Australian Outback. If this sounds like an exaggeration, consider climate change, for starters. Then, think of millennia of cutting forests, planting crops, and tending grazing animals in some parts of the world. Think of straightening and deepening rivers, building levees, trapping beavers, pulling large wood from the channels—for more than a century in much of the world. Think of dams large and small, canals that divert water away from rivers to thirsty crops and cities, pumps that bring underground water up and away from rivers. It all adds up, so human influences inexorably creep into my work on even seemingly natural rivers.

My research focus has followed a braided path through time. For my PhD work, I used sediments deposited by large floods in bedrock canyons of tropical Australia to infer the history of tropical cyclones and the floods they caused. This work continued a research line pioneered by my PhD advisor, Vic Baker, and carried on to great effect for decades by his research group. I examined flood sediments in Arizona, Utah, Colorado, and Virginia, then took a slight tangent and focused more on the forms of the bedrock canyons in which the flood sediments were deposited. That research took me to various parts of the United States, as well as to South Africa, Spain, Israel, Japan, Sweden, and India.

I got my first (and thus far only) job at Colorado State University, and it wasn't too long before I decided I needed to focus more on mountain rivers. I examined mountain rivers in the western United States and compared them with rivers in Japan, Italy, New Zealand, Chile, and Nepal. While walking the mountain rivers of Colorado, in particular, I spent too much time avoiding portions of the river with logjams or beaver dams before doing an about-face and deciding to focus on these features. That work took me across the United States and to Panama, Costa Rica, and the Canadian Arctic.

Along the way, a colleague made an offhand remark that triggered an aha moment for me. As we slipped and banged our shins and crawled through a jungle gym of downed timber in an old-growth forest along a mountain creek in Colorado, Kate Dwire wondered aloud, “How much carbon is stored here?”

I realized that the wet, black soils in river corridors with logjams and beaver dams probably stored a lot of organic carbon and I began to measure that carbon. Because most of the carbon stored along rivers is in the floodplain, I shifted my focus to forms and processes in floodplains, especially along the rivers in my part of Colorado, which have experienced wildfires and floods during the past decade. Those studies led to questions about what features along a river create resilience to natural disturbances.

I'm approaching the end of my professional research career now, but there may be another branch yet to follow: time will tell.

I also grew up a teacher. If that sounds paradoxical, it is. Both my parents were teachers and as a child I was dead set against being a teacher myself. But . . . I liked telling other people about what I learned. I enjoyed writing book reports about natural history and elaborately tracing drawings of plants, animals, and minerals. One of my elementary school art projects was block cuts of different types of bacteria. I know this because my parents kept all these things, not because I actually remember doing them.

The need to tell others about something that is fascinating seems inherent to me: not sharing insights such as that individual trees use an underground network of roots dense with fungi to help neighboring trees in times of stress, or that beaver dams and canals change a single river channel into a mesh of ponds and channels that branch and rejoin, creating thick, black soils rich in carbon would be pointless—much like a miser hiding a pile of jewels and shining coins.

The urges to see, study, and understand, and to communicate gave rise to this book. My aims are to help you see rivers differently than you may have and to understand what you see. And to have some fun along the way. I presume no one wishes to cry themselves a river, but I hope many would like to read themselves a river.

A Word about River Forms

My intent is to limit the use of technical terms in this book and to explain each term as I introduce it, but it is helpful to understand that river scientists think about channels and the adjacent floodplains in three dimensions: longitudinal (upstream-downstream), lateral (across the channel or between the channel and floodplain), and vertical (between different depths of flow in the channel and between the surface and subsurface). In other words, rivers, of course, flow downstream, but they do more than that—they also flow into and out of the ground and across the floodplain, and the animals living in rivers regularly move upstream (think of migrating salmon or eels). The lateral and vertical dimensions of rivers are not just interesting side notes; they are fundamental to the health of the river, as I'll explain later in the book.

Additionally, river scientists look for recurring patterns that can provide insight into how rivers operate. The ways of water and sediment can vary if ice is present, for example, or if all the rain comes at once versus gradually throughout the year, but the interactions of water and sediment create consistent river patterns, from the arctic regions to the tropics, and from deserts to rainforests. These patterns are described across entire river networks as drainage patterns and longitudinal profiles, and within much more limited lengths of river as planforms and bedforms.

The drainage pattern is the arrangement of channels on a map or an aerial image. Examples of commonly occurring drainage patterns include dendritic, which resembles the branches on a tree and forms where the underlying surface is relatively homogeneous. In contrast, rectangular drainage patterns occur where underlying fractures in the rock create weaker areas on which channels form.

Like drainage patterns, longitudinal profiles provide clues to the history of a river. A longitudinal profile is a side view along the entire length of a river. A longitudinal profile can be a smooth curve or can include steeper segments where the river flows over a waterfall or down a long stretch of rapids. Steeper segments indicate where the river flows over more resistant

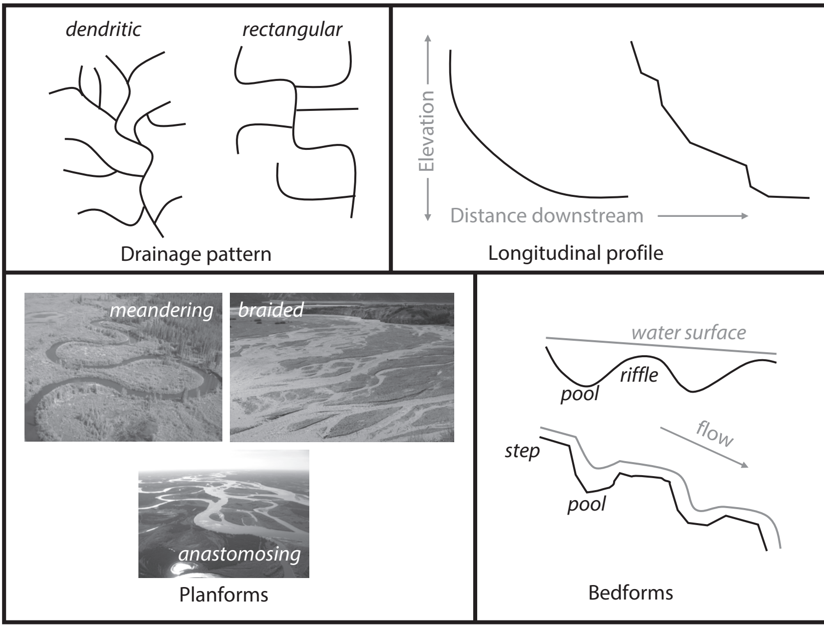

FIGURE 1. A basic illustration of different aspects of river form, from the scale of an entire drainage basin, as seen in map view (upper left); or as seen in side view (upper right); to progressively smaller scales of planforms, as seen in map view (lower left); and bedforms, as seen in side view (lower right).

rock or record a history of tectonic uplift of the entire drainage basin—more about that later.

At distances of miles to tens of miles, river channels exhibit characteristic shapes when viewed from above. The most common planforms are straight, meandering, braided, and anastomosing. A straight channel doesn't have many interruptions by many bars and islands and follows a path with relatively few curves. The channel is meandering if the ratio of the actual channel length to the straight-line distance between two points along the channel is 1.5 or greater. A braided channel includes numerous secondary channels that branch around islands and bars before rejoining downstream. An anastomosing channel also has secondary channels that branch and then rejoin downstream, but the areas between secondary channels are much wider than each channel and are likely to host stable, forested floodplain rather than the frequently changing, minimally vegetated bars of braided channels. Each of these planforms reflects the interactions among water, sediment, vegetation, and the underlying geology. As these interactions vary downstream, the planform of a river also varies downstream, such as where a straight or braided channel in mountainous terrain takes on a meandering planform as it enters the adjacent lowlands.

Bedforms, as the name implies, are patterns in the riverbed. Among the most common are the downstream alternations between relatively deep pools and shallow riffles. Steeper channels alternate downstream between vertical steps and a plunge pool at the base of each step. As with planforms, bedforms reflect the interactions among water, sediment, and the steepness of the valley floor, and typically vary downstream over lengths of a mile to a few miles.

Each scale of patterning provides clues to the past and present influences on a river, and what follows in this book will help you learn how to interpret these clues.

INDEX