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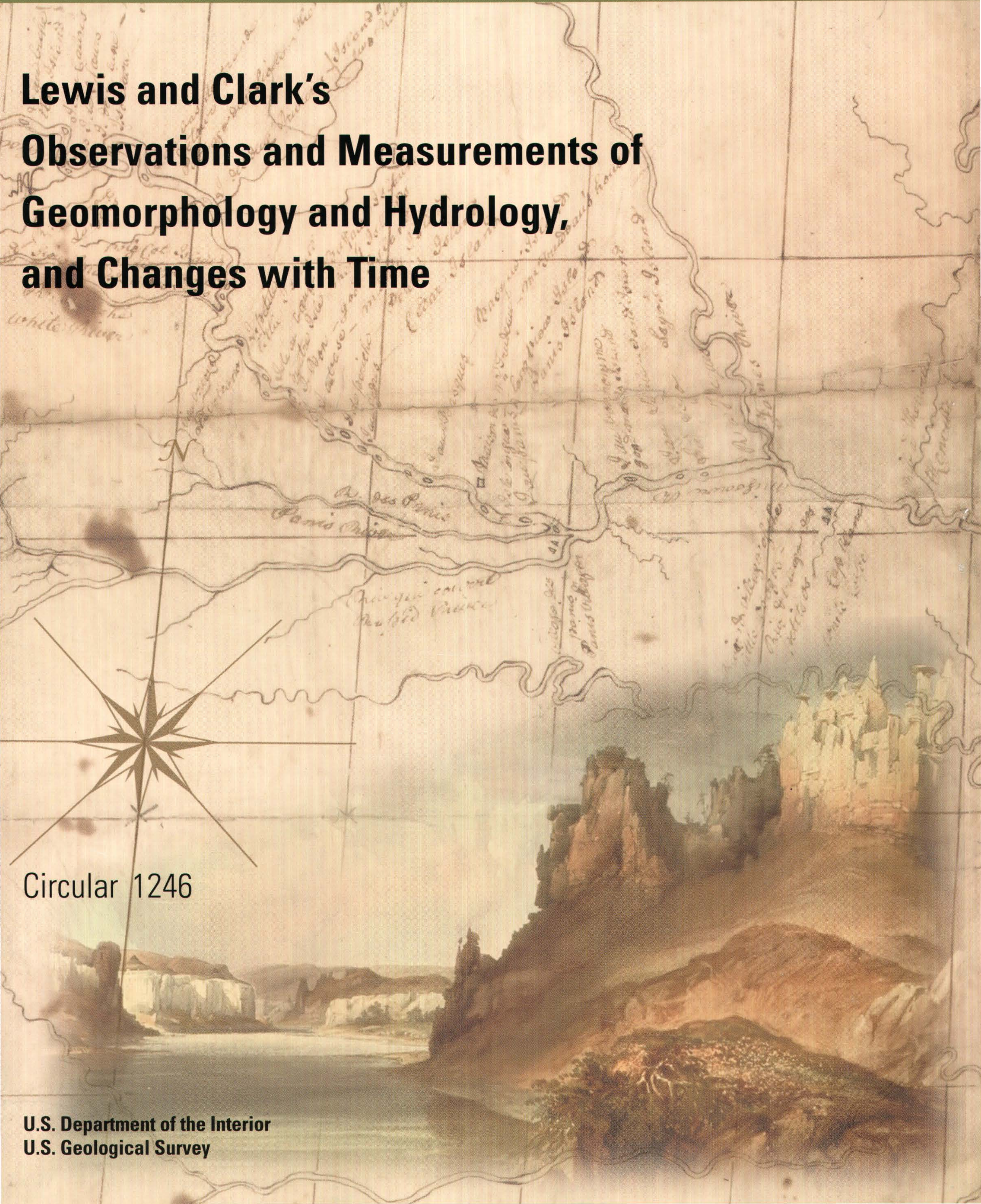
Lewis and Clark's Observations and Measurements of Geomorphology and Hydrology, and Changes with Time



Circular 1246

U.S. Department of the Interior
U.S. Geological Survey

Lewis and Clark's Observations and Measurements of Geomorphology and Hydrology, and Changes with Time

John A. Moody

Robert H. Meade

David R. Jones

U.S. Department of the Interior

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U.S. DEPARTMENT OF THE INTERIOR

Gale Norton

Secretary

U.S. GEOLOGICAL SURVEY

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Contents

"Junction of the Yellowstone and the Missouri" painted by Karl Bodmer is based on a study done in 1833 and painted in Europe after his return from North America.

Foreword

THE ROOTS of the U.S. Geological Survey still thrive in the soil prepared two centuries ago by Lewis and Clark. The Lewis and Clark Expedition of 1803–06 was, in the words of John Logan Allen (1975), "...the first of what was to become a lengthy series of scientific explorations sponsored by the government of the United States...[in which] trained and intelligent observers gathered and analyzed geographical information in what can only be described as a scientific method and documented the resulting geographical images fully in maps and regional descriptions." Notable successors to those first intrepid explorers were the railroad surveys that crossed the trans-Mississippi west at different latitudes before the Civil War. Then, after the war, came the western exploratory surveys led by Clarence King, Ferdinand Vandeveer Hayden, George Wheeler, and John Wesley Powell. Those four postwar surveys led directly to the creation in 1879 of a permanent government agency to continue to carry out the topographic, geologic, and hydrographic functions of those surveys of exploration—the U.S. Geological Survey.

But making the connection between the Lewis and Clark Expedition and the present-day USGS is a deeper matter than the easy tracing of institutional genealogies. Even the casual reader of the scientific and engineering data collected and analyzed by Lewis and Clark will find in them the initial forays of the description and explanation of the topographic, geologic, hydrologic, and biologic characteristics of the landscape that have been the central thread of the work of the USGS for the past 124 years. The work of the modern USGS, like the work of Lewis and Clark, is motivated by the complementary goals of describing and understanding the physical world and providing a scientific basis for planning how society might best live in harmony with the land and its natural resources.

This Circular expands on the rich descriptions of the hydrology and geomorphology—two sciences that had yet to be named 200 years ago—produced by Lewis and Clark. This Circular connects their work with 200 years of subsequent observation and knowledge produced by the USGS and other "trained and intelligent observers." Lewis and Clark provided the first major scientific documentation of the American West. The USGS scientists of today are proud to continue that tradition to explore, document, and explain the changing world around us.

Robert M. Hirsch

Robert M. Hirsch
Associate Director for Water
U.S. Geological Survey

Models: Researched and built by Richard C. Boss for the Fort Clatsop National Memorial. Photo: Jim Wylder

Scale model of the keelboat (top) and red pirogue (bottom) used by Lewis and Clark.

Acknowledgments

ALL EXCERPTS in italics are from the University of Nebraska Press edition of The Journals of the Lewis and Clark Expedition edited by Gary E. Moulton and used by permission. Available wherever books are sold or from the University of Nebraska Press (800-526-2617) and on the Web at nebraskapress.unl.edu. Early stage data for the Ohio River at Louisville, Kentucky, were found by Steve Holmstrom of the U.S. Army Corps of Engineers. Photographic copies of the Bodmer paintings were provided by the Joslyn Art Museum, Omaha, Nebraska: gift of Enron Art Foundation, and copies of Clark's maps of the falls on the Columbia River were provided by the American Philosophical Society in Philadelphia, Pennsylvania. Early photographs of some sites on the Columbia River were provided by the U.S. Army Corps of Engineers, the Bonneville Power Administration, The University of Washington, and Washington State University. Other photographs were supplied by Bob Lindholm, Jim O'Connor, Norm Stucky, Lyn Topinka, Jim Wark, and Bill Woodcock.

Mike Beckwith, Dale Blevins, Craig Brengle, Dan Driscoll, Tom Herrett, Robb Jacobson, David Kresch, Pat La Tour, Steve Lipscomb, Mary Kidd, Deborah Martin, Jim O'Connor, and J. Dungan Smith have been part of the volunteer corps helping to complete this Circular. They have reviewed parts of the manuscript, made significant suggested improvements, and sought out and found interesting details that have added to this story of Lewis and Clark.

CONVERSIONS

This Circular uses mostly English units. To determine equivalent metric values from English values, multiply the English values by the conversion factors listed below. To determine equivalent English values from metric values, divide the metric values by the conversion factors listed below.

MEASUREMENT	MULTIPLY	BY	TO OBTAIN
Length	inch	25.4	millimeter
	foot	0.3048	meter
	mile	1.609	kilometer
Area	square foot	0.09290	square meter
	square mile	2.590	square kilometer
	acre	0.4047	hectare
Volume	acre-foot	1,233	cubic meter
	cubic yard	0.7645	cubic meter
Mass	ounce	28.35	gram
	pound	0.4536	kilogram
Force	slug	0.132	newton
Volume per unit time (flow)	foot per second	0.3048	meter per second
	cubic foot per second	0.02832	cubic meter per second
Temperature	degree Fahrenheit	$\frac{°F-32}{1.8}$	degree Celsius
Other units used by Lewis and Clark	bushel	2,150.42	cubic inch (in^3)
	link	7.92	inch (in)
	pole	16.5	foot (ft)
	pole	25	link
	chain (4-pole)	66	foot (ft)
	rod	16.5	foot (ft)
	rod	100	link
	league	3	mile (mi)
	fathom	6	foot (ft)
	yard	3	foot (ft)

Vertical Datum

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929." "Mean sea level" is not used with reference to any particular vertical datum; where used, the phrase means the average surface of the ocean as determined by calibration of measurements at tidal stations.

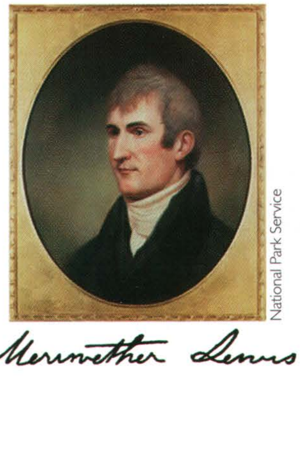
I

Introduction

TWO VERY different men, Meriwether Lewis and William Clark, joined to make the first recorded set of scientific observations and measurements of geomorphology and hydrology west of the Mississippi River. They did not limit themselves to these two scientific topics but were true naturalists, making observations and measurements related to astronomy (Large, 1979; Bedini, 1984; Plamondon, 1991; Bergantino, 1998), biology (Cutright, 1969), ecology, ethnology (Ronda, 1984a), geology (Bluemle, 2001; Bergantino, 1998), and phenology, as well as to the general geographical understanding of the arrangements of rivers and other topographical features of the trans-Mississippi West (Allen, 1975).

Meriwether Lewis

Meriwether Lewis was born near Charlottesville, Virginia, on August 18, 1774. He was the expedition's biologist and botanist. His journal entries are the more descriptive and narrative and can often transport the modern reader back in time. An excerpt from Lewis's journal entry describing the White Cliffs area of the Missouri Breaks (page 89, bottom left) in Montana illustrates his writing style:


National Park Service

> *...The hills and river Clifts which we passed today exhibit a most romantic appearance. The bluffs of the river rise to the hight of from 2 to 300 feet and in most places nearly perpendicular; they are formed of remarkable white sandstone which is sufficiently soft to give way readily to the impression of water; two or thre thin horizontal stratas of white free-stone, on which the rains or water make no impression, lie imbeded in these clifts of soft stone near the upper part of them... The water in the course of time in decending from those hills and plains on either side of the river has trickled down the soft sand clifts and woarn it into a thousand grotesque figures, which with the help of a little immagination and an oblique view at a distance, are made to represent eligant ranges of lofty freestone buildings, having their parapets well stocked with statuary; collumns of various sculpture both grooved and plain, are also seen supporting long galleries in front of those buildings; in other places on a much nearer approach and with the help of less immagination we see the remains or ruins of eligant buildings; some*

collumns standing and almost entire with their pedestals and capitals; others retaining their pedestals but deprived by time or accident of their capitals, some lying prostrate an broken othes in the form of vast pyramids of connic structure bearing a sereis of other pyramids on their tops becoming less as they ascend and finally terminating in a sharp point... As we passed on it seemed as if those seens of visionary inchantment would never have and end; for here it is too that nature presents to the view of the traveler vast ranges of walls of tolerable workmanship, so perfect indeed are those walls that I should have thought that nature had attempted here to rival the human art of masonry had I not recollected that she had first began her work...31 May 1805

Of this remarkable passage, J.L. Allen (1975, p. 268) wrote: "Lewis's prose was worthy of the landscape; never has a better description of the Breaks and their glory been penned. And not until John Wesley Powell, more than a half-century later, made his celebrated first trip down the Colorado River would any observer come so close to describing the landforming processes so characteristic of arid environments." Two weeks later, Lewis described the Great Falls of the Missouri:

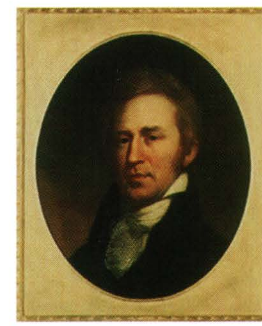
...a smoth even sheet of water falling over a precipice of at least eighty feet, the remaining part of about 200 yards on my right formes the grandest sight I ever beheld, the hight of the fall is the same of the other but the irregular and somewhat projecting rocks below receives the water in it's passage down and brakes it into a perfect white foam which assumes a thousand forms in a moment sometimes flying up in jets of sparkling foam to the hight of fifteen or twenty feet and are scarcely formed before large roling bodies of the same beaten and foaming water is thrown over and conceals them. in short the rocks seem to be most happily fixed to present a sheet of the whitest beaten froath for 200 yards in length and about 80 feet perpendicular. the water after decending strikes against the butment before mentioned or that on which I stand and seems to reverberate and being met by the more impetuous courant they role and swell into half formed billows of great hight which rise and again disappear in an instant...13 June 1805

However, Lewis was not pleased and later wrote on that same day:

...after wrighting this imperfect discription I again viewed the falls and was so much disgusted with the imperfect idea which it conveyed of the scene that I determined to draw my pen across it and begin agin, but then reflected that I could not perhaps succeed better than pening the first impressions of the mind; I wished for the pencil of Salvator Rosa or the pen of Thompson, that I might be enabled to give to the enlightened world some just idea of this truly magnifficent and sublimely grand object...13 June 1805

William Clark

William Clark was born near Charlottesville, Virginia, on August 1, 1770. He was the expedition's cartographer and riverman. His journal entries, while complete, are often brief and present only the necessary facts. His style makes for entertaining reading because his journal entries use many abbreviations (see Glossary) and have novel punctuation and spellings. A word is often spelled several ways but each is phonetically correct. He characteristically spells "very" with two r's. Clark appears to capitalize those words he wants to emphasize. Clark wrote in 1804 below the Kansas River:



National Park Service

...rain last night after fixing the new Oars and makeing all necessary arrangements, we Set out under a jentle breese from the S. E. and proceeded on passed two large Islands on the S.S. leaving J. Shields and one man to go by land with the horses Some verry hard water, passed Several Islands & Sand bars to day at the head of one we were obliged to cleare away Driftwood to pass, passed a Creek on the L. Side Called <Tabboe> 15yds. wide passed a large Creek at the head of an Island Called Tiger River on the S. S. The Island below this Isd. is large and Called the Isle of Panters, formed on the S.S. by a narrow Channel, I observed on the Shore Goose & Rasp berries in abundance in passing Some hard water round a Point of rocks on the L. S. we were obliged to take out the roape & Draw up the Boat for 1/2 a mile, we Came too on the L.S. near a Lake of the Sircumfrance of Several miles, Situated on the L.S. about two miles from the river...19 June 1804

Careful Observers

The observations made by Lewis and Clark were mostly localized in time and space to the narrow river corridors they were traversing on any given day. However, based on these local observations, they frequently commented on the potential future uses of the land and rivers and made remarkably prescient and insightful conjectures, inferences, and conclusions about the character of the land beyond the immediate river corridors. Their visions of the potential uses of various lands were influenced by the agrarian character of America at that time and by the heavy dependence upon rivers for energy and transportation. Comments on actual and potential land use were common in the journal entries during the period when Lewis and Clark were laboring upriver against the Missouri River current through what are now the States of Missouri, Iowa, and Nebraska. Clark wrote near the Chariton River between Jefferson City and Kansas City, Missouri:

...Some high land which has a great quantity of Stone Calculated for whetstons...I walked out three miles, found the prarie composed of good

Land and plenty of water roleing & interspursed with points of timberd land, Those Praries are not like those, or a number of those E. of the Mississippi Void of every thing except grass, they abound with Hasel Grapes & a wild plumb of a Superior quallity, called the Osages Plumb...10 June 1804

Later, farther up the Missouri, Lewis and Clark noted potential industrial use on the Platte River in northwestern Missouri.

...passd the (1) mouth of a Small river 10 ms above the Kanseis Called by the french Petite River Platte (or Shoal river) from the number of falls in it, this river is about 60 yards wide at its mouth and runs Parrilel with the Missouries for ten or twelve miles, told that the lands on this Small river is good, and on its Several falls well Calculated for mills...30 June 1804

Observations made by Lewis and Clark were localized to the narrow river corridors they were traversing (orange). They also could extrapolate their vision of the nature of the land beyond the narrow river corridors to the interior of each river basin.

In retrospect, however, this Platte River (not the Platte River in Nebraska) was not suitable for mills. It is a slow and meandering river with very few and small riffles (Dale Blevins, oral communication, 2002). Bazile Creek in northeastern Nebraska was also noted for potential industrial uses:

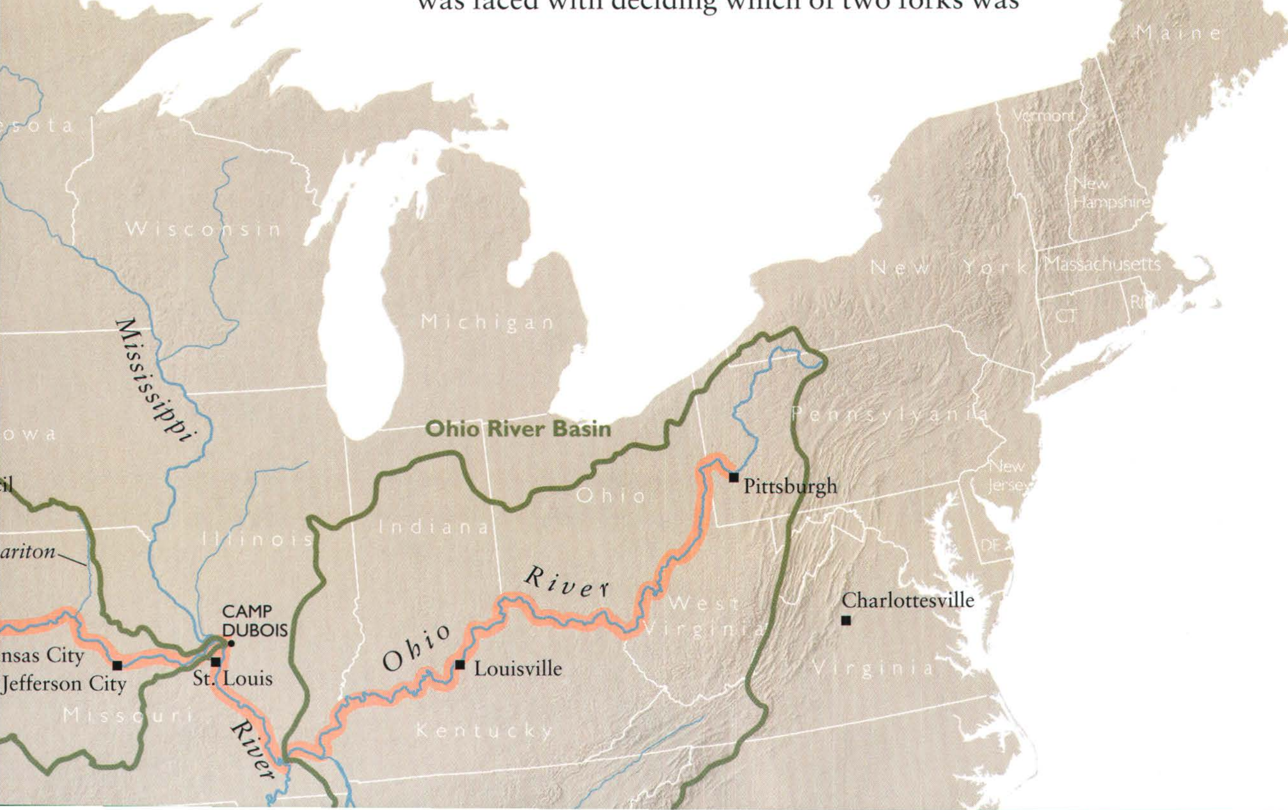
> ...*possesses many excellent situations for grist mills and other waterworks*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 356.

They even noted potential construction materials a few miles north of what is now Omaha, Nebraska, and at the mouth of the Cheyenne River in South Dakota:

> ...*The Situation of this place which we Call Council Bluff which is handsom ellevated a Spot well Calculated for a Tradeing establishment, the Bank high & leavel on top well Calculated for a fort...those Bluffs afford good Clay for Brick, a great quantity of the 3 points one Opsd. one abov & one below..3 August 1804*

> ...*large quantities of tar may be procured on the river near the Black hills, and may be readily brought down the river. tar and sand in the proportion of one gallon to the Bushel, make a furm and strong cement. if an establishment is made at this place, the work must of necessity be principally formed of brick; there being no stone and but little timber. the drift-wood of the Missouri will supply an ample quantity of fuell*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 360.

Not only did Lewis and Clark predict potential uses in the future, but they "saw" far into the interior of the Louisiana Purchase. Their continuing ability to extrapolate their vision of the nature of the land beyond the narrow river corridors was essential to the success of the expedition. During their upriver traverse, on Monday, June 3, 1805, the expedition was faced with deciding which of two forks was



Science in 1800: Historical Context

When Thomas Jefferson was Minister to France and lived in Paris from 1785 to 1790, he probably found opportunities to inform himself about the new ideas relative to the earth sciences that were emerging in the scientific centers of Europe. We can surmise also that, following his return to Virginia and his ascendancy to the Presidency, he discussed at least some of these new ideas with Meriwether Lewis before the expedition began. Several decades earlier, Paolo Frisi had published his "Treatise on Rivers and Torrents with Methods of Regulating their Courses and Channels" (Frisi, 1762). Although Frisi's treatise was not translated from Italian to English until 1818, Jefferson, with his facility in Latin and Italian, would have been able to read it if it had come to his attention. The late 1700s also saw the beginnings of the great revolution of geologic thought that would culminate in 1830 in Sir Charles Lyell's "The Principles of Geology." James Hutton, the Scottish geologist who is considered the father of uniformitarianism, had laid the foundations, in his 1785 book, for the notion that the present is the key to the past and that earth surface processes operated in a slow but continuous manner. But it was not until 1802, when John Playfair published his "Illustrations of the Huttonian Theory of the Earth," that these ideas began to reach a wide audience. As counterpoint to the uniformitarian ideas that were emerging in Great Britain at the end of the 18th century, others had proposed a form of catastrophism stemming from the Biblical Flood but expanded to include ordinary floods, wildfires, volcanic eruptions, and earthquakes as explanations of some earth-surface processes. Principal among the proponents of catastrophism were Abraham Gottlob Werner and, during his earlier years of scientific endeavor, Professor Werner's most illustrious student, Alexander von Humboldt, who pioneered land-based exploration with a scientific bent (Tinkler, 1985).

Lewis and Clark's was therefore not the only scientific expedition into unmapped territory during the years that opened the 19th century. Baron Alexander von Humboldt and his colleague Aime Bonpland had been exploring the "equinoctal regions" of South America, beginning in 1799, and had been accumulating, along with those of plants and animals, observations of hydrologic phenomena, including the navigable connection between the headwaters of the Amazon and Orinoco Rivers in what is now southernmost Venezuela. It is doubtful, however, whether significant news of any of Humboldt's observations had reached North America by the time Lewis and Clark departed for the western rivers.

Whether the ideas of Frisi, Hutton, Playfair, Werner, von Humboldt, and other European earth scientists had come to America in time for Lewis and Clark to carry them across the continent and incorporate them into the underlying assumptions of their journal writings is not entirely clear. From reading the journals, we are inclined to suggest that most of Lewis and Clark's hydrologic and geomorphologic observations were too original and too motivated by practical matters to have been much encumbered by the more theoretical concerns and controversies that were being aired elsewhere in the scientific world of the early 1800s. There is no doubt, however, that the explorations of Lewis and Clark were an enormous source of inspiration to later efforts by others—most directly and notably, to the exploration of the peoples and landscapes of the Missouri River 30 years later by the Prussian prince, Maximilian von Wied, and the Swiss artist, Karl Bodmer (Thwaites, 1966). Somewhat farther removed in space and time, but also clearly inspired by Lewis and Clark, was the exploration of the Amazon River valley made 50 years later by U.S. Naval Lieutenant William Lewis Herndon (Herndon, 1853).

the Missouri River (one was the Missouri River; the other one was later named the Marias River). This was a critical decision. Choosing the correct fork would lead them to the Great Falls and a possible route through the Rocky Mountains to the Columbia River and the Pacific Ocean. Lewis wrote:

...An interesting question was now to be determined; which of these rivers was the Missouri,...to this end an investigation of both streams was the first thing to be done; to learn their widths, debths, comparitive rappidity of their courants and thence the comparitive bodies of water furnished by each...The noth fork is deeper than the other but it's courant not so swift; it's waters run in the same boiling and roling manner which has uniformly characterized the Missouri throughout it's whole course so far; it's waters are of a whitish brown colour very thick and terbid, also characteristic of the Missouri; while the South fork is perfectly transparent runds very rappid but with a smoth unriffled surface it's bottom composed of round and flat smooth stones like most rivers issuing from a mountainous country. the bed of the N. fork composed of some gravel but principally mud; in short the air & character of this river is so precisely that of the missouri below that the party with very few exceptions have already pronounced the N. fork to be the Missouri; myself and Capt. C. not quite so precipitate have not yet decided but if we were to give our opinions I believe we should be in the minority, certain it is that the North fork gives the colouring matter and character which is retained from hence to the gulph of Mexico. I am confident that this river rises in and passes a great distance through an open plain country I expect that it has some of it's souces on the Eastern side of the rocky mountain South of the Saskashawan, but that it dose not penetrate the first range of these Mountains and that much the greater part of it's sources are in a northwardly direction towards the lower and middle parts of the Saskashawan in the open plains. convinced I am that if it penetrated the Rocky Mountains to any great distance it's waters would be clearer unless it should run an immence distance indeed after leaving those mountains through these level plains in order to acquire it's turbid hue...thus have our cogitating faculties been busily employed all day...3 June 1805

Confluence of the Marias (left) and Missouri (right) rivers looking downstream.

Photo: Montana Tourism

After crossing the Continental Divide, the expedition was in the vicinity of Missoula, Montana, and contemplating the Clark Fork as a possible route to the Columbia because the Snake River route was impassable. Lewis again extrapolates beyond his immediate observations to deduce that the Clark Fork would also be impassable:

...it is hear a handsome stream about 100 yards wide and affords a considerable quantity of very clear water, the banks are low and it's bed entirely gravel. the

stream appears navigable, but from the circumstance of their being no sammon in it I believe that there must be a considerable fall in it below...9 September 1805

Their prediction was confirmed 5 months later while interviewing native people at Fort Clatsop near the mouth of the Columbia River. Clark's version is given here:

> *...from the same information* [Indians] *Clarks river* [Clarks Fork] *like that of the S. E. branch of the Columbia* [Snake River?] *which heads with Jefferson's and Maddisons river's can not be navagated thro' the rocky mountains in consequence of falls and rapids and as a confirmation of the fact we discovered that there were no Salmon in Clark's river, which is not* [Lewis' version does not have this "not"] *the Case in the S. E. branch of the Columbia altho it is not navagable. added to this, the Indians of different quartes further inform us, that Clark's river runs in the direction of the Rocky Mountains for a great distance to the north before it discharges itself into the Columbia river—. from the Same information the Columbia from the enterance of the S. E. branch to the enterance of Clark's river is obstructed with a great number of dificuelt and dangerous rapids (and the place Clark's river comes out of the Rocky mountains is a tremendious falls &c which there is no possibillity of passing the mountains either by land or water.)...14 February 1806*

and again later on the return trip in 1806 near Lewiston, Idaho, on the Clearwater River:

> *...at this place we met with three men of a nation called the Skeets-so-mish who reside at the falls of a large river disharging itself into the Columbia on it's East side to the North of the entrance of Clark's river. this river they informed us headed in a large lake in the mountains and that the falls below which they resided was at no great distance from the lake...6 May 1806*

The large river was the Clark Fork, which flows into the northeast corner of Lake Pend Oreille and becomes the Pend Oreille River as it leaves the lake. The falls were probably the Albeni Falls at the northwest end of Lake Pend Oreille. These falls are only about 8 feet high (Craig Brengle, written communication, 2002), and unless the salmon arrived at low water in the fall, it is unclear if this height would halt the runs of salmon and steelhead so effectively that neither species is found in the Clark Fork. However, the native people may have had in mind the larger Post Falls on the Spokane River at the outlet of Coeur d'Alene Lake only 50 miles to the south—or perhaps other potential barriers, located downstream from Albeni Falls at Kettle Falls on the Columbia River, at Z Canyon on the Pend Oreille River at the boundary between Washington and British Columbia, or at Box Canyon and Metaline Falls in Washington (all under reservoirs now) (Mike Beckwith, written communication, 2002). After recrossing the Continental Divide, the expedition divided into two groups. Clark's group explored the Yellowstone River in July 1806 while Lewis's group explored the Marias River. Here Clark made another extrapolation:

> *...Tongue River it dicharges itself on the Stard. Side and is 150 yards wide of water the banks are much wider....but finding that its' water So muddy and worm as to render it very disagreeable to drink...The water of this river is nearly milk worm very muddy and of a lightish brown Colour....I believe that the Country back thro' which this river passes is an open one where the water is exposed to the Sun which heats it in its passage...29 July 1806*

Itinerary

Lewis started down the Ohio River in August 1803 and met Clark near Louisville (in what is now Kentucky) in October 1803. Together, they continued down the Ohio and traveled up the Mississippi River to St. Louis (pages 4 and 5). Their expedition spent the winter of 1803–04 at Camp Dubois opposite the mouth of the Missouri River. They started up the Missouri River on May 14, 1804, and reached the Mandan village near the present city of Bismarck, North Dakota, in October 1804; there they spent the winter of 1804–05. During 1805, they "*proceeded on*," circumvented the Great Falls of the Missouri and then crossed, recrossed, and again crossed the Continental Divide, searching and eventually finding a route to the Pacific. The winter of 1805–06 was spent near the mouth of the Columbia River at Fort Clatsop. They returned in 1806 but spent several months at Camp Chopunnish, waiting for the snow to melt before they could cross the Rocky Mountains. The expedition arrived back in St. Louis on September 23, 1806.

Authors' Notes

Thomas Jefferson conceived the idea of a scientific expedition of discovery, gave Lewis and Clark detailed instructions regarding scientific observation, and was essentially the third person commanding the Corps of Discovery (page 6, "Science in 1800"). The scientific observations of Lewis and Clark in this circular are not organized in chronological order but by two major topics—geomorphology and hydrology. The regional-scale geomorphic features are reflected in their maps and descriptions of the surrounding landscapes. Valley-scale features are flood plains and terraces. The channel-scale features are riffles, rapids, falls, and sandbars. The "Geomorphology" section ends with Lewis and Clark's observations of erosion, sediment transport, and deposition processes that change the river and the landscape. The "Hydrology" section begins with observations of the runoff processes. Runoff determines river characteristics, hydraulic geometry, and river velocities. The final section summarizes the changes that have occurred in the 200 years since the Lewis and Clark expedition.

All excerpts (*italics*) in this Circular have been taken from Moulton's (1983–93) eight annotated volumes of the Journals of Lewis and Clark. The journals include their maps, field notes, and numerous codices as well as personal journals. The excerpts are included verbatim such that punctuation, spelling, and capitalization are those of Lewis and Clark. Material inserted by Moulton is indicated by *[]* with the text in an italic font. Material inserted by the authors of this Circular is indicated by [] but with the text not italicized. Material inserted by other editors is indicated by <> and is in italics. The date of each excerpt is given in the form *18 June 1804* to be consistent with the form most often used by Lewis and Clark. Often, they repeated each other's entries or made similar entries in both their individual journals as well as in field notes. However, usually each entry can be identified by the distinctly personal style of each writer.

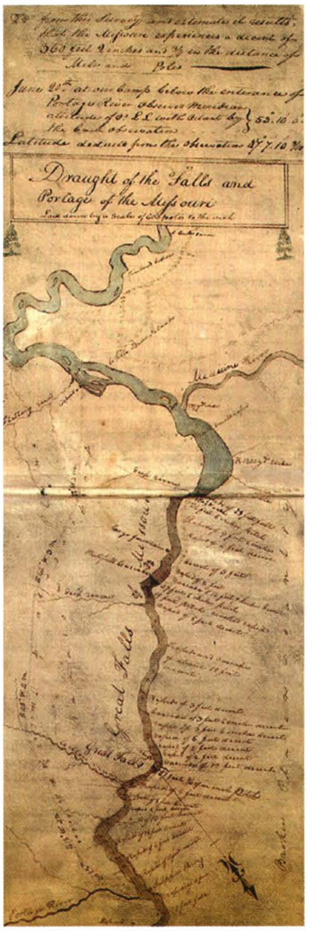
Map: Library of Congress

In March of 1803 cartographer Nicholas King was commissioned to prepare a map of the West using the most current cartographic sources. Notes on the map by Lewis suggest that it was probably carried by the expedition. Notice the large blank (unmapped) area between the Pacific coastline (left) and Great Lakes (right).

II

Geomorphology

LEWIS and Clark provided some of the first descriptions of flood plains and other geomorphic features in the United States and how these features were altered by erosion, sediment transport, and deposition. One primary geomorphologic contribution was the creation of detailed maps that Lewis and Clark made of the network of rivers and landforms. Adjectives they used to describe the landforms they encountered, traversing several physiographic provinces, are found today in the standard names of the subdivisions of these provinces.



Lewis and Clark prepared maps daily such as this one of the Great Falls in Montana. Notice the detailed notation along the river.

Smithsonian

Maps

Clark made the first accurate maps of the rivers adjacent to their route and of the surrounding country. These maps (Moulton, 1983, volume 1) were based not only on personal observations and measurements but also on extensive discussions with the native people (Ronda, 1984). During the winter of 1804–05, while at Fort Mandan near the present town of Bismarck, North Dakota, Lewis and Clark wrote "A Summary view of the River and Creeks..." and in it Lewis mentions the method of obtaining information:

> *...As we have only ascended the Missouri, a few miles above the Mouth of Knife river, the subsequent discription of this river, and it's subsidiary streams are taken altogether from Indian Information. the existence of these rivers, their connection with each other, and their relative positions with rispect to the Missouri, I conceive are entitled to some confidence. information has been obtained on this subject, in the course of the winter, from a number of individuals, questioned seperately and at different times. the information thus obtained has been carefully compared, and those points only, in which they generally agreed, have been retained, their distances they give, by days travel, which we have estimated at 25 miles pr. day...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 362.

Clark was the expedition's cartographer. He carefully recorded the magnetic compass bearing for each reach of river and the length of each reach traversed during the day (page 13). While descending the Ohio River, he stopped and mapped the confluence with the Mississippi River in November of 1803. He measured the magnetic compass bearing of the Mississippi River shoreline (*S 74° W*) and the

AUTHORS' NOTE

The place names mentioned in this section can be found on the map on pages 102–103.

Instruments used to Measure Distance, Heights, and Angles

This is a brief description of some of Lewis and Clark's instruments used to measure distance, heights, and angles. Lewis gives *A summary discription of the apparatus employed ...some remarks on the manner in which they have been employed...22 July 1804.*

* **Circular protractor and index** for measuring and plotting angles on paper.

* **Circumferentor** is a magnetic compass that measures the horizontal angle between magnetic north and a landmark.

* **Logline and reel.** At the end of the line was a log or flat, triangular piece of wood weighted along one edge so that it would be partially submerged in the water. A bridle of three short lines connected each corner of the wood log to the line. Knots were tied in the line or attached to the line like an appendage, at intervals of 7 fathoms. The line was wound around a reel. The log was cast over the side into the water and the line was pulled off the reel by the motion of the boat moving relative to still water. Similarly, if the boat was anchored in a river, then the water moving downstream pulled the line off the reel. By counting the number of knots that came off the reel during a specific time, the speed of the boat or the speed of the water could be calculated.

* **Pocket compass** is a small version of the circumferentor.

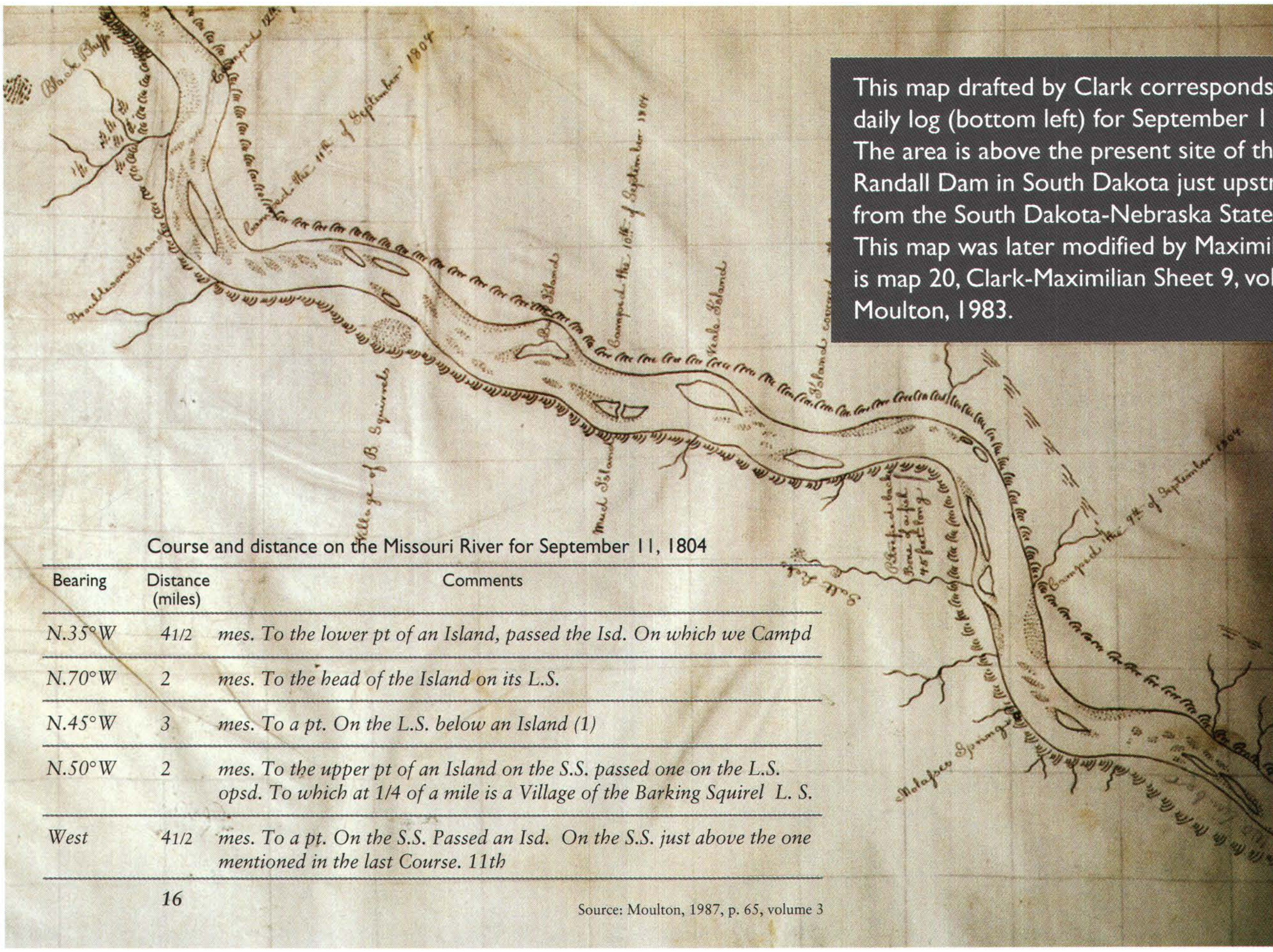
William Clark's pocket compass and case

Smithsonian

* **Spirit level** is similar to present-day carpenter levels with a bubble of air trapped in a tube of liquid to determine when a surface is horizontal.

* **Two-pole chain** consisted of 50 links. Each link was 7.92 inches long so that the two-pole chain was 33 feet long.

A more detailed discussion, especially of the astronomical instruments, has been published by Bedini (1984) and Plamondon (1991).



This map drafted by Clark corresponds to the daily log (bottom left) for September 11, 1804. The area is above the present site of the Fort Randall Dam in South Dakota just upstream from the South Dakota-Nebraska State line. This map was later modified by Maximilian and is map 20, Clark-Maximilian Sheet 9, volume 1, Moulton, 1983.

Course and distance on the Missouri River for September 11, 1804

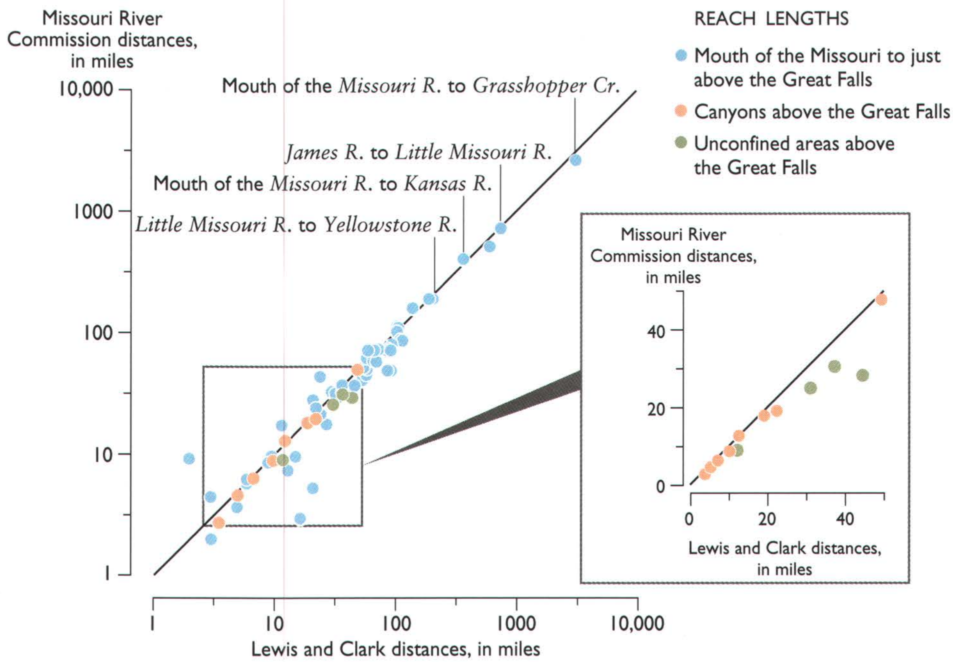
Bearing	Distance (miles)	Comments
N.35°W	41/2	*mes. To the lower pt of an Island, passed the Isd. On which we Campd*
N.70°W	2	*mes. To the head of the Island on its L.S.*
N.45°W	3	*mes. To a pt. On the L.S. below an Island (1)*
N.50°W	2	*mes. To the upper pt of an Island on the S.S. passed one on the L.S. opsd. To which at 1/4 of a mile is a Village of the Barking Squirel L. S.*
West	41/2	*mes. To a pt. On the S.S. Passed an Isd. On the S.S. just above the one mentioned in the last Course. 11th*
	16	

Source: Moulton, 1987, p. 65, volume 3

bearing of the Ohio River shoreline (*N 52 1/2° W*) where they meet at the confluence point by using *the Circumferenter.*

> *...A Circumferentor, circle 6 Inches diameter, on the common construction; by means of this instrument adjusted with the sperit level, I have taken the magnetic azimuth of the sun and pole Star. It has also been employed in taking the traverse of the river...22 July 1804*

His measurement of the angle between these shorelines at the confluence was therefore 53.5°. The present-day magnetic bearings of the shorelines measured from the 1978 version of the U.S. Geological Survey's 7.5-minute quadrangle (Wyatt Quadrangle) are N 52°W and S 77.5° W. The angle between the shorelines at the confluence point is 50.5°. Clark established a baseline along both shores starting at the confluence point or vertex of the angle. He may have measured the length of the baseline by using a cased measuring tape (Bedini, 1984) but probably used a surveyor's chain consisting of 100 metal links and equal to 66 feet. He probably did not use the chain to measure distance across rivers as wide as the Ohio



Comparison of the lengths of various reaches measured by Lewis and Clark in 1803-04 with those measured by the Missouri River Commission between 1892 and 1895 before major changes. A log-log graph shows differences of both the short and long reaches. The inset shows in more detail the reach lengths above the Great Falls.

and Mississippi Rivers. Clark could have determined the width across a river by first drawing a map showing the baseline and two angles or bearings measured at either end of the baseline to a landmark on the opposite side of a river and then measuring the width of the river on his map. The baseline along the Ohio River was *115 po* or 1,897.5 feet long, and the baseline along the Mississippi River was *117 po* or 1,930.5 feet long.

> *...asscertained by the Circumferenter and projection that the width of the Ohio from the point [confluence point] was— 1274 Yards [and] The Missippi— [was] 1435 Yards and the width of them both from those observed points on their respective banks was—2002 Yards...14 November 1803*

One way to assess the accuracy of Clark's river distances is to compare them with those measured from the maps published by the Missouri River Commission (1892–95) and based on some topography as early as 1878. We compared the length of a number of unconfined reaches of the Missouri River between the Great Falls and the Mississippi River (figure above). Some differences in reach lengths between 1803–05 and 1892–95 may be explained by geomorphic processes like meander cutoffs. A part of the Missouri River in what is now western Montana passes through a landscape alternating from unconfined rolling prairie reaches near Great Falls to stable canyon reaches near the Gates of the Rockies (now the site of Canyon Ferry Reservoir) to unconfined reaches and back to canyon reaches near Three Forks, Montana, where the Jefferson, Madison, and Gallatin Rivers join to form the Missouri River. Distances within the stable canyon reaches (smaller graph, above) should change very little as a result of geomorphic processes during the intervening 90 years between Clark's measurements and the surveys done by the Missouri River Commission (MRC) between 1892 and 1895. For eight canyon reaches ranging in length from about 3 to 50 miles, the average difference (MRC's – Clark's) was –1.1 mile, or a 6.9-percent difference. For four unconfined reaches ranging in length from about 12 to 45 miles, where changes would more likely be a result of geomorphic processes, the average difference was –8.0 miles. This shortening may represent cutoffs during the intervening 90 years. Clark's total river distance (3,064 miles) from the mouth of the Missouri near St. Louis, Missouri, to Willards Creek (now Grasshopper Creek, p. 102, v. 5, Moulton, 1988), where the expedition ended their travel by water, is 649 miles longer than the distance measured on maps in 1998.

Meanders

Meandering rivers do not stay the same length. They become longer in some reaches as meanders grow larger across the meander belt (following page, "River Terms"). They become shorter in other reaches as chutes cut across meander bends to eventually become the main channel while isolating the old meander bends as oxbow lakes. The first observations of meanders were recorded in the Lewis and Clark journals during their descent of the Ohio River in the fall of 1803 at a time of unusually low water. Lewis comments after having pulled the boat over a riffle near what is now Ambridge, Beaver County, Pennsylvania (p. 69, v. 2, Moulton, 1986)

> *...The hills on either side of the ohio are from 3 to 400 feet which runing parrallel to each other keep the general course of the river, at the distance of about two miles while the river pursuing a serpentine course between them alternately washes their bases... thus leaving fine bottom land between itself and the hills in large boddys, and freequently in the form of a simecicles or the larger segment of a circle or horseshoe form...2 September 1803*

Clark recognized oxbow lakes in Missouri above Kansas City that were once river meanders:

> *...a large Lake on the S. S. which has the apperance of being once the bed of the river & reaches parrelel for Several Miles...4 July 1804*

> *...I neglected to mention yesterday that the Lake on the S. S. was large Say 3/4 me. wide & 7 or 8 long...5 July 1804*

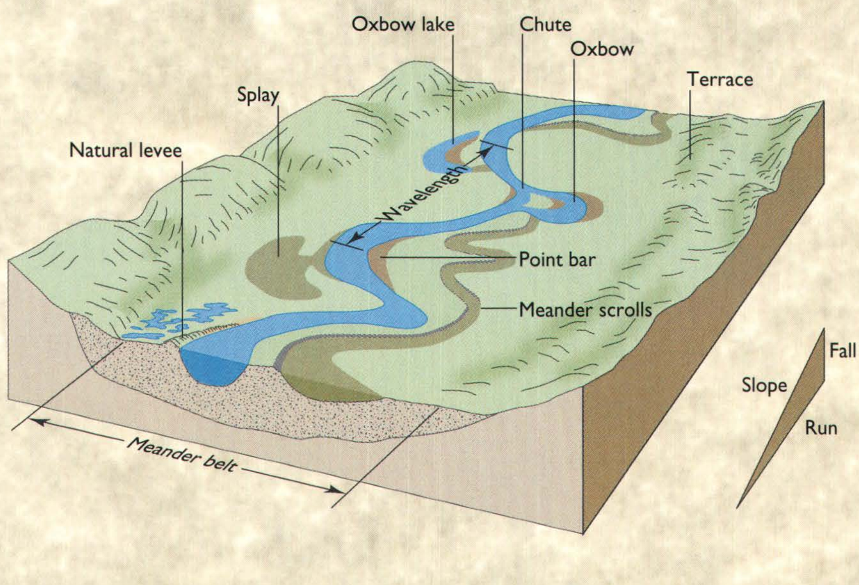
Later, on the Missouri River about 100 miles above the Platte River in Nebraska, Clark made additional observations:

> *...I have observed a number of places where the River has onced run and now filled or filling up & growing with willows & cottonwood)...(I have*

River Terms

* **Alluvium** is any material ranging in size from clay to gravel that is eroded, transported, and deposited by a river to form its channel and flood plain.
* **Bankfull** refers to the water level that corresponds to the tops of the riverbanks. Discharge at bankfull level (one of many possibilities) is thought to be important in determining the geometry of a river channel. Bankfull conditions, on average, can be expected to be reached or exceeded about 2 of every 3 years or about every 1.5 years (Leopold and others, 1964).
* **Braided rivers** have many shifting channels, and the slopes are steeper than the slopes of meandering rivers. See the multiple channels between sandbars and islands in Clark's maps on page 13 and 18.
* **Chute** is a new channel that forms across the base of a meander. As it grows in size, it carries more of the flow.
* **Crossing** is the transitional area between bends of a river where the deep part of the channel switches from one side of the river to the other side. Sometimes called a riffle (page 36, "Riffle Formation").
* **Cutbank** is a steep vertical bank, usually actively eroding at its base (page 36, "Riffle Formation").
* **Discharge** is the volume of water passing a point on the river during a specific period of time. It is usually expressed in cubic feet per second in the United States.
* **Flood plain** is the relatively flat area adjacent to the river that is shaped by the erosion and deposition of sediment during floods.
* **Meander** is a single, S-shaped channel pattern formed in alluvial material.
* **Meander belt** is the area between the edges of the valley that is sculpted by the river moving laterally, with time, across the flood plain.
* **Meander scroll** is a sediment formation made by deposition along a former channel boundary.
* **Natural levee** is formed when the river overflows the top of the bank, the water velocity decreases, and coarse material drops out of suspension along the bank to form a ridge.
* **Oxbow** is created after a chute cuts across a tight meander bend, leaving the old channel (oxbow) only partially connected to the new one (Riffle Formation, page 36).
* **Oxbow lake** is a lake that has formed by sediment filling in both ends of an ox bow. This prevents the oxbow lake from having a direct surface connection with the main channel during normal in-channel flows.
* **Point bar** is a sloping bank consisting of sand or gravel on the inside of a river meander bend opposite a cutbank (page 36, "Riffle Formation").

* **Reach** is a segment or section of river of any length chosen by the observer.
* **Sinuosity** is a ratio of the length between two distant points in the river following the channel, divided by the length between these same distant points along the valley axis. The sinuosity shown in Clark's map on page 13 is 1.1.
* **Slope** is the fall of the water divided by the run or distance over which the fall is measured.
* **Splay** is a deposit of sediment formed during a flood when the river breaks through a natural or artificial levee.
* **Stage** is the height of the water surface relative to some fixed reference point on land. The channel bed is irregular because of sandbars, pools, and point bars, so that stage usually does not correspond closely to the local depth.
* **Terrace** is a relatively flat surface above the main flood plain of the river that usually represents an older flood plain.
* **Water year** ends on September 30, having begun on October 1 of the previous year. This year was designated because most of the rivers of the United States reach their lowest stages in October.
* **Wavelength** is the straight-line distance between two cutbanks or between two point bars on a meandering river.



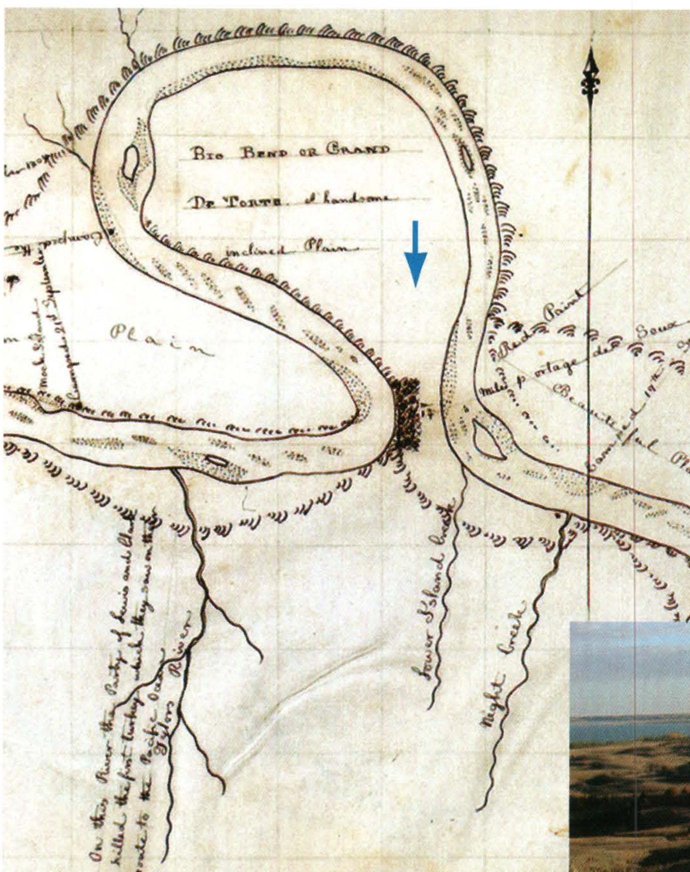
> *observed a number of places where the river has Changd its Bead at different times)...11 August 1804*

and Lewis noted in the Missouri River valley about 50 miles above Big Muddy Creek in Montana that:

> *...river bottom, which is also wider than usual being from 5 to 9 ms. in width; traces of the ancient beds of the river are visible in many places through the whole extent of this valley...3 May 1805*

Frequently they commented on the crookedness (sinuosity) of various tributaries near their mouths (the Yellowstone, Musselshell, Smith, and Jefferson Rivers) and the crookedness of the Missouri River itself. Above the Great Falls, Lewis mentioned that:

> *...we find it inconvenient to take all the short meanders of the river which has now become cooked and much narrower than below, we therefore take it's*



Copy provided by Joslyn Art Museum, Omaha, Nebraska

Clark's map of the Big Bend of the Missouri River was later modified by Prince Maximilian and is sheet 11 in the Atlas, volume 1, Moulton, 1983.

The view in the photograph of the neck of the Big Bend is shown by the blue arrow on the map.

Photo: John Moody

general course and lay down the small bends by the eye on our daily traverse or chart. ...15 July 1805

Above the Platte River of Nebraska, they encountered a couple of unusual single bends, and Clark wrote:

...Burnt Stump on the Bank in the bend to L. S. at which place I was yesterday at this place within 3/4 of a mile & round the bends 13 ms...10 August 1804

...we halted in a bend to the left to take the Meridian altitude, & Dine, & Sent one man across where we took Dinner yesterday to Step off the Distance across Isthmus, he made it 974 yards, and the bend around is 183/4 miles...12 August 1804

Later, at the Big Bend of the Missouri River (downstream from present sites of Pierre, South Dakota, and Big Bend Dam, see Clark's map on page 18), Clark listed in his course summary:

...to a Ceder hill on the L. S in a bend opposit the Gorge of this bend where the river is only 11/4 mile across & 30 Miles around...20 September 1804

and later adds in the journal that "*the bend is a Butifull Plain thro which I walked.*"

Clark later wrote a detailed account of the meandering of the Jefferson River above the Big Hole River between Twin Bridges and Dillon, Montana. Clark gave the distance along the river, the distance along the valley axis, and the number of bends (right). From these data, the sinuosity of the Jefferson River in 1805 ranged from 1.5 to 4.0, and the wavelengths of these meanders ranged from 0.11 to 0.43 mile. Lewis and Clark gave the river width, w, of the Jefferson River as 45 yards so that, based on their data, the wavelengths, λ, of these meanders averaged 9.4 river widths. Much later, Leopold and Wolman (1960) developed a similar empirical relation, $\lambda=10.9w^{1.01}$, for streams worldwide with widths ranging from 1 foot to 10,000 feet.

Measurements of the meanders of the Jefferson River*

Date 1805	River distance (miles)	Valley distance (miles)	Number of bends	Wavelength (miles)	Sinuosity
August 7	7	3	7	0.43	2.3
August 8	5	2	7	0.29	2.5
	14	6	35	0.17	2.3
August 9	11	4	16	0.25	2.8
	3	1	4	0.25	3.0
August 10	6.5	2	8	0.38	3.2
	6.5	2	18	0.11	3.2
August 11	3.0	1	6	0.17	3.0
	3.5	1.5	7	0.21	2.3
	7.5	2.5	15	0.17	3.0
August 12	5.5	2	9	0.22	2.8
	6.5	2	—	—	3.2
August 13	4	1	—	—	4.0
	6	3	—	—	2.0
August 14	22	8	—	—	2.8
August 15	6	4	—	—	1.5
	3	1	—	—	3.0
August 16	7	3	—	—	2.3
	4	2	—	—	2.0
	1.5	1	—	—	1.5
August 17	10	4	—	—	2.5

*Lewis and Clark called the river the Beaverhead River. It is located approximately between the present towns of Twin Bridges and Dillon, Montana.

Landscapes

Lewis and Clark were keen observers of the landscape with eyes sharpened by the self-sufficient character of their predominantly agrarian society. They transected extensive gradients of physiography and precipitation, unknown to them at first, which were imperceptible each day but were later synthesized by Lewis when they finally reached the Rocky Mountains.

> *...this convinces me that we have ascended to a great hight since we have entered the rocky Mountains, yet the ascent has been so gradual along the vallies that is was scarcely perceptable by land...10 August 1805*

Their scattered daily vignettes were written while the expedition crossed half a continent but, when collected together, paint a reference picture of the landscapes of the Western United States that is 200 years old and helps to determine the changes of the landscape with time (page 85, "Geomorphic and Hydrologic Changes in 200 Years"). The physiographic provinces of these landscapes (opposite) are based on surface geomorphic characteristics (Hammond, 1964). Some of these geomorphic characteristics were first observed and recorded by Lewis and Clark. In addition to the geomorphic characteristics, Lewis and Clark inevitably described the distributions of the characteristic vegetation of these landscapes. These vegetation patterns are indicators of the landscapes, the precipitation regimes, and ecological regions (Bailey, 1995). Many of their observations repeat earlier observations, and so the most descriptive and interesting observations have been selected to illustrate their impressions of these provinces. The early observations of landscapes in the journals, from about 23 May 1804 to 16 September 1804, are Clark's. No earlier entries describing the landscape have been found for Lewis, whose entries start about 16 September 1804. He wrote *"A Summary view of the Rivers and Creeks"* during the winter of 1804–05 (p. 336–369, v. 3, Moulton, 1987). They skirted the Ozark-Ouachita Highlands coming up the Mississippi River and again going up the Missouri River near St. Louis, Missouri.

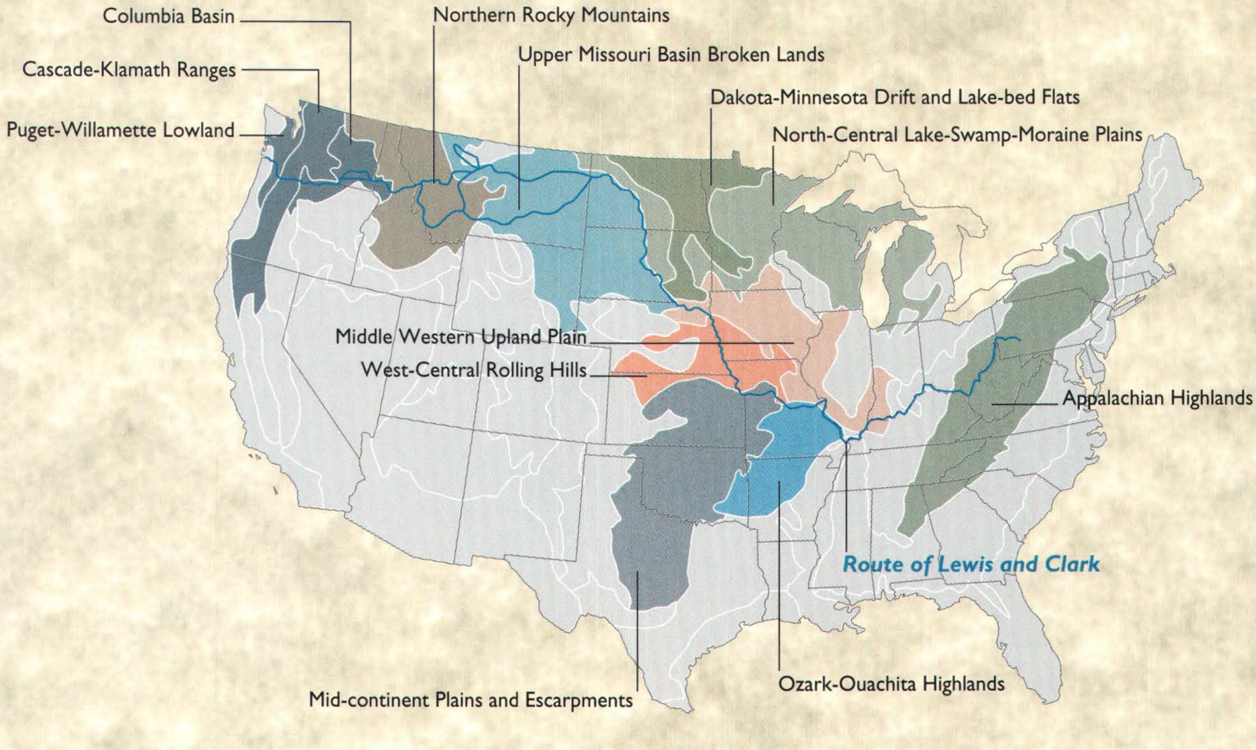
OZARK-OUACHITA HIGHLANDS

> *....A ridge of Hills 200 feet high make across the river at this place; and the Gd. Tower* [Grand Tower] *as well as the sugarloaf point, as also a rock detached from both these and likewise the hills, another side of the bason all appear once to have formed a part of the range of hills which cross the Mississippi at this place, and which in the course of time have been broken down by the river...at 3/4 of a mile above Gabia Creek the high lands juts to the river and form a most tremendious Clift of rocks near the Commencement of this Clift I saw a Cave...26 November 1803 and 4 December 1803*

> *...the country watered by this river* [Gasconade], *is generally broken, thickly covered with timber and tolerably fertile. the hills which border on the*

Physiographic Provinces

Lewis and Clark followed a fluvial landscape crafted by the Ohio, Mississippi, Missouri, Clearwater, Snake, and Columbia Rivers. These fluvial landscapes were embedded in larger landscapes shaped by glaciers, ancient and modern episodes of mountain uplifts, and sediment erosion and deposition. The North-Central Lake-Swamp-Moraine Plains and Dakota-Minnesota Drift and Lake-bed Flats were shaped by a continental glacier during the last 1 million years. The glacier ploughed across the landscape gouging out lakes, pushed the Missouri and Ohio Rivers to much of their present positions, and ground the soils into fine silt and clay particles. During warm spells at the end of the glacial period about 18,000 years ago, this fine sediment was transported by wind near the edge of the glacier and deposited as thick layers of loess (Ruhe, 1969) commonly found capping the hills and bluffs of the Middle Western Upland Plain and the West-Central Rolling Hills in parts of Missouri, Iowa, and Nebraska. The Appalachian Mountains were uplifted about 270 million years ago to form the core of the Appalachian Highlands Province. The Northern Rocky Mountains were uplifted about 70 million years ago. Erosion of the Rocky Mountains and deposition of thick layers of sediment east of the mountains helped shape the Mid-continent Plains and Escarpments province, which included parts of the Great Plains (Trimble, 1980). Regions of sedimentary rock deposited and formed in ancient oceans were uplifted also to form relatively flat areas called plateaus. The Ozark-Ouachita Highlands consist of uplifted rocks older than about 250 million years, and the dissected Upper Missouri Basin Broken Lands are younger rocks uplifted about 5 million years ago (Trimble, 1980). Modern-day volcanism associated with tectonic activity has shaped the Columbia Basin, the Cascade-Klamath Ranges, and the Puget-Willamette Lowland provinces.



Adapted from USGS National Atlas, 1970

Missouri near the moth of this river are about 300 feet high...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 338.

The observation *"tolerably fertile"* is questionable because little fertile soil is now found in the Ozarks (Dale Blevins, written communication, 2002). This suggests some degree of caution in evaluating some of Lewis and Clark's observations. They did not actually see the Gasconade Basin, and probably this and other information came from interviews with travelers or natives of regions they did not specifically traverse. Thus, this type of "observation" may be inaccurate. The following observations are reported to be accurate (Dale Blevins, written communication, 2002).

...*The country watered by this river* [Osage River], *is generally level & fertile, tho' it is more broken on the lower portion of the river; the bottom lands are wide, well timbered, and but partially liable to inundation; the soil consists of a black rich loam many feet in debth. the uplands also consist of a dark loam overlaying a yellow or red clay; a majority of the country consist of plains intersperced with groves of timber. the timber still diminishes in quantity as you proceed Westwardly with the river*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 339.

...[Lamine River] *takes it's rise in an open hilly country with Bluewater river and some of the Northern branches of the Osage river...The country through which it passes is generally fertile, and consists of open plains and praries intersperced with groves of timber*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 342.

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation.

Karl Bodmer's watercolor of the "Confluence of the Missouri and Gasconade" in the Ozark-Ouachita Highlands (April 13, 1833). The Gasconade River is a tributary that drains the Ozark-Ouachita Highlands and joins the Missouri about midway between St. Louis and Jefferson City, Missouri.

MIDDLE WESTERN UPLAND PLAIN

...*On the East Side of the Mississippi a leavel rich bottom extends back about 3 miles, and rises by Several elevations to the high Country, which is thinly timbered with Oake &. On the lower Side of the Missouri, at about 2 miles back the Country rises graduilly, to a high plesent thinly timberd Country*...undated, Moulton, 1986, v. 2, p. 218.

...*the Village of St. Charles, situated on the North bank of the river, in a narrow tho' elivated plain, which is bounded in the rear by a range of small hills; hence the appellation of Petit cote*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 337.

MIDCONTINENT PLAINS AND ESCARPMENTS

...*Passed some Charming land, I have not Seen any high hils above Charliton and the hils below for Several days Cannot to turmed hills but high Land, not exceeding 100 abov the high water mark...13 June 1804*

...*The country through which it* [Grand River] *passes is similar to that discribed on the large Shariton river. about the entrance of this river the lands are extreemly fertile; consisting of a happy mixture of praries and groves, exhibiting one of the most beatifull and picteresk seens that I ever beheld*....Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 343.

...*The Countrey about this place is butifull on the river rich & well timbered on the S. S. about two miles back a Prarie coms. which is rich and interspursud with groves of timber, the County rises at 7 or 8 miles Still further back and is roleing— on the L. S. the high lands & Prarie Coms. in the bank of the river and Continus back, well watered...17 June 1804*

...*This Prarie is butifull a high bottom for 11/2 a mile back and risees to the Common leavel of the Countrey about 70 or 80 feet and extends back out of view...22 June 1804*

...[Big Blue River] *passes through a roling country. the lands are tolerably good*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 343.

...*This river* [Kansas] *takes it's rise not very distant from the principal branch of the Arkanas in a high broken sandy country...from hence it takes it's course nearly East about 300 leagus through fertile and leavel, plains & praries, intersperced with groves of timbered land; it then enters a country equally fertile and well timbered, through which it meanders about 20 leagues further and discharges itself into the Missouri*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 343.

...*about 3/4 of a mile from the entrance of this river* [Kansas] *on it's North side there is a handsome bluff about 100 feet high, which furnishes an excellent* *situation for a fortication*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 344.

...*A high Clift, on the upper Side of the Kansis 1/2 a mile up below the Kanses the hills is about 11/2 miles from the point on the North Side of the Missouries the Hill or high lands is Several miles back,...27 June 1804*

WEST-CENTRAL ROLLING HILLS

...*and throught it's* [Big Nemaha River] *whole course, passes through rich, and level plains, and praries. there is some timber on it's borders*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 346.

...[Nishnabotna River] *passes through a fertile country deversifyed with plains meadows and woodlands; considerable bodys of the latter appear in some parts of this country....the country lying between the Missouri and this river from the Balld pated prarie nearly to it's mouth, is one of the most beautiful, level and fertile praries that I ever beheld; it is from one to three miles in width. there is considerable quantity of timber on the banks of the Missouri, and but little on the Nishnabatona*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 346–347.

...*This Prarie I call Ball* [possibly Bald] *pated Prarie, from a range of Ball Hills parrelel to the river & at from 3 to 6 miles distant from it, and extends as far up & Down as I can See...16 July 1804*

...[Weeping Water Creek] *heads in high broken plains near Salt river, and passes through a roling country, mostly uncovered with timber and not very fertile there is a scant proportion of timber on it banks and some clumps of trees are scattered over the face of the country*...Fort Mandan Miscellany,Moulton, 1987, v. 3, p. 347.

...[Mosquito Creek] *heads with the Nishnahbatona river in an open country. the Missouri bottom through which it passes is about 6 miles wide, level, extreemly fertile and about one half well covered with timber*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 353.

Lewis and Clark described the interior of the Platte River Basin. It is not clear how they obtained the information, but it probably was from discussions with the native people. Because the Elkhorn and Loup Rivers are northern tributaries to the Platte River, these descriptions reflect the region of north-central Nebraska consisting of West-Central Rolling Hills and the Nebraska Sand Hills.

[Platte River] *passing the heads of the Arkansas at no great distance from Santa Fee, continues it's rout to the Missouri, through immence level and* *fertile plains and meadows, in which, no timber is to be seen except on it's own borders and those of it's tributary streams*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 349.

[Elkhorn River] *it takes it's rise in some sandy plains between the Wolf River* [Loup] *and the Quecurre* [Niobrara River];*...passes through a fertile level country, parallel with the Missouri to the River Platte*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 350.

[Loup River] *This stream takes it's rise in a remarkable large fountain situated in a level plain, equadistant between the rivers Quicurre and Plat, at some little distance below the Cote noir or Black Hills; from whence it passes through level and fertile plains and meadows in which there is scarcely a tree to be seen except on it's own borders,*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 350.

[Bazile Creek] *takes it's rise in a broken Hilly and open country between the Quicurre and Hart's horn* [Elkhorn] *rivers. passes through a broken country with some handsome plains an praries,*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 357.

MIDDLE WESTERN UPLAND PLAIN/DAKOTA-MINNESOTA DRIFT AND LAKE-BED FLATS

...*The* [Big Sioux] *disembogues on the N. side above a bluff;...it takes it's rise with the St. Peter's and Vulter rivers, in a high broken and woody country called the Hills of the prarie. it waters a deversifyed country, generally level fertile and uncovered with timber; in some parts particularly near the falls* [Sioux Falls], *it is broken & stoney, and in others, intersected by a great number of small lakes which possess some timber generally on their borders*...Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 355.

Karl Bodmer's watercolor of the "Missouri in the Morning below Council Bluffs" painted on May 4, 1833, in the west-central rolling hills. View is looking east and located about 1 to 2 miles north of the present city of Council Bluffs, Iowa.

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation.

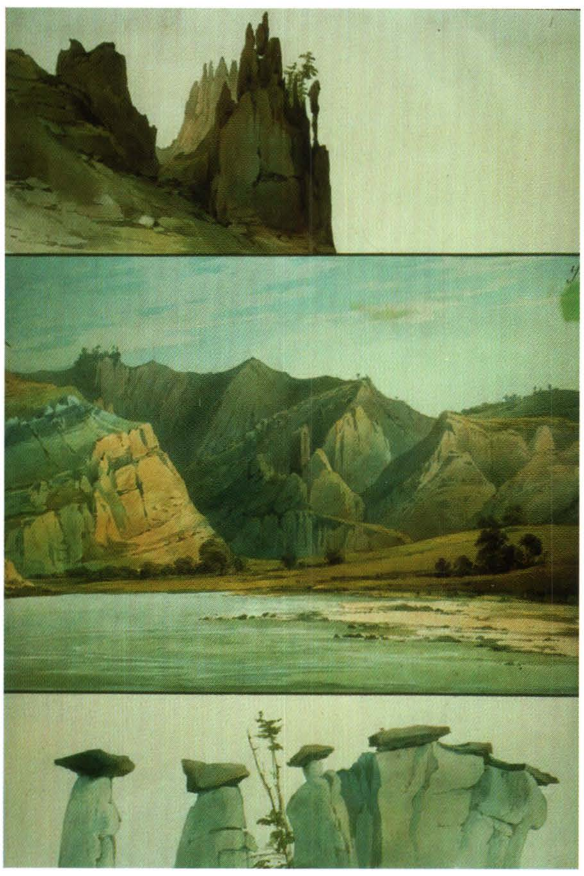
UPPER MISSOURI BASIN BROKEN LANDS

...this river [Niobrara] *takes it's rise in the Black hills, about one hundred leagues West of it's mouth, and passes through a variagated country. at it's source and for seventy five leagues below the country is mountanous rockey and thickly covered with timber, principally pine;...the country on it's lower portion for 25 leagues consists of open plains and meadows, with but a very small proportion of timber;...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 357–358.

...mountanious Countrey without water & riseing to 5 or 600 hundred feet...on the S. S. much higher hills than usial appear to the North distant 8 miles recently burnt....The Countrey on the S S. is pore & broken...Some broken Country which Continus about 3 miles back & then is leavel & rich all Plains...8-11 September 1804

...found the country in every direction for about three miles intersected with deep revenes and steep irregular hills of 100 to 200 feet high; at the tops of these hills the country breakes of[f] as usual into a fine leavel plain extending as far as the eye can reach. from this plane I had an extensive view of the river below, and the irregular hills which border the opposite sides of the river and creek. the surrounding country had been birnt about a month before and young grass had now sprung up to hight of 4 Inches presenting the live green of the spring. to the West a high range of hills, strech across the country from N. to S and appeared distant about 20 miles; they are not very extensive as I could plainly observe their rise and termination no rock appeared on them and the sides were covered with virdue similar to that of the plains...17 September 1804

They crossed the 100th meridian on about September 24, 1804. This is an important climatic line. Annual rainfall east of the line is more than 20 inches, and



Karl Bodmer's watercolor of "Rock Formations on the Upper Missouri" painted on August 2, 1833.

unaided agriculture is possible; annual rainfall west of the line, with some exceptions, is less than 20 inches and agriculture is exceedingly difficult without some form of irrigation. Wallace Stegner (1954), in his book "Beyond the Hundredth Meridian," stated the importance of this line succinctly: "That one simple fact was to be, and is still to be, more fecund of social and economic and institutional change in the West than all the acts of all the Presidents and Congresses from the Louisiana Purchase to the present."

NORTH-CENTRAL LAKE-SWAMP-MORAINE PLAINS

...[Spring Creek] *heads in a small lake a few leagues distant and passes through a rich level plain; the land is fertile but without timber...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 361.

*Beaver Creek...heads in some small lakes a few miles from the river, and passes through a level fertile and open country...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 361.

[Badger Creek] *takes it's rise in small lakes, in the open plains, and passes through handsome plains and meadows...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 361–362.

UPPER MISSOURI BASIN BROKEN LANDS

...*The Northern branch of this river* [Cheyenne River] *penetrates the Black hills, and passes through a high broken well timbered country to it's source, the Southern fork takes it's rise in the Black hills, on their E side, and passes through a broken country covered with timber, to it's junction with the N fork; from whence united, they take their course through a woody and broken country fror some few leagus, then entering an open fertile and level country it continues it's rout to the Missouri...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 359.

...*The Countrey in this quarter is Generally leavel & fine Some high Short hills, and some ragid ranges of Hills at a Distans...18 October 1804*

...*the Cannon Ball river...passes through a variety of country, some broken & partially timbered, near it's source; other parts broken, hilly and bare of timber, and in others beautifull and extensive plains and meadows, with but little timber, all sufficiently fertile, and some extreemly so...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 361.

...*The Countrey is fine, the high hills at a Distanc with gradual assents...20 October 1804*

...*a butifull Countrey on both Sides of the river...24 October 1804*

The last two entries reflect the slight changes in the character of the Upper Missouri Basin Broken Lands drained by the Heart and Knife Rivers near Bismarck, North Dakota. Lewis mentions in his summary that these rivers pass through open plains and meadows, generally fertile, and always untimbered reflecting the westward decrease of timber. Their observations of the landforms broke off during the winter at Fort Mandan and began again in the spring of 1805:

> ...*from it's source it* [Yellowstone River] *takes it's course for many miles through broken ranges of the Rocky mountains, principally broken, and stoney, and thickly timbered. the vallies said to be wide in many places and the lands fertile. after leaving the Rocky mountains it descends into a country more level, tho' still broken, fertile and well timbered. this discription of country continues as far down as the Oke-tar-pas-ah-ha, where the river enters an open level and fertile country through which it continues it's rout to the Missouri; even in this open country it possesses considerable bodies of well timbered land...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 363–364.

> ...*it* [Big Muddy Creek] *meanders through a butifull & extencive vallie as far as can be Seen about N 30° W. I saw only a Single tree in this fertile vallie...29 April 1805*

> ...*the country appears much more pleasant and fertile than that we have passed for several days; the hills are lower, the bottoms wider, and better stocked with timber,...1 May 1805*

> ...*the courant reather stronger than usual and the water continues to become reather clearer, from both which I anticipate a change of Country shortly...13 May 1805*

> ...*the great number of large beds of streams perfectly dry which we daily pass indicate a country but badly watered...17 May 1805*

> ...*The high Country in which we are at present and have been passing for Some days I take to be a continuation of what the Indians as well as the French Engages call the Black hills. This tract of Country So Called Consists of a Collection of high broken and irregular hills and Short Chains of Mountains, sometimes 100 miles in width and again becoming much narrower, but always much higher than the Country on either Side...26 May 1805*

The dry climate west of the 100th meridian suggested an experiment to Lewis:

> ...*the air of the open country is asstonishingly dry as well as pure. I found by several experiments that a table spoon full of water exposed to the air in a saucer would avaporate in 36 hours when the murcury did not stand*

higher than the temperate point at the greatest heat of the day; my inkstand so frequently becoming dry put me on this experiment...30 May 1805

The Rocky Mountains were within view in the clean dry air, perhaps never again to be equaled in clarity.

...*I* [Clark] *took one man and walked out this morning, and ascended the high countrey to view the mountains...I crossed a Deep holler and assended a part of the plain elevated much higher than where I first viewed the above mountains; from this point I beheld the Rocky Mountains for the first time with Certainty, I could only discover a fiew of the most elivated points above the horizon. the most remarkable of which by my pocket Compas I found bore S. 60 W...26 May 1805*

...*In the after part of the day I* [Lewis] *also walked out and ascended the river hills which I found sufficiently fortiegueing. on arriving to the summit one of the highest points in the neighbourhood I thought myself well repaid for any labour....these points of the Rocky Mountains were covered with snow and the sun shone on it in such manner as to give me the most plain and satisfactory view. while I viewed these mountains I felt a secret pleasure in finding myself so near the head of the heretofore conceived boundless Missouri; but when I reflected on the difficulties which this snowey barrier would most probably throw in my way to the Pacific, and the sufferings and hardships of myself and party in them, it in some measure counterballanced the joy I had felt in the first moments in which I gazed on them; but as I have always held it [little Short of Criminality in Clark's version] a crime to anticipate evils I will believe it a good comfortable road untill I am compelled to beleive differently...26 May 1805*

...*I now boar out from the river* [Lewis is going by land and Clark is going by boat] *in order to avoid the steep ravines of the river which usually make out in the plain to the distance of one or two miles;...for the plain through which we had been passing possesses no water and is so level that we cannot approach the buffaloe within shot before they discover us and take to flight...we passed a ridge of land considerably higher than the adjacent plain on either side, from this hight we had a most beatifull and picturesk view of the Rocky mountains which wer perfectly covered with Snow and reaching from S. E. to the N. of N. W.— they appear to be formed of several ranges each succeeding range rising higher than the preceding one untill the most distant appear to loose their snowey tops in the clouds; this was an august spectacle and still rendered more formidable by the recollection that we had them to pass...12 June 1805*

While the expedition was above the Great Falls and could see the mountains, the expedition was not yet in the mountains.

> ...*The country in most parts very level and in others swelling with gentle rises and decents, or in other wirds what I have heretofore designated a wavy country destitute of timber except along the water-courses...14 July 1805*

NORTHERN ROCKY MOUNTAINS

> ...*whever we get a view of the lofty summits of the mountains the snow presents itself, altho' we are almost suffocated in this confined vally with heat....this evening we entered much the most remarkable clifts that we have yet seen. these clifts rise from the waters edge on either side perpendicularly to the hight of 1200 feet. every object here wears a dark and gloomy aspect. the towing and projecting rocks in many places seem ready to tumble on us. the river appears to have forced it's way through this immence body of solid rock for the distance of 5 3/4 miles...the river appears to have woarn a passage just the width of it's channel or 150 yds...from the singular appearance of this place I called it the gates of the rocky mountains...19 July 1805*

> ...*the country was rough mountainous & much as that of yesterday untill towards evening when the river entered a beautifull and extensive plain country of about 10 or 12 miles wide which extended upwards further that the eye could reach this valley is bounded by two nearly parallel ranges of high mountains which have their summits partially covered with snow* [probably now the site of the Canyon Ferry Reservoir]...*21 July 1805*

> ...*and that the river was confined between inacessable mountains, was very rapid and rocky insomuch that it was impossible for us to pass either by land or water down this river* [Salmon River] *to the great lake where the white men lived...13 August 1805*

The Gates of the Rockies are large limestone cliffs bordering the Missouri about 45 miles upstream from Great Falls, Montana.

Photo: USGS

...we made a number of inquires of those people about the Columbia River the Countrey game &c. The account they gave us was verry unfavourable, that the River abounded in emence falls, one perticularly much higher than the falls of the Missouri & at the place the mountains Closed So Close that it was impracticable to pass, & that the ridge Continued on each Side of perpendicular Clifts inpenetratable,...17 August 1805

PUGET-WILLAMETTE LOWLAND

...we were now convinced that there must be some other considerable river [Willamette River] *which flowed into the columbia on it's south side below us which we have not yet seen, as the extensive valley on that side of the river lying between the mountainous country of the Coast and the Western mountains must be watered by some stream which we had heretofore supposed was the quicksand river. but if it be a fact that the quicksand river heads in Mount Hood it must leave the valley within a few miles of it's entrance and runs nearly parallel with the Columbia river upwards. we indeavoured to ascertain by what stream the southern portion of the Columbian valley was watered but could obtain no satisfactory information of the natives on this head...1 April 1806*

Flood Plains and Terraces

Lewis and Clark observed within these regional-scale landscapes many specific fluvial, valley-scale geomorphic features. One feature was the character of the flood plains. Early in the expedition Lewis describes the terraces that compose the present and ancient flood plains (page 33, "River Terraces"). While descending the Ohio he described the meander features mentioned above and went on to describe the flood plains and terraces, which he called bottoms:

...on each side of the river there are three banks, or suddon rises from the summets of which the land generally brake off for a certain distance pretty level untill arrives at the high hills before mentioned which appear to give a direction to the river— the fist bank or that which the river washes is generally from twenty to twentyfive feet, and the bottom lying on a level with this is only overflown in remarkable high floods, the consequence is that there is no drowneded or marsh lands on this river; this bottom which is certainly the richest land from it's being liable some times to be overflowed is not esteemed so valuable as the second bottom— The second buttum usually rises from twentyfive to thirty feet above the first and is allways safe or secure from inundation; usually good when wide from the 3d bank and contrary when the bottom is narrow or the river brakes against the 2d near

the 3rd bank which it sometimes dose what is called the third bottom is more properly the high benches of the large range of hills before noticed and is of a more varied discription as well as it respects the fertility of it's soil as shape and perpendicular hight, the river sometimes but very seldom brakes against this bank— the second and third of these banks allways run parrallel with the high hills and that bordering on the river is of course shaped by it...2 September 1803

This description indicates that Lewis's insights into geomorphology were similar to those published at nearly the same time by Playfair (1802) in England (page 6, "Science in 1800: Historical Context"). One wonders whether either Jefferson or Lewis had a chance to read Playfair's descriptions before the expedition set out in 1803. Darwin (1846) would later publish a description of coastal terraces in South America and this work would later be extrapolated to rivers (Miller, 1883). One also wonders what impact Lewis's observations would have had in molding the yet unnamed field of geomorphology had he published his observations in the early 1800s. Clark added to this description of the flood plains and terraces a description of the typical vegetation that occurred downstream from the Kansas River:

...The Countrey and Lands on each Side of the river is various as usial and may be classed as follows. viz: the low or over flown points or bottom land, of the groth of Cotton & Willow, the 2nd or high bottom of rich furtile Soils of the groth of Cotton, Walnut, Som ash, Hack berry, Mulberry, Lynn & Sycamore. the third or high Lands risees gradually from the 2nd bottom (cauht whin it Coms to the river then from the river) about 80 or 100 foot roleing back Supplied with water the Small runs of (which losees themselves in the bottom land) and are covered with a variety of timber Such as Oake of different Kinds Blue ash, walnut &c. &c. as far as the Praries...21 June 1804

Near the Great Falls, the flood plains were not persistent:

...scarcely any bottoms to the river; the hills high and juting in on both sides, to the river in many places...26 May 1805

...here the hills recede from the river on both sides, the bottoms extensive particularly on the Stard. side... here also the river spreads to more than 3 times it's former width and is filled with a number of small and handsome Islands...28 May 1805

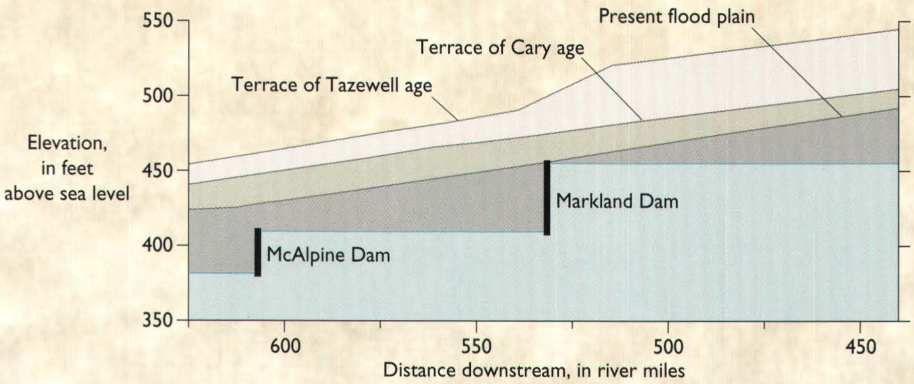
And now above the Great Falls:

...the bottoms are hadsome level and extensive on both side; the bank on this side is not more than 2 feet above the level of the water...25 June 1805

River Terraces

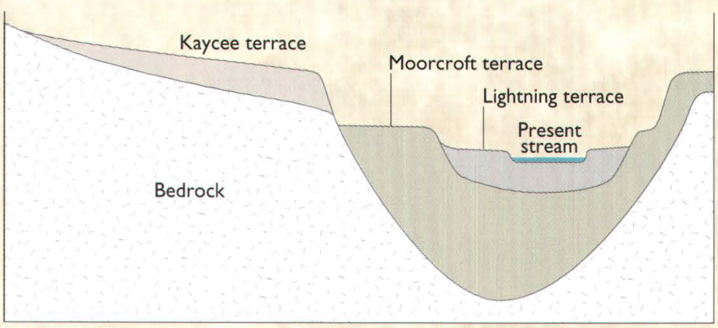
Playfair (1802) maintained the Huttonian or uniformitarian theory (page 6, "Science in 1800: Historical Context") that rivers, through slow and steady action, have formed terraces at "different levels on which the river has run at different periods of time" (Miller, 1883). Some river terraces are abandoned flood plains, and the change in the levels can be in response to changes in climate or changes in base level.

The change from a wetter to a drier climate will cause a decrease in the height of the annual floods such that the old flood plain is abandoned, leaving a terrace. For example, the three terrace levels along the Ohio River are perhaps most comprehensively described by Ray (1974, p. 58–65; see especially his Figure 18) who clearly correlates the separate levels with climate change associated with different episodes of discharges related to the melting of the great continental glaciers during and after the Pleistocene ice ages.



Profiles of the two terraces of the Wisconsinan glacial age and the flood plain of the Ohio River (Ray, 1974). The river level is shown as a series of steps behind the navigation dams.

Two examples of a change in base level may be (1) the sudden drop of the mouth of a river in response to changes in sea level or tectonic activity or (2) the river slowly incising into the valley floor such that "...each meander will sweep past a given point at a slightly lower level than that of its predecessor; and each time the meander belt swings across the valley from one side to the other and back again, it will return at a distinctly lower level than the level at which it left" (Davis, 1902). Thus, old flood plains are abandoned and become terraces. Leopold and Miller (1954) described three levels of flood plain and terraces along the Powder River in Wyoming, which they interpreted as having formed entirely after the end of the ice ages.



Profile of three terrace levels on Powder River in eastern Montana thought to have formed after the end of the last ice age (Leopold and Miller, 1954).

They frequently commented on whether or not the lowest bottom or flood plain has been flooded:

It's [Musselshell River] banks abbrupt and about 12 feet high yet never appear to overflow while the banks of Judith River were low yet appeared seldom to overflow.

Farther upstream, above the Great Falls, they described the Sun River with:

...banks which were formed principally of darkbrown and blue clay were about the hight of those of the Missouri or from 3 to 5 feet; yet they had not the appearance of ever being overflown...14 June 1805

While Lewis's party crossed back over the Continental Divide in 1806 to explore the Marias River, he encountered a tributary, Badger Creek, to the southern branch, Two Medicine River, of the Marias and commented that:

...another branch of nearly the same dignity formed a junction with it, coming from the S. W. this last is shallow and rappid; has the appearance of overflowing it's banks frequently and discharging vast torrants of water at certain seasons of the year...26 July 1806

Channel-Scale Geomorphic Features

Within the larger valley-scale, geomorphic features are smaller features such as riffles, rapids, falls, sandbars, point bars, and braided streams. Riffles, rapids, and falls were obstacles encountered while going downstream on the Ohio, Snake, and Columbia Rivers. Rapids, falls, sandbars, point bars, and braided channels were encountered while going upstream on the Missouri River.

RIFFLES

Riffles were mentioned early and frequently in the journals while Lewis and Clark were descending the Ohio River, which was especially low, even for the late summer and fall season:

...proceeded to a ripple of McKee's rock where we were obleged to get out all hands and lift the boat over about thirty yards; the river is extreemly low; said to be more so than it has been known for four year...30 August 1803

...we passed the little horsetale ripple or riffle with much deficulty, all hands laboured in the water about two hours before we effected a passage; the next obstruction we met was the big-horse tale riffle, here we wer obliged to unload all our goods and lift the emty Boat over, about 5 OCock we reach the riffle called Woollery's trap, here after unloading again and exerting all

our force we found it impracticable to get over, I therefore employed a man with a team of oxen...ten miles this day...1 September 1803

...[s]truck on a riffle which we got over with some difficulty and in the distance of two miles and a half passed 4 others three of which we were obliged to drag over with horses; the man charged me the exorbitant price of two dollars for his trouble...struck on a riffle about two miles below the town hoisted our mainsail to assist in driving us over the riffle the wind blew so heard as to break the spreat of it...the oxen arrived got off with difficulty the oxen drew badly however with their assistance we got over two other riffles which lyed just below...ten miles this day..6 September 1803

...passed several bad riffles and one particularly at the lower end of the long reach called Willson's riffle here we were obliged to cut a channel through the gravel with our spade and canoe paddles and then drag the boat through...20 miles this day...12 September 1803

These riffles on the Ohio River represent two of the riffle-forming processes (following page, "Riffle Formation"). On the Missouri River, the expedition seemed to have first encountered riffles and rapids during the fall of 1804, just before reaching the Mandan villages. Some riffles and rapids may have existed on the lower Missouri River but probably were covered by deeper water during the summer. As the expedition approached the Mandan villages, riffles may have been exposed at low water.

...passed a verry bad riffle of rocks in the evining...25 October 1804

The next mention seems to be while the expedition is passing through the Missouri River Breaks in Montana below Marias River and illustrates an understanding of the third process, debris riffles, responsible for forming riffles in canyon reaches:

...the courant strong particularly arround the points against which the courant happened to set, and at the entrances of the little gullies from the hills, those rivulets having brought down considerable quantities of stone and deposited it at their entrances forming partial barriers to the water of the river to the distance of 40 or 50 feet from the shore, arround these the water run with great violence,...25 May 1805

...scarcely any bottoms to the river; the hills high and juting in on both sides, to the river in many places...late this evening we passed a very bad rappid which reached quite across the river...these are the most considerable rappids which we have yet seen on the missouri and in short the only place where there has appeared to be a suddon decent...26 May 1805

...the river becomes more rappid and is intercepted by shoals and a greater number of rocky points at the mouths of the little gulies than we experienced yesterday....great quantities of stone also lye in the river and garnish it's

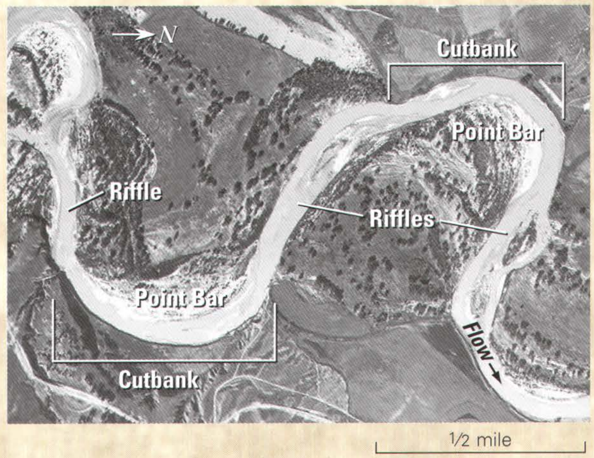
Riffle Formation

Several types of riffles may exist in rivers: (1) bedrock riffles, (2) alluvial riffles, and (3) debris riffles.

Bedrock riffles are formed as a river erodes down through the layers of sediment in the bed of the river and exposes erosion-resistant bedrock across the channel. Alluvial riffles form in reaches of rivers that are composed of erodible materials and thus are free to adjust their channel geometry (Matthes, 1941; Leopold and Wolman, 1957; Meade, 1985; Nelson and Smith, 1989).

Alluvial riffles are formed in meandering rivers. As the water enters a bend, the flow near the surface turns slightly from the downstream direction and heads toward the cutbank while the flow near the bottom turns slightly in the opposite direction (toward the point bar). The flow near the bank erodes sediment from the cutbank and from the river bottom adjacent to the cutbank in the pool (right). The inward component of the near-bottom flow moves the eroded sediment out of the pool and toward the inner bank. As the water leaves the bend, the surface and bottom flows slowly turn back to the downstream direction. In order to generate an equilibrium topography, the sediment transport must be the same at all cross sections. Most of the sediment removed from the cutbank is deposited on the next point bar downstream, as Lewis and Clark observed. But in order to convey the correct volume of passing sediment, the crossing must be somewhat shallower than the average depth of the channel near the apex of the bend. This requires that sediment be added to the riffle that occupies the relatively shallow area where the curvature of the bend changes direction. The water then exits the next bend and the erosion and deposition process is repeated.

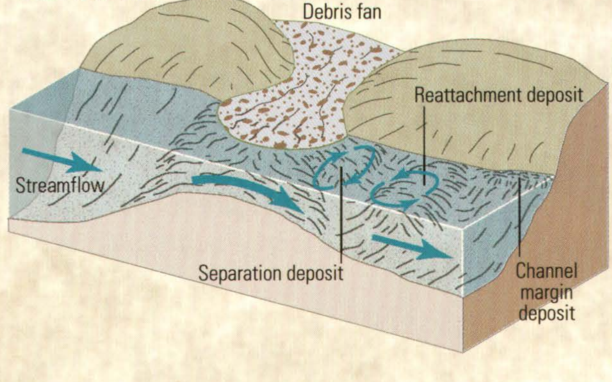
Alluvial Riffles



This aerial photograph of a meandering river was taken after the 1978 flood on the Powder River in southeastern Montana. Alluvial riffles are at the crossings between bends. Notice that some sand (white areas) was deposited as floodwaters overflowed the banks and slowed down while crossing the point bar through trees. Older meander scrolls can be seen outlined by cottonwood trees.

Debris riffles are formed by lateral inputs of debris into the main channel from hillslopes or from tributaries. The resulting debris fan partially fills the river and creates a narrower and shallower channel (below). These debris deposits are reworked by the river leaving the coarse sediment in the channel as a riffle and forming separation, reattachment, channel-margin deposits (Schmidt and Graf, 1990).

Debris Riffles



borders,...the river is generally about 200 yds. wide, very rappid and has a perceptable fall or declination through it's whole course...27 May 1805

...we employed the chord generally to which we also gave the assistance of the pole at the riffles and rocky points; these are as numerous and many of them much worse than those we passed yesterday; arround those points the water drives with great force, and we are obliged in many instaces to steer our vessels through the appertures formed by the points of large sharp rocks which reach a few inches above the surface of the water, here sould our chord give way the bough is instantly drivin outwards by the stream and the vessel thrown with her side on the rocks...28 May 1805

RAPIDS

Lewis realized that the expedition had ascended to *a great hight since we have entered the rocky Mountains*, and therefore, the rivers in the Columbia River Basin would be steeper than the Missouri River:

...but this I can scarcely hope from a knowledge of its [the Columbia River] *having in it comparitively short course to the ocean the same number of feet to decend which the Missouri and Mississippi have from this point to the Gulph of Mexico...10 August 1805*

...The River [Salmon River] *from the place I left my party to this Creek is almost one continued rapid, five verry Considerable rapids the passage of either with Canoes is entirely impossable, as the water is Confined betwen hugh Rocks & the Current beeting from one against another for Some distance below &c. &c. at one of those rapids the mountains Close So Clost as to prevent a possibility of a portage with great labour...This river is about 100 yards wide and can be forded but in a few places. below my guide and maney other Indians tell me that the Mountains Close and is a perpendicular Clift on each Side, and Continues for a great distance and that the water runs with great violence from one rock to the other on each Side foaming & roreing thro rocks in every direction, So as to render the passage of any thing impossible...The Torrents of water which come down aftr a rain carries with it emence numbers of those Stone into the river ...23 August 1805*

Instead of trying to go down the Salmon River, the expedition went by horse overland to the confluence of the Clearwater and North Forth of the Clearwater Rivers near what is now Orofino, Idaho. This was a difficult passage through what was essentially a rain forest of dark, heavy timber. The expedition had a difficult time finding a navigable river. The native peoples name for the Salmon River means "River of No Return." The Lochsa River was and is today (ClassV-VI whitewater river) a boulder-strewn, steep tributary to the Clearwater River, filled with rapids, and whose name means "Rough Water" in Nez Perce (Mike Beckwith, written communication, 2002). However, they *proceeded on* and found the Clearwater River, built canoes, and set off down the Clearwater on October 7, 1805:

> *...The after part of the day Cloudy proceded on passed 10 rapids which wer danjerous the Canoe in which I was Struck a rock and Sprung a leak in the 3rd rapid...7 October 1805*

> *...A Cloudy morning...passed 15 rapids four Islands and a Creek on the Stard Side at 16 miles just below which one canoe in whick Serjt. Gass was Stearing*

Course and distance on the Clearwater River for October 10, 1805

Bearing	Distance (miles)	Comments
South	1	*mile passed a bad rapid at the head of an Isd. on Ld. Side*
S. 20°W	11/2	*miles to a Ld bend, passed a Isd on Ld. Side rapid at the Head bad. passed Lower pt. of the other at the mouth of a run on Stand.*
West	1/2	*to a St. bend passed a Small Isd. Ld side and a rapid*
S. 30° W	3	*mile to a Ld. bend passed a Creek Cg on the Ld Side at 1/2 a mile on which is Cotton wood bottoms Inds. Camp below the Creek*
West	2	*miles to the head of an Isd. at bad rapid on bother Sides Curt* [*current*] *on the right Side*
S. 30° W	4	*mile pd. a rapd at Lower point of Isd & rapid at 1 mile, a rapd at 11/2 miles rocky bottoms on each Side a rapid at 21/2 miles a run & (Inds. Camp) on Stard Sd at 3 miles a rapid at 31/2 miles to a Lard. bend, low plain 100 ft*
West	2	*mile to a Stard bend, (passed an Indian bathing in hot bath) rapid an Island on the L. S. Shole waters at the head opsd. to which verry bad rapid we Call raged rapid one Canoe Struck & lodged Sprung a Leak onload Passed Several Inds camps on the Island. Took Meridian altitd. on the Island with Sextent made it 74°26' Latd 46° 29' 217/10" North*
SW	1	*mile to a bend on the St. Side psd 2 rapid*
South	1	*mile to the L. bend passed 2 rapid a large bottom on each Side*
S80W	3	*miles to the mouth of a Large fork Caled by the Inds. Ki-moo-e-nem* [Snake River] *passed 2 rapids Isd. in mouth*
West	1	*mile to a Ld. bend ps Shore in the mouth. Wind high which obliged us to Stop. Kimooenem has two forks on the South Side, & Camps of Inds. all the way up 2d fork called Pâr-nâsh-te about 50 ms. camped on Std. Side to make observt*

Taken from p. 253-254, volume 5, Moulton, 1988.

and was nearle turning over, She Sprung a leak or Split open on one Side and Bottom filled with water & Sunk on the rapid...8 October 1805

Clark's course and distances for October 10, 1805, give a good idea of the rapids on the Clearwater River to the confluence with the Snake River. Course and distance read with a similar detailed accounting of the rapids downstream to the mouth of the Snake River (below).

Rapids also dominated the journal entries while they went down the Snake River:

...we passed to day [blank] rapids Several of them very bad and came to at the head of one (at 30 miles) on the Stard. Side to view it before we attemptd. to dsend through it. The Indians had told us was verry bad— we found long and dangerous about 2 miles in length, and maney turns necessary to Stear Clare of the rocks, which appeared to be in every direction. The Indians went through & our Small Canoe followed them, as it was late we deturmined to camp above untill the morning...12 October 1805

...at 12 miles we Came too at the head of a rapid which the Indians told me was verry bad, we viewed the rapid found it bad in decending three Stern Canoes Stuk fast for Some time on the head of the rapid and one Struk a rock in the worst part, fortunately all landed Safe below the rapid which was nearly 3 miles in length...after dinner we Set out and had not proceded on two miles before our Stern Canoe in passing thro a Short rapid opposit the head of an Island, run on a Smoth rock and turned broad Side, the men got out on the [rock] all except one of our Indian Chiefs who Swam on Shore, The Canoe filed and Sunk...14 October 1805

...a Suckcession of Sholes, appears to reach from bank to bank for 3 miles which was also intersepted with large rocks Sticking up in every direction, and the chanel through which we must pass crooked and narrow. we only made 20 miles today, owing to the detention in passing rapids &c...15 October 1805

FALLS

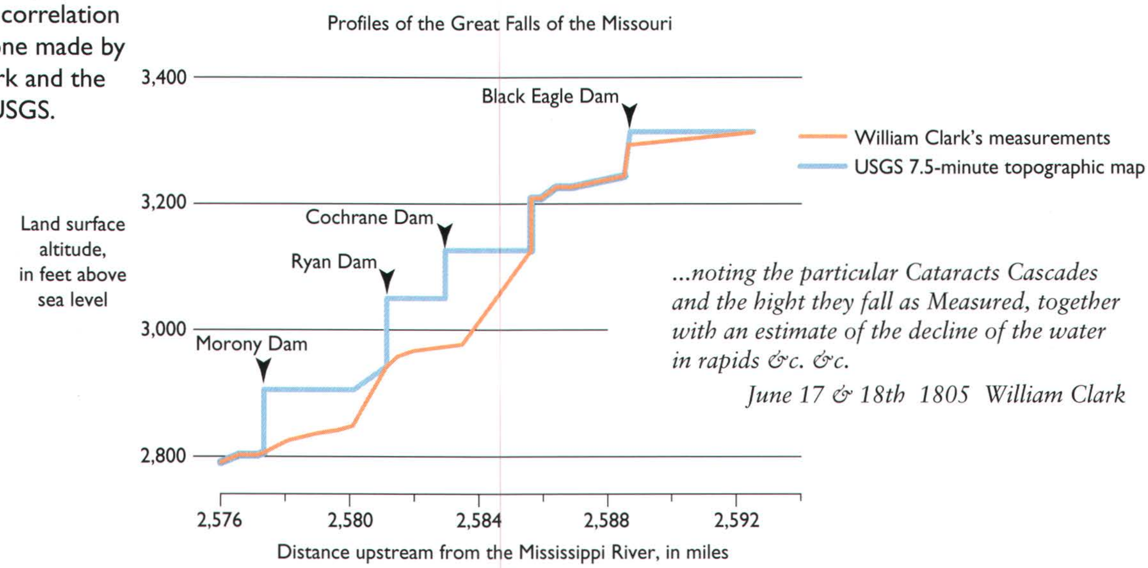
The Great Falls of the Missouri River The first major falls that Lewis and Clark encountered were the Great Falls of the Missouri River. They spent about a month (June 16–July 14, 1805) portaging the Great Falls, and during this time Clark measured their profile. He gives the course, horizontal distances in poles (see "Conversions" and "Glossary") and vertical distances in feet. The total horizontal distance is 14.83 miles with a total drop of 360 feet or an average slope of 0.005. Superimposed upon Clark's profile of the Great Falls (next page) are the approximate locations of four dams. The largest fall was 93.75 feet high according to Clark and is now part of the Ryan Dam. Today, Crooked and Rainbow Falls can still be seen and were measured by Clark to be 34 and 47.67 feet high, respectively.

Major falls on the Columbia River The final obstacles on the Columbia River were three major falls. The Great Falls (later Celilo Falls), the Falls at the Short and Long Narrows (later The Dalles), and the Great Rapids (later The Cascades) were each mapped by Clark (pages 42, 43, and 44). These maps record the morphology in 1805 of the falls which today are all under water impounded in the reservoirs behind The Dalles (footnote 11, p. 326, v. 5, Moulton, 1988) and Bonneville Dams. At Celilo Falls:

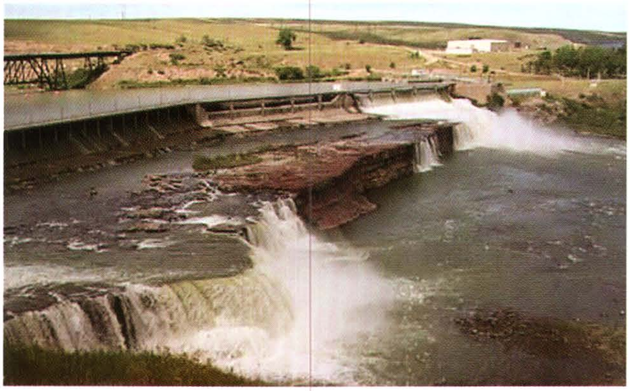
> *... the waters is divided into Several narrow chanels which pass through a hard black rock forming Islands of rocks at this Stage of the water...22 October 1805*

These numerous channels observed and mapped by Clark represent channels carved in the Columbia River basalts by flow velocities (up to 40 miles per hour) associated with catastrophic floods that emanated from Lake Missoula, in what is now

A comparison of profiles shows a close correlation between the one made by Lewis and Clark and the other by the USGS.



...noting the particular Cataracts Cascades and the hight they fall as Measured, together with an estimate of the decline of the water in rapids &c. &c.
June 17 & 18th 1805 William Clark



The Black Eagle Dam is located just above Rainbow and Crooked Falls.

Photo: USGS

This 1888 map from the U.S. Army Corps of Engineers shows the location of several of the major rapids and falls along the lower reach of the Columbia River. Today this reach is under water impounded by the Dalles Dam.

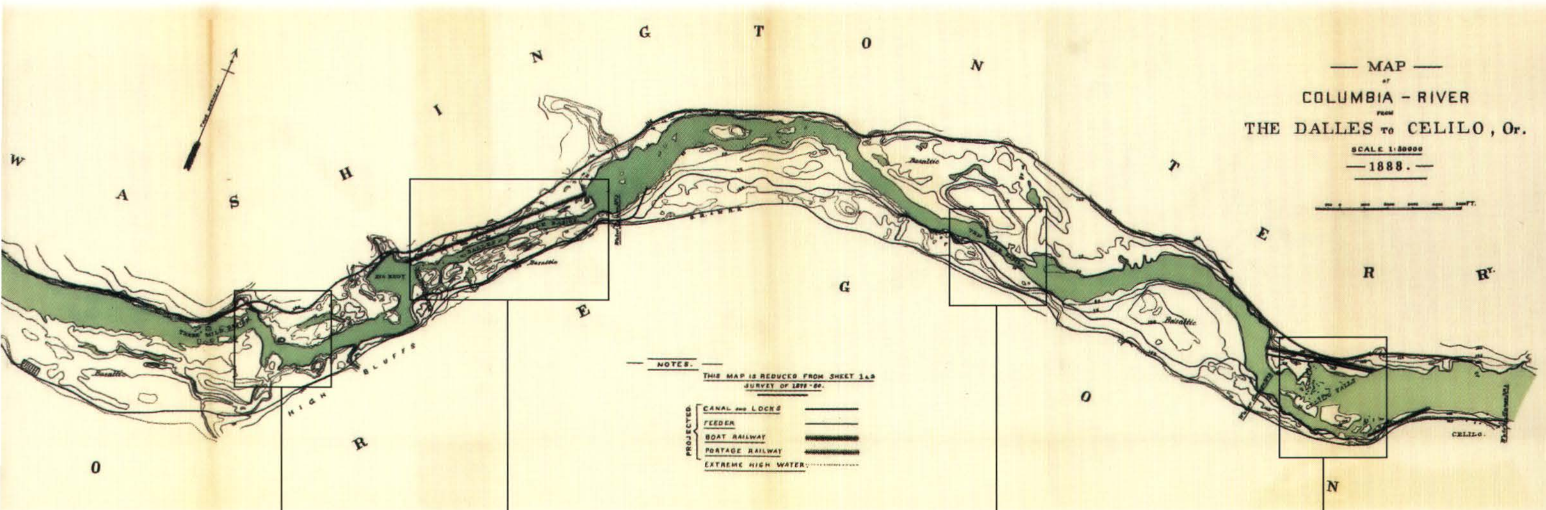


Photo: Washington State University

Site of the Dalles Dam | The Dalles or Five-Mile Rapids (Long Narrows) | Ten Mile Rapids (Short Narrows) | Celilo Falls (The Great Falls)

Montana. The ice dam across the outlet of the lake broke several times at the end of the ice age about 16,000 to 12,000 years ago and released about 400 cubic miles of water each time. The water flowed across what is now eastern Washington and down the Columbia River (Bretz, 1930; Allen and others, 1986). A short distance downstream were the two falls at The Dalles. Dalles means "gutter" in French and refers to the numerous slotlike channels in the basalt probably created by the Lake Missoula Floods. At the beginning of a narrow reach of the Columbia River:

> ...*The first pitch of this falls is 20 feet perpendicular, then passing thro'a narrow Chanel for 1 mile to a rapid of about 18 feet fall below which the water has no perceptable fall but verry rapid See Sketch No. 1. It may be proper here to remark that from Some obstruction below, the cause of which we have not yet learned* [see next excerpt below], *the water in high fluds (which are in the Spring) rise <nearly> below these falls nearly to a leavel with the water above the falls; the marks of which can be plainly trac'd around the falls. at that Stage of the water the Salmon must pass up which abounds in Such great numbers above...24 October 1805*

This observation makes an interesting connection between geomorphology, hydrology, and biology. The obstruction is the *Long Narrows*, which is described in the next excerpt and was later known as Five-Mile rapids. The peak runoff on the

Photograph shows the Celilo Falls as viewed from downstream and looking upstream before the construction of The Dalles Dam completed in 1960.

The view in the photograph is shown by the blue arrow on the map.

Photo: U.S. Army Corps of Engineers and the Bonneville Power Administration.

Clark's map of the Celilo Falls on the Columbia River.

Map: American Philosophical Society

Columbia River at The Dalles occurs in summer (page 68, "River Hydrographs"), and the salmon runs have probably evolved to peak during the summer. Chinook salmon begin arriving in February, but the main population of fish do not arrive until May, June, and July and then diminish rapidly after July (Chapman, 1986). Thus, the salmon can surmount the falls at the only time of year when it would be possible as suggested by Lewis and Clark. In drought years, when the peak flow was much less, the flow may not have backed up to a sufficient depth to allow the salmon to pass the falls. Just downstream from *The Great Falls*, the Columbia River went through the *Short Narrows*:

> *....from the top of which I could See the dificuelties we had to pass for Several miles below; at this place the water of this great river is compressed into a Chanel between two rocks not exceeding forty five yards wide and continues for a 1/4 of a mile when it again widens to 200 yards and continues this width for about 2 miles when it is again intersepted by rocks. This obstruction in the river accounts for the water in high floods riseing to Such a hite at the last falls. The whole of the Current of this great river must at all Stages pass thro' this narrow chanel of 45 yards wide...24 October 1805*

and then through the *Long Narrows* where:

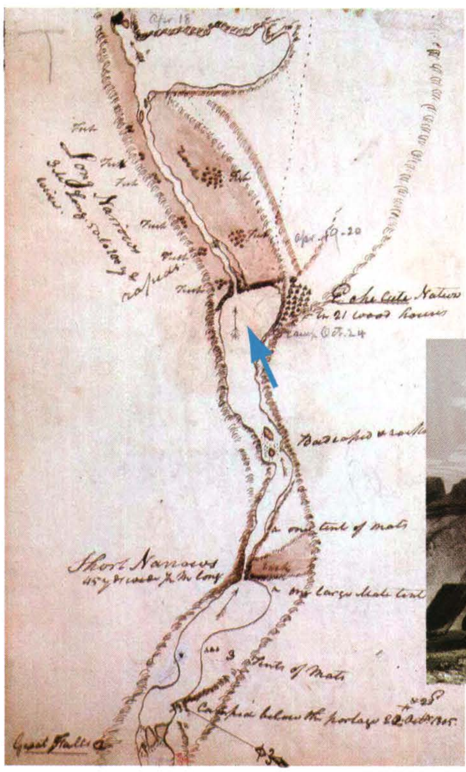
...the Chanel is narrow and compressed for about 2 miles, when it widens into a deep bason to the Stard. Side, & again contracts into a narrow chanel divided by a rock....24 October 1805

The *deep bason* may also have been created by the Lake Missoula Floods, which could pluck out large areas of bedrock in a somewhat random pattern. Because *the portage was impractiable with our large Canoes, we Concluded to Make a portage of our most valuable articles and run the canoes thro.* After passing the *Long Narrows* they

...proceeded on down the water fine, rocks in every derection for a fiew miles when the river widens and becoms a butifull jentle Stream of about half a mile wide...25 October 1805

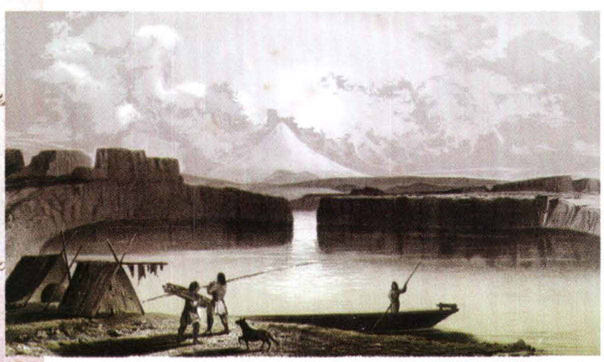
Upstream from the Cascades, Clark made an interesting observation:

...a remarkable circumstance in this part of the river is, the Stumps of pine trees are in maney places are at Some distance in the river, and gives every appearance of the rivers being damed up below from Some cause which I am not at this time acquainted with, the Current of the river is also verry jentle not exceeding 1 1/2 mile pr. hour and about 3/4 of a mile in width....here



Map: American Philosophical Society

Clark's map of The Dalles, or Short and Long Narrows, on the Columbia River. Westward flow is from bottom to top.



University of Washington

This lithograph looking downstream into the Long Narrows was made from an engraving by J.M. Stanley in 1853.

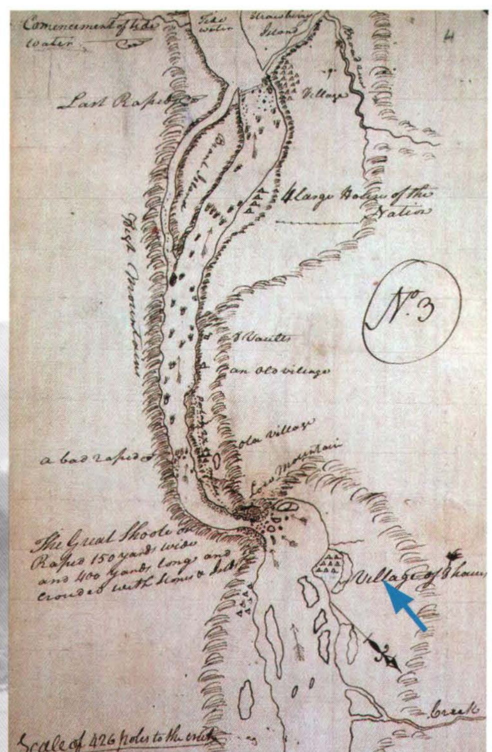
The view in the engraving is shown by the blue arrow on the map.

the river widens to about one mile large Sand bar in the middle, a Great [rock] both in and out of the water, large <round> Stones, or rocks are also permiscuisly Scattered about in the river...30 October 1805

Clark observes the remnants of the landslide downstream, a day later on October 31, 1805 (opposite):

...This Great Shute or falls is about 1/2 a mile with the water of this great river Compressed within the Space of 150 paces in which there is great numbers of both large and Small rocks, water passing with great velocity forming & boiling in a most horriable manner, with a fall of about 20 feet, below it widens to about 200 paces and current gentle for a Short distance. a Short distance above is three Small rockey Islands, and at the head of those falls, three Small rockey Islands are Situated Crosswise the river, Several rocks above in the river & 4 large rocks in the head of the Shute; those obstructions together with the high Stones which are continually brakeing loose from the

Clark's map of the Cascades Rapids [*Great Shute*] of the Columbia River.



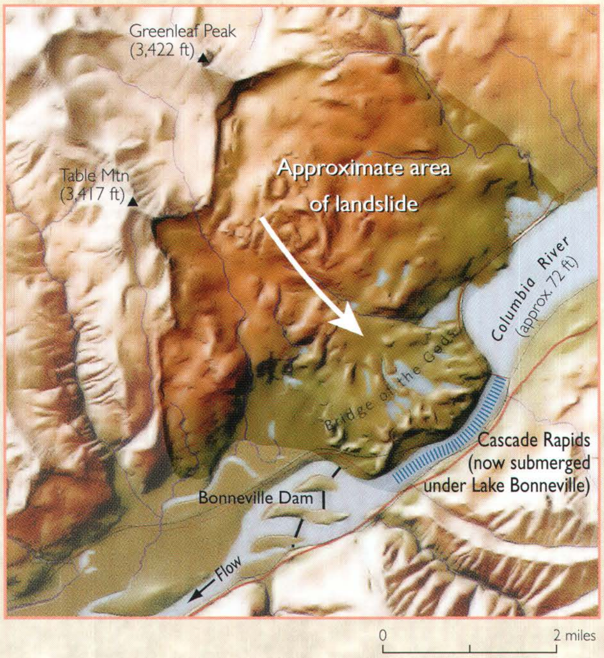
Map: American Philosophical Society

The view in the photograph is shown by the blue arrow on the map.

This 1929 photograph is looking downstream into Cascade Rapids. The Bonneville Dam was constructed at the terminus of the rapids.

Photo: U.S. Army Corps of Engineers and the Bonneville Power Administration

Bonneville Landslide



The stumps of the "submerged forest" have puzzled many scientists since Lewis and Clark made their observations. Current thinking attributes the stumps to the submergence of a forest by water backed up behind the Bonneville landslide on the Columbia River, near the former location of Cascade Rapids. The cause of the landslide is not clear, but the stumps have been dated to provide an estimate of when the landslide occurred. Lawrence and Lawrence (1958) estimated the date to be between A.D. 988 and 1588; Pringle and Schuster (1998) and Schuster and Pringle (2002) estimated ages ranging from A.D. 1500 to 1760 on the basis of radiocarbon dating. More recent radiocarbon dates (Jim O'Connor, written communication, 2002) indicates the blockage of the Columbia River was between A.D. 1400 and 1465.

mountain on the Stard Side and roleing down into the Shute aded to those which brake loose from those Islands above and lodge in the Shute, must be the Cause of the rivers daming up to Such a distance above, where it Shows Such evidant marks of the Common current of the river being much lower than at the present day...31 October 1805

SANDBARS

On the Missouri, sandbars were numerous and the most troublesome feature encountered in June of 1804. In what is now Iowa and Missouri, the expedition had to labor upriver against the peak runoff (page 68, "River Hydrographs") through the sandbars (see the stippled areas on Clark's map on pages 13 and 18) and sometimes over them:

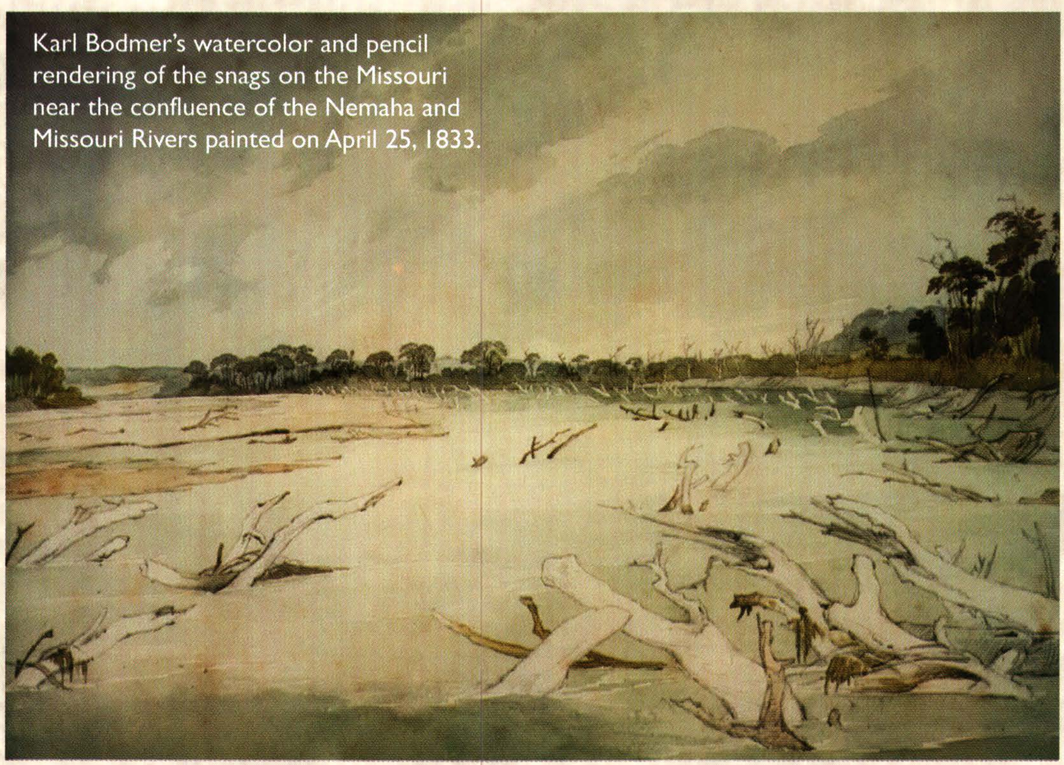
...passd. a bad Sand bar on which we Stuck for a Short time this is Said to be the worst part of the river...15 June 1804

and near the White River in South Dakota

...the Sandbars So noumerous; it is not worth mentioning them...9 September 1804

River Snags

Snags are tree stumps and parts of trees buried in sandbars. Snags continue to trap sediment as the river flows among them. If enough snags are present in an area, trapped sediment may accumulate vertically until the sandbar is high enough to become new flood plain and alter the course of the river. During later floods, the river may cut a channel through the flood plain, which was once a sandbar, and expose these buried tree parts. In some tributaries to the Missouri River, these buried snags have ages ranging from 100 to 11,270 years before the present (Guyette and Dey, 2001). Karl Bodmer's painting in 1833 is probably the best visual impression of snags on the Missouri River. Mark Twain's paragraph in "Roughing It" (written about his trip up the Missouri River by steamboat in 1861) is among the best verbal descriptions of snags:



Karl Bodmer's watercolor and pencil rendering of the snags on the Missouri near the confluence of the Nemaha and Missouri Rivers painted on April 25, 1833.

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

We were six days going from St. Louis to "St. Joe"—a trip that was so dull, and sleepy, and eventless that is has left no more impression on my memory than if its duration had been six minutes instead of that many days. No record is left in my mind, now, concerning it, but a confused jumble of savage-looking snags, which we deliberately walked over with one wheel or the other; and of reefs which we butted and butted, and then retired from and climbed over in some softer place; and of sand bars which we roosted on occasionally, and rested, and then got out our crutches and sparred over. In fact, the boat might almost as well have gone to St. Joe by land, for she was walking most of the time, anyhow—climbing over reefs and clambering over snags patiently and laboriously all day long. The captain said she was a "bully" boat, and all she wanted was more "shear" and a bigger wheel. I thought she wanted a pair of stilts, but I had the deep sagacity not to say so.

...Set out verry early, the river wide & Shallow the bottom narrow, & the river Crouded with Sand bars...11 September 1804

...we found great dificuelty in passing between the Sand bars the water Swift and Shallow, it took 3/4 of the day to make one mile...12 September 1804

These sandbars were populated by snags (opposite).

...a fair morning, the River rise a little we got fast on a Snag Soon after we Set out which detained us a Short time...9 June 1804

...we Set out and proceeded on under a gentle breeze from the N.W. passed Some verry Swift water Crouded with Snags ...22 June 1804

...the bank was falling in and lined with Snags as far as we could See down,...14 July 1804

...a bend to L.S. choked up with Snags...8 August 1809

It was not until May of 1805 downstream from the Musselshell River that the number of sandbars seem to decrease:

...the sandbars, and with them the willow points have almost entirely disappeared...17 May 1805

...there are now but few sandbars, the river is narrow and current gentle...18 May 1805

...fewer sandbars and the courant more gentle and regular...22 May 1805

On the return trip in 1806, they traveled down the Missouri River downstream from the Yellowstone River after the summer peak runoff in later summer and fall, and Clark observed that:

...in places where there was Sand bars in the fall 1804 at this time the main Current passes, and where the current then passed is now a Sand bar—Sand bars which were then naked are now covered with willow Several feet high...20 August 1806

Near the Big Sioux River he noted that:

...the river [Missouri] *much crowded with Sand bars, which are very differently Situated from what they were when we went up...3 September 1806*

and

...passed the enterance of the great river Platt which is at this time low the water nearly clear the Current turbelant as usial; the Sand bars which Choked up the Missouri and Confined the [river?] to a narrow Snagey Chanel are wastd a way and nothing remains but a fiew Small remains of the bear [bar] which is covered with drift wood...9 September 1806

This view of the Powder River was taken near the Wyoming-Montana State line.

Photo: John Moody

Point bars are a special subset of sandbars and were first mentioned as a batteau (a sandy beach on the inside curve of a river, footnote 9, p. 299, v. 2, Moulton, 1986). Clark described the maintenance of point bars on the Missouri River upstream from the Platte River:

...In every bend the banks are falling in from the Current being thrown against those bends by the Sand points which inlarges and the Soil I believe from unquestionable appearns. of the entire bottom from one hill to the other being the mud or ooze of the River at Some former Period mixed with Sand and Clay easily melts and Slips into the River, and the mud mixes with the water & the Sand is washed down and lodges on the points...5 August 1804

and later on the Big Horn River:

...like the Missouri, it washes away its banks on one Side while it forms extensive Sand bars on the other side...26 July 1806

BRAIDED REACHES

No mention was made of the braided character of the Missouri until October 3, 1804, when there is a brief entry: *we attempted several chanels and could not find water to assend.* Multiple channels, separated by islands and sandbars, are shown in Clark's maps. Prior to October 3, 1804, the river stage may have been high enough that the expedition's boats could navigate the channels. Lewis and Clark frequently would give the measured width of the Missouri or mention that it was wide or narrow. However, near the Cheyenne River in South Dakota, more observations of the braided character appear in their journals, perhaps because the river stage had fallen. If they had traversed the lower Missouri River in September–October rather than in May–June, they may have had more comments about the braided character of the river.

...we were obliged to Drop down 3 miles to get the Chanel Suft. deep to pass up...4 October 1804

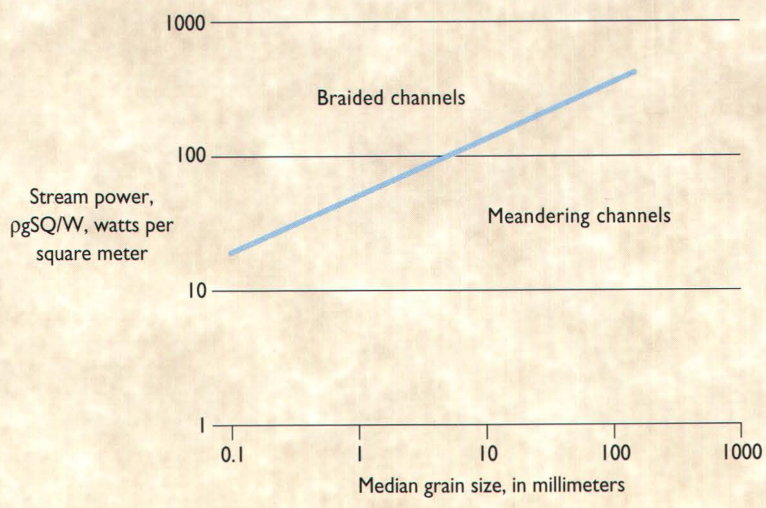
...we proceeded on found the river Shole we made Severl. attempts to find the main Channel between the Sand bars, and was obliged at length to Drag the boat over to Save a league which we must return to get into the deepest Channel, we have been obgd to hunt a Chanl. for Some time past the river being devided in many places in a great number of Chanels...6 October 1804

...many Sand bars and bad places, water much devided between them...26 October 1804

...the river for several days has been as wide as it is generally near it's mouth, tho' it is much shallower or I should begin to dispair of ever reaching it's

Channel Patterns

Why a river is straight, meandering, or braided has been studied by many scientists since Lewis and Clark made their observations. These channel patterns represent a continuum, and all three types may be found in the same river. For example, Russell (1954) mentions that the Meander River in Turkey, from which the term is derived, has both meandering and braided reaches. With some exceptions, the Missouri River was generally a braided river downstream from the Great Falls and a meandering river in unconfined reaches upstream from the falls. Channels with sinuosity (pages 16 and 17, "River Terms') greater than 1.5 was a definition used by Leopold and Wolman (1957) to separate straight reaches from meandering reaches within the continuum of channel patterns. Scientists have found that the type of channel pattern also depended upon the channel width, the discharge, the channel slope, the grain size of the sediment on the riverbed, and the amount and frictional resistance of the sediment in the channel (Matthes, 1941; Leopold and Wolman, 1957; Langbein and Leopold, 1966; Schumm, 1977; van den Berg, 1995). In general, for a fixed discharge and median diameter, meandering reaches will have slopes less than the slopes of braided reaches (below). Similarly, for a fixed slope and grain size, braided reaches will have a greater discharge than meandering reaches. The channel pattern can also be changed by adding more sediment to the channel through such processes as landslides (Lisle and others, 1983), dumping mine tailings into a river (Gilbert, 1917), and erosion from watersheds burned by wildfire (Moody, 2001).



The variable on the vertical axis is called the unit stream power or stream power per unit width, where ρ is the density of water and g is the acceleration of gravity, and each are constants. S is the channel slope, Q is the discharge at bankfull, and W is the channel width.

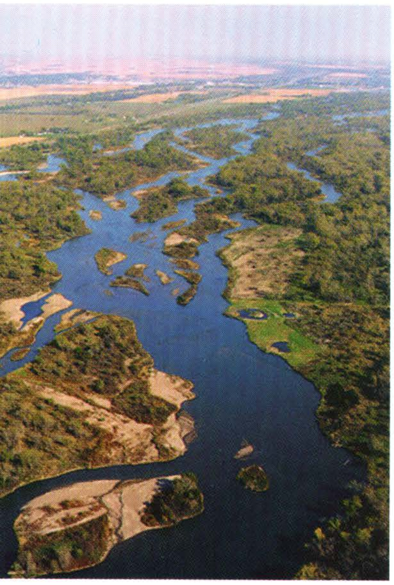
Adapted from van den Berg (1995).

source; it has been crouded today with many sandbars; the water also appears to become clearer, it has changed it's complexin very considerably...9 May 1805

and above the Gates of the Rocky Mountains:

...the river immediately on entering this valley assumes a different aspect and character, it spreads to a mile and upwards in width crouded with Islands, some of them large, is shallow enough for the use of the seting pole in almost every part and still more rappid than before; it's bottom is smooth stones and some large rocks as it has been since we have entered the mountains...21 July 1805

...the river is still divided by a great number of islands, it channels sometimes seperating to the distance of 3 miles; the current very rapid with a number of riffles; the bed gravel and smooth stones...23 July 1805



Braided reach of the Platte River, Nebraska.

Photo: University of Nebraska

They mentioned the activities of the beaver along this braided reach within the mountains:

...we saw many beaver and some otter today; the former dam up the small channels of the river between the islands and compell the river in these parts to make other channels; which as soon as it has effected that which was stoped by the beaver becomes dry and is filled up with mud sand gravel and drift wood. the beaver is then compelled to seek another spot for his habitation wher he again erects his dam. thus the river in many places among the clusters of islands is constantly changing the direction of such sluices as the beaver are capable of stoping or of 20 yds. in width. this anamal in that way I beleive to be very instrumental in adding to the number of islands with which we find the river crouded...24 July 1805

Erosion, Sediment Transport, and Deposition

Lewis and Clark also made observations of processes that change the geomorphic features. They made a few observations of hillslope erosion, but the majority of the entries in their journals dealt with bank erosion along the Missouri River.

EROSION

Clark described the erosion process near the White River in South Dakota:

...The rain Continued the Greater part of the day in My ramble I observed, that all those parts of the hills which was Clear of Grass easily disolved and washed into the river and bottoms, and those hils under which the river run, Sliped into it and disolves and mixes with the water of the river, the bottoms

of the river was covered with the water and mud frome the hills about three Inches deep— those bottoms under the hils which is Covered with Grass, also receves a great quantity of mud...14 September 1804

Clark observed mass wasting near the Bald Pate Prairie in the vicinity of the Nishnabotna River:

...this Hill has Sliped from the top which forms a Bluff above & 200 foot above the water, about 3/4 of a mile in length & about 200 feet in Depth has Sliped into the river...18 July 1804

and later Lewis noted some mass wasting near the mouth of the Little Missouri:

...the lard. shore on which I walked was very broken, and the hills in many places had the appearance of having sliped down in masses of several acres of land in surface...14 April 1805

Bank erosion was noted more frequently in the journals than hillslope erosion but was limited to the period from May 15, 1804 (when they started up the Missouri River) to about June 28. This was a rainy period according to the journals. Clark noted that the river *begin to rise* on May 28, then *rises fast*, (May 30), *rose last night a foot* (June 6), *rise a little* (June), *riseing fast*, (June 15), *raised 3 Inches last night* (June 21), *rose 4 Inchs last night* (June 22), *the river rose a little last night* (June 27), and *the river Missourie has raised yesterday last night & today about 2 Foot this evening it is on a Stand* (June 28). The river apparently crested on June 28, 1804. This rise of the river was after the spring rise associated with snowmelt at lower elevations (page 68, "River Hydrographs"). *The larger river rise is the annual inundation of the river, which usually happen in the month of June* near the mouth. Smaller rises are the consequence of local storms. Most of the bank erosion was observed during periods when the river was rising.

...we attempted to pass up under the Lbd. Bank which was falling in So fast that the evident danger obliged us to Cross between the Starbd. Side and a

Photo: John Moody

A bank failure of a type that might have been seen by Lewis and Clark. This example was photographed on the Ob River in Siberia near Khanty-Mansiysk and has birch and conifer trees on the bank rather than the cottonwood and willow trees Lewis and Clark would have seen.

Sand bar in the middle of the river...24 May 1804

...The banks are falling in Verry much to day...6 June 1804

...immense Current & falling banks on the S.S...14 June 1804

...all at once the river became Crowded with drift that it was dangerous to cross this I Suppose was from the caveing in of the banks at [t]he head of Some Island above...2 July 1804

...the Banks washing away & trees falling in constantly for 1 mile...4 August 1804

Some bank erosion was noted after a local storm:

...My notes of the 13th of July by a Most unfortunate accident blew over Board in a Storm in the morning of the 14th..last night at about 10 oClock a violent Storm of wind from the N.N.E. which lasted with Great violence for about one hour, at which time a Shower of rain Succeeded...13 July 1804

...Some hard Showers of rain this morning [14th] prevented our Setting out untill 7 oClock...and the opposit Shore, the bank was falling in and lined with Snags as far as we could See down...14 July 1804

and some bank erosion involved large areas:

......passed a place above the Island L.S. where about 20 acres of the hill has latterly Sliped into the river above a clift of Sand Stone for about two miles...16 July 1804

The banks eroded and so did sandbars; the Missouri River was a dynamic system—always changing:

...last night or reather this morng at a half past one oClock the Sand bar on which we Camped began to give way, which allarmed the Serjt on guard &

Photo: Environmental Protection Agency

Sediment-laden (muddy) water from the Knife River flowing into the Missouri River (June 2001). The crumbling bank is a source of the sediment.

the noise waked me, I got up and by the light of the moon observed that the Sand was giving away both above & beloy and would Swallow our Perogues in a few minits, ordered all hands on board and pushed off we had not got to the opposit Shore before pt. of our Camp fel into the river...21 September 1804

No entries of bank erosion are found after the end of July and through the remainder of the summer into the fall. A few entries appear in April 1805 as the expedition started up the Missouri River from their winter quarters at Fort Mandan. Once again bank erosion seems to be associated with the rising river. However, the expedition probably did not encounter the annual rise in 1805, which probably peaked after April.

SEDIMENT TRANSPORT

Lewis and Clark made observations of eolian transport, suspended-sediment transport, and bedload transport. Eolian transport was first mentioned in August 1804 near the Big Sioux River and indicated transport to the east:

...The Wind blew hard <West> [another editor probably meant West wind, based on the prevailing winds in Montana and North Dakota] and raised the Sands off the bar in Such Clouds that we Could Scercely <See> this Sand being fine and verry light Stuck to every thing it touched, and in the Plain for a half a mile the distance I was out every Spire of Grass was covered with the Sand or Dust...23 August 1804

Eolian transport was not mentioned again until 1805 when they were headed up the Missouri River in what is now western North Dakota and eastern Montana. Several entries bemoaned the wind and culminated in the following entries in April 1805:

...a cold morning at about 9 oClock the wind as usial rose from the N W and continued to blow verry hard untill late in the evening...23 April 1805

...The wind blew so hard during the whole of this day, that we were unable to move...Soar eyes is a common complaint among the party. I believe it origenates from the immence quantities of sand which is driven by the wind from the sandbars of the river in such clouds that you are unable to discover the opposite bank of the river in many instances. the particles of this sand are so fine and light that they are easily supported by the air, and are carried by the wind for many miles, and at a distance exhibiting every appearance of a collumn of thick smoke. so penitrating is this sand that we cannot keep any article free from it; in short we are compelled to eat, drink, and breath it very freely...24 April 1805

Muddy Missouri

A century and a half after Lewis and Clark's observation of the source of the mud in the Missouri River, Colby and others (1956, page 2) reiterated this observation in quantitative detail in their study of sedimentation in the Wind River Basin of Wyoming: "The [Rocky Mountain] area underlain by Precambrian rocks covers 14 percent of the basin, yields 59 percent of the water, and yields much less than 1 percent of the sediment. In contrast, the [riverbank] area underlain by rocks [sediments] of Quaternary age covers 16 percent of the basin, yields about 63 percent of the sediment, but only about 2.5 percent of the water."

The suspended-sediment load near the mouth of the Missouri River was 320,000,000 tons per year before flood-control dams were built from 1953 to 1967 (Keown and others, 1986). After the dams were built, the suspended-sediment load was 86,000,000 tons per year, which is almost one fourth less than before the dams. Lewis and Clark report that precipitate of one pint of Missouri water weighed 80:65 grs. The meaning of the ":" is unclear, but assuming they meant about 80 grains per pint, then this would be a concentration of about 9,400 milligrams per liter. A recent (June 10, 1990) measurement of a sample of the suspended-sediment concentration made at high discharge of the Missouri River (similar to what Lewis and Clark may have encountered in 1804) at St. Charles, Missouri, was 2,300 milligrams per liter (Moody and Meade, 1993). This sample was 14 percent sand and 86 percent silt and clay or "mud." The total concentration in this recent sample is just about one-fourth less than the concentration estimated from Lewis and Clark's observations in 1804.

> *...at 11 oClock the wind rose and continued to blow verry hard a head from the N. W. untill 4 oClock P M, which blew the Sand off the Points in Such clouds as almost Covered us on the opposit bank...27 April 1805*

This phenomenon observed by Lewis and Clark is a smaller scale analog to that which built the great deposits of loess after the ice ages, but it is probably very rare today because of bank stabilization, which has narrowed the river and eliminated most sandbars (Dale Blevins, oral communication, 2002). Deposition from this type of transport was observed above the Great Falls of the Missouri River.

> *...on the banks of the river there are many large banks of sand much elivated above the plains on which they ly and appear as if they had been collected in the course of time from the river by the almost incessant S. W. winds; they always appear on the sides of the river opposite to those winds...15 July 1805*

They observed and described the sediment transport process that today is well known as lateral accretion and is characteristic of many alluvial rivers.

...In every bend the banks are falling in from the Current being thrown against those bends by the Sand points which inlarges and the Soil I believe from unques-

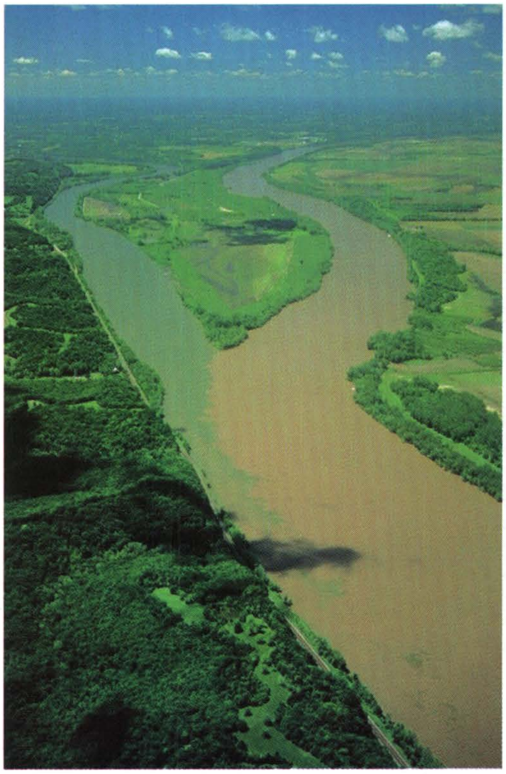
tionable appearns. of the entire bottom from one hill to the other being the mud or ooze of the River at Some former Period mixed with Sand and Clay easily melts and Slips into the River, and the mud mixes with the water & the Sand is washed down and lodges on the points...5 August 1804

The amount of suspended sediment in the Missouri made the river distinctive. Apparently some people thought it came from the Platte River, but Lewis thought otherwise when he observed the confluence of the Platte and Missouri Rivers:

> ... *The river Platte does not furnish the Missouri with it's colouring matter, as has been asserted by some; but it throws into it immence quanties of sand and gives a celerity to it's current, of which it does not abate untill it joins the Mississippi. The water of the Platte is turbid at all seasons of the year, but it is by no means as much so, as that of the Missouri; the sediment it deposits consists of small particals of white sand, while that of the Missouri is composed principally of a dark rich loam in much greater quantity...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 348.

They felt the source was the banks of the Missouri River itself:

> ...*The Muddiness of the Missouri is Caused by the Washing in of it's banks—within the rocky mountains the Water is Clear...*Postexpeditionary Miscellany, Moulton, 1993, v. 8, p. 414.



This view of the confluence of the Osage (left) and Missouri Rivers shows a sediment-laden Missouri. The amount of sediment is only a fraction of the the historical load.

The Sandy River (*Quick Sand River*) with headwaters on Mount Hood had similar characteristics of the Platte River. After Clark explored the mouth of the Quick Sand River, he wrote:

> ...*I arrived at the enterance of a river which appeared to Scatter over a Sand bar, the bottom of which I could See quite across and did not appear to be 4 Inches deep in any part; I attempted to wade this Stream and to my astonishment found the bottom a quick Sand, and impassable— I called to the Canoes to put to Shore, I got into the Canoe and landed below the mouth, & Capt Lewis and my Self walked up this river about 11/2 miles to examine this river which we found to be a verry Considerable Stream Dischargeing its waters through 2 Chanels which forms an Island of about 3 miles in length on the river and 11/2 miles wide, composed of Corse Sand which is thrown out of this quick Sand river Compressing the waters of the Columbia and throwing the whole Current of its waters against its Northern banks, within a Chanel of 1/2 a mile wide, Several Small Islands 1 mile up*

Lahars

The large quantity of sand in the Sandy River, Oregon, may have been produced by a lahar from Mount Hood. Radiocarbon dating of wood samples and dendrochronological work indicate that the Old Maid Eruptive Period on Mount Hood was between A.D. 1686 and 1806 (Cameron and Pringle, 1986). Tree ring characteristics suggest a tree-damaging event around A.D. 1794 (Cameron and Pringle, 1987). The expedition may have arrived soon after one of these lahars, which filled the channel and caused the river to overflow its banks. At present, the river has a boulder-armored bed, and the channel is 3 to 4 m deep, and its banks are not inundated by moderate spring or fall floods (Cameron and Pringle, 1987). Similar lahars came off Mount St. Helens after the 1980 eruption, down the Cowlitz River and into the Columbia River. The normal navigation channel in the Columbia River near the mouth of the Cowlitz River is 40 feet deep. This volcanic material from Mount St. Helens clogged the river, and the depth of the navigation channel was reduced to 15 feet (David Kresch, written communication, 2002).

this river, This Stream has much the appearance of the River Platt: roleing its quick Sands into the bottoms with great velocity after which it is divided into 2 Chanels by a large Sand bar before mentioned...A Mountain which we Suppose to be Mt. Hood is S. 85° E about 47 miles distant from the mouth of quick sand river...3 November 1805

and later on the return trip Lewis added:

Sergt. Pryar returned in the evening and reported that he had ascended the river six miles; that above the point at which it divides itself into two channels it is about 300 yds wide tho' the channel is not more than 50 yds and only 6 ft deep. this is a large vollume of water to collect in so short a distance; I therefore think it probable that there are some large creeks falling into it from the S. W. the bed of this stream is formed entirely of quicksand; it's banks are low and at preasent overflows. the water is turbid and current rapid....several different tribes informed us that it heads at Mount Hood...1 April 1806

Clark's observations relative to the Sandy River and Mount Hood are pertinent to the Cowlitz River and Mount St. Helens in 1980 (above).

Quantitative measurements of the suspended-sediment concentration are few, but Clark makes this measurement downstream from the Kansas River:

...The water we Drink, or the Common water of the missourie at this time, contains half a Comn Wine Glass of ooze or mud to every pint...21 June 1804

and later they send back to Thomas Jefferson a sample described in the Fort Mandan Miscellany (Moulton, 1987, v. 3, p. 475) as:

25. Precipitate of one pint of Missouri water weight 80:65 grs

Upriver in North Dakota, *the Current of the Missourie is less rapid & contains much less Sediment* and the water of the Yellowstone *is turbid, tho' dose not possess as much sediment as that of the Missouri.* They observed some unusual type of suspended sediment near the Yellowstone River:

...more Pumice Stone & Lava washed down to the bottoms and some Pumice Stone floating in the river...17 April 1805

Samples of pumice stone were saved and sent back to Thomas Jefferson as samples 62 and 67 described in the Fort Mandan Miscellany as:

62 Specimen of the pummice Stone found amongst the piles of drift wood on the Missouri, Sometimes found as low down as the mouth of the osage river. I can hear of no burning mountain in the neighborhood of the Missouri or its Branches, but the bluffs of the River are now on fire at Several places, particularly that part named in our chart of the Missouri The Burning Bluffs. The plains in many places, throughout this great extent of open country, exhibit abundant proofs of having been once on fire— Witness the Speciments of Lava and Pummicestone found in the Hills near fort mandon—

67. A Speciment of Lava & pummice Stone found in great abundance on the Sides of the Hills in the Neighborhood of Fort Mandan 1609 miles above the mouth of the Missouri...The tract of Country which furnishes the Pummice Stone seen floating down the Misouri, is rather burning or burnt plains than burning mountains—

This pumice stone was a sample of sediment transported by the Missouri River and collected by Lewis and Clark.

Sample from Academy of Natural Sciences of Philadelphia (Pumice stone: Seybert Collection, 534; Spamer and others, 2000).

The Missouri River was probably one of the best rivers in which to observe bedload transport. Lewis and Clark first noted one reach in the lower Missouri in June 1804 as *one of the worst quick or moveing sand bars Which I have Seen.* A day later, Clark described sand waves and possibly antidunes that move upstream (page 58, "Riverbed Forms"):

...the river riseing, water verry Swift Passed a Creek on the L. S. passed between two Islands, a verry bad place, Moveing Sands, we were nearly being Swallowed up by the roleing Sands over which the Current was So Strong that we Could not Stem it with out Sales under a Stiff breese in addition to our ores...15 June 1804

...the Bows man Peter Crousat viewed The water on each Side of the Island which presented a most unfavourable prospect of Swift water over roleing Sands which rored like an immence falls...21 June 1804

Riverbed Forms

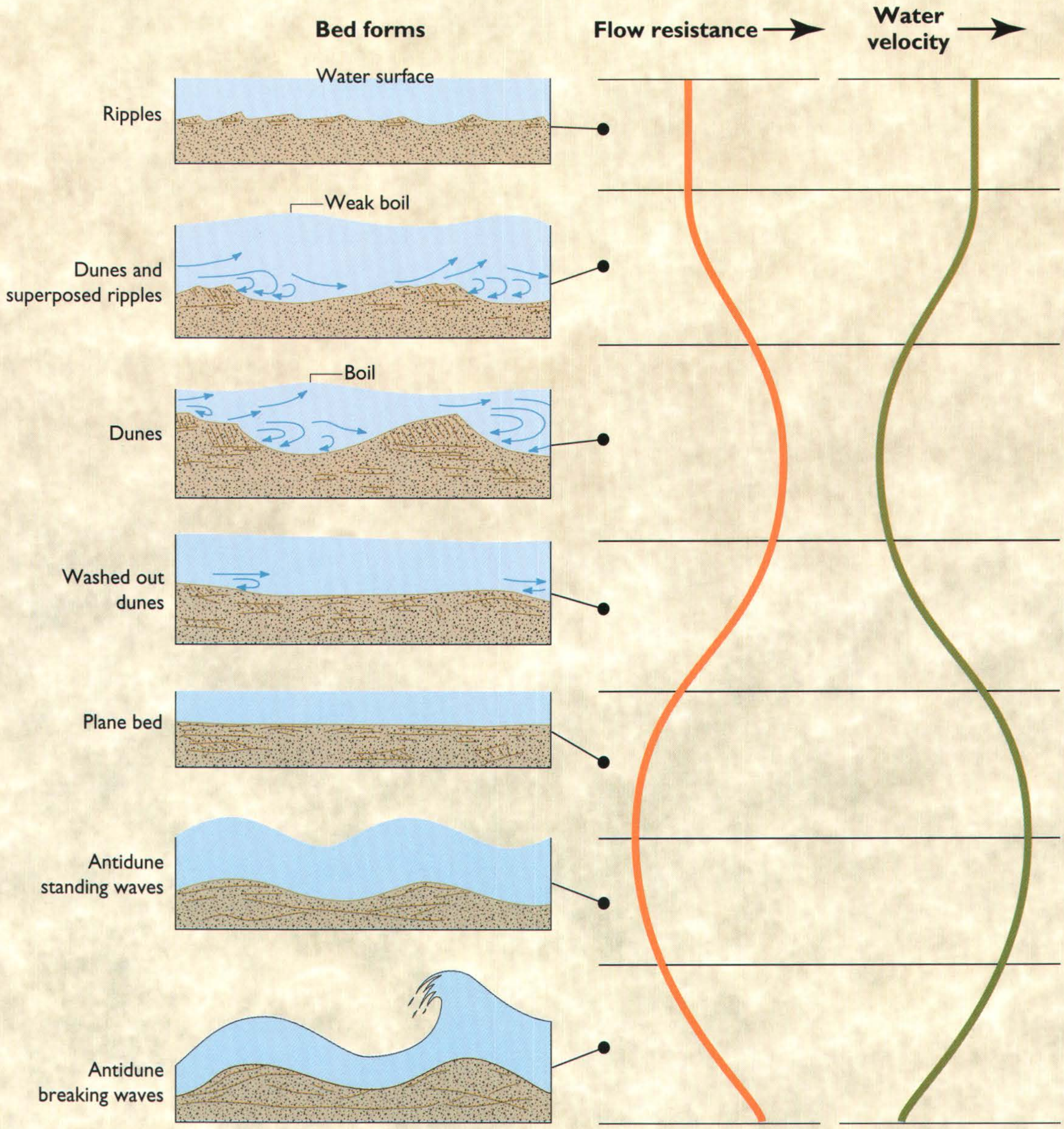
Classification of bed forms is based on particle size, the method of sediment transport, and the flow resistance created by the bed forms. Some studies were done by Simons and Richardson (1966) in flumes. Their results depended in some degree on the size of the flume but paved the way for later studies in the field.

Ripples are repetitive asymmetrical bed forms that have geometries related to the size of the material composing them (Yalin, 1972). They typically have heights that are small relative to the flow depth. The upstream surface (stoss side) of a ripple slopes gently upward to a crest, and the downstream surface (lee side) slopes steeply downward into the ripple trough. This pattern is repeated in a wavelike manner. Sediment rolls and hops up the gentle slope and avalanches down the steep lee side into the trough. Ripples do not affect the water surface above them. Some of the largest ripples (20 to 30 feet high and 200 to 300 feet apart) have been identified (Pardee, 1942; Weis and Newman, 1971) on the bottom of the ice age Lake Missoula. The ripples were formed about 12,000 years ago when Lake Missoula drained after the ice dam broke, releasing water at speeds of about 78 feet per second or 58 miles per hour and in water depths exceeding 800 feet (Allen and others, 1986).

Dunes also are repetitive asymmetrical bed forms, but in this case their heights are sufficient for them to interact with the surface of the water. This interaction, rather than their composition, sets their geometric properties. Dunes can grow up to one-third of the average flow depth (Mohrig and Smith, 1996), but more typically they have heights that are less than one-fifth of the water depth (J. Dungan Smith, oral communication, 1989). The dune form moves downstream as sediment is eroded from the gently sloping upstream side and deposited on the downstream side in the trough. Turbulence in rivers, initiated near the crests of the dunes, often rises to the water surface, creating boils that push the water surface slightly higher than the surrounding water.

Plane bed is flat and, depending upon the water velocity, sediment can be stationary or moving. Geomorphologists recognize both upper and lower plane-bed regimes. The former exists when grains move by rolling but not by saltation. The latter exists when all sizes of the sediment composing the riverbed go into suspension.

Antidunes are symmetrical bed forms that are coupled to the water surface. These features form when the sediment is transported as bedload and the mean velocity of the flow is approximately equal to the speed of surface waves such that the surface waves do not propagate upstream. The water is highest over the crest and lowest over the trough. Their heights and lengths depend on the mean flow velocity and the properties of the coupled surface wave. Antidune heights can equal about one-half the water depth. In contrast to dunes, sediment is deposited on the upstream sides and eroded from the downstream sides of antidunes such that the form of the antidune moves upstream or is stationary. The sediment always moves downstream. The antidunes grow until the associated surface waves reach the shapes at which they must break. The turbulence produced by breaking of the surface waves puts the very loosely compacted sediment composing the antidunes temporarily into suspension (J. Dungan Smith, written communication, 2002). The antidunes continue this cycle of forming, growing, and breaking as long as the flow velocity is greater than the speed of a surface wave.



Bed forms are shaped by flow resistance and water velocity in rivers.

Source: The bed forms shown in column 1 were adapted from Simons and Richardson (1966). The generalized plot of flow resistance shown in column 2 was adapted from Simons and others (1973).

One of the best places to observe bedload transport was at the mouth of the Platte River in the summer during high flow:

> *...The bed of the river Platte is composes almost entirely of white sand, the particles of which, are remarkably small and light; these collecting, from[form?] large masses, which being partially buoyed up, are hurryed along at the bottom by this impetuous torrent, with irresistible force; sometimes obstructed by each other, suddonly stop; and form large sandbars in the course of a few hours, which are again as suddenly dissipated to form others, and to give place perhaps to the deepest channel of the river...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 348.

Transport at the mouths of the Niobrara (*Que Courre*), White, Cheyenne, and Grand (*We tar hoo*) Rivers had similarities to and differences with that of the Platte River:

> *...passed the mouth of the River* [Niobrara] *Que Courre (rapid R) on the L. S. and Came to a Short distance above, this River is 152 yards wide at the mouth & 4 feet Deep Throwing out Sands like the Platt (only Corser) forming bars in its mouth...this river widens above its mouth and is devided by Sand and Islands, the Current verry rapid...the colour like that of the Plat is light,...4 September 1804*

> *...Capt Lewis and my Self went up this river* [White] *a Short distance and Crossed, found that this differed verry much from the Plat or que Courre, threw out but little Sand, about 300 yard wide, the water confind within 150 yards, the current regular & Swift much resemblig the Missourie, with Sand bars from the points a Sand Island in the mouth...15 September 1804*

> *...this river* [Cheyenne] *Comes in from the S W. and is about 400 yards wide, the Current appears gentle, throwing out but little Sands...1 October 1804*

> *...passed the mouth of a River* [Grand] *called by the ricares We tar hoo on the L. S. this river is 120 yards wide, the water of which at this time is Confined within 20 yards, dischargeing but a Small quantity, throwing out mud with Small propotion of Sand...8 October 1804*

Draining the sand hills of central and western Nebraska, the Platte River and its tributaries and the Niobrara River later became, in the tradition of Lewis and Clark, outdoor laboratories for the study of bedload transport. The high proportion of sand relative to other sizes and the shallowness of the rivers made bedload transport particularly accessible to scientific and engineering studies (Colby and others, 1953; Hubbell and Matejka, 1959; Sayre and Hubbell, 1965; Smith, 1970, 1971; Williams, 1978; Eschner and others, 1983; Karlinger and others, 1983; Kircher, 1983; and Mohrig and Smith, 1996).

DEPOSITION

Observations of bank erosion and deposition on point bars downstream have been described above (page 36, "Riffle Formation"). Generally, at high flows in the spring and early summer, the Platte and some other tributaries deposited sediment into the Missouri River channel which fed the notorious sandbars and islands downstream. At other times the larger river created backwater conditions and deposited sediment into the mouths of tributaries:

> ...*The Mississippi when full throws large quantitys of mud into the mouths of these rivers whose courents not being equal to contend with it's power become still or eddy for many miles up them the mud is thus deposited and as they are but comparitively short their courents subside before that of the Mississippi which when it dose subside and leave them free to act they have so small a quantity of water to discharge that it finds it's way to the river in a very small channel which it cuts through this mud; thus in a manner conscealing their magnitude from the passanger along the main river...25 November 1803*

> ...*after a delay of two hours we passed a narrow channel of 45 to 80 yds wide five miles to the mouth of (3) Nadãwã River, This river Coms in from the North and is navagable for Perogues Some distance. it is about 70 yards wide a little above the mouth, at the mouth not So wide, the mud of the Gut running out of the Missourie is thrown and Settles in the mouth...8 July 1804*

These last two journal entries describe one of many processes that are recognized today as flood-plain-forming depositional processes. Eolian transport (Bagnold, 1954) is another and deposits sediment on the flood plain downwind from the river. Vertical accretion (Schumm and Lichty, 1963; Moody and others, 1999) deposits sediment on sandbars and snags and on the banks when they are *liable some times to be overflowed*. Lateral accretion (Wolman and Leopold, 1957; Nelson and Smith, 1989) was yet another process described above as *Sand* that

Photo: USGS

The Missouri River at the confluence of the Niobrara River, Nebraska *lodges* on point bars and builds flood plains at the same time *the banks are falling in from the Current being thrown against those bends by the Sand points* and the flood plain is recycled, moving the river and its flood plain laterally and downriver across the meander belt. Throughout the regional landscapes traversed by Lewis and Clark, their observations indicated that they saw the Missouri as a dynamic river which *has Changd its Bead at different times and has onced run and now filled, up & growing with willows & Cottonwood with traces of the ancient beds of the river are visible in many places through the whole extent of this valley.*

III

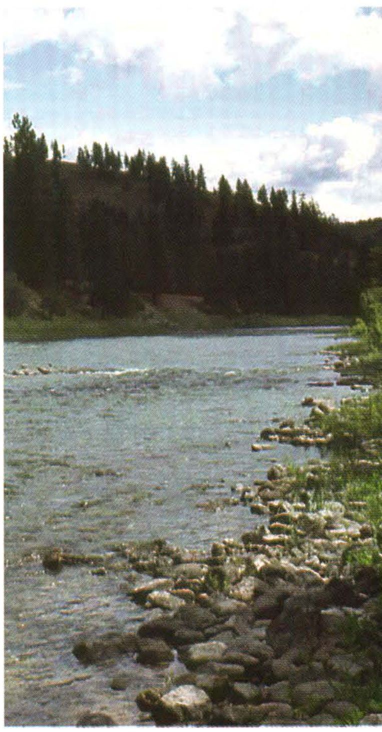
Hydrology

LEWIS and Clark measured the rise and fall of rivers, which can be related in some situations to their temperature measurements. For many streams and rivers they recorded the navigability, water color, saltiness, and the size of the bed material. They accurately measured the width of most streams they encountered, from 4 yards to more than 1,000 yards. They probably made the first velocity measurements of most of the major rivers they encountered and provided some of the first descriptions, excellent even by modern standards, of turbulent processes in these rivers. Part of Thomas Jefferson's instructions to Lewis stated that:

> *...The object of your mission is to explore the Missouri river, & such principal stream of it, as, by it's course & communication with the waters of the Pacific Ocean...*(Bergon, 1989)

Runoff

Lewis and Clark took initiative and expanded Jefferson's instructions to include observations of basic hydrology. This included measurements of the stage of the rivers over time to produce hydrographs (page 68). They made inferences about the relations between precipitation and runoff shown by the hydrograph—a basic hydrologic topic that is still being studied today. Lewis and Clark's observations of the hydrology provide us today with insight into the natural characteristics of many western rivers before these rivers were altered and controlled by engineering projects. They made observations, measurements, and inferences relative to different types of runoff: snowmelt in the mountains of Idaho, rain-on-snow phenomena creating flash floods, ice breakup on the Missouri and Mississippi Rivers, and summer thunderstorm rainfall and runoff.



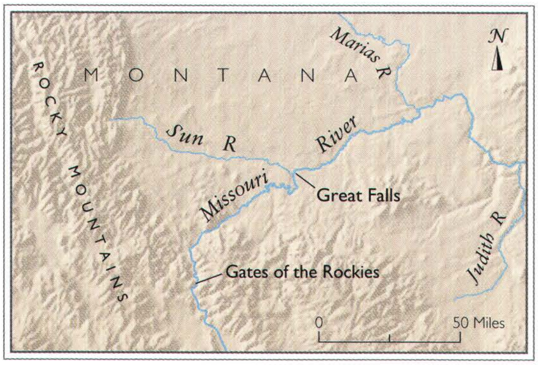
Blackfoot River in Montana

Photo: USGS

SNOWMELT

They first made inferences about snowmelt based on the characteristics of the channel of the Sun River (*Medecine River*) just above the Great Falls:

> *...medecine river, found it a handsome stream, about 200 yds. wide with a gentle current, apparently deep, it's waters clear, and banks which were formed principally of darkbrown and blue clay were about the hight of those of the Missouri or from 3 to 5 feet; yet they had not the appearance of ever*



being overflown, a circumstance, which I did not expect so immediately in the neighbourhood of the mountains, from whence I should have supposed, that sudden and immence torrents would issue at certain seasons of the year; but the reverse is absolutely the case. I am therefore compelled to beleive that the snowey mountains yeald their warters slowly, being partially effected every day by the influence of the sun only, and never suddonly melted down by haisty showers of rain...14 June 1805

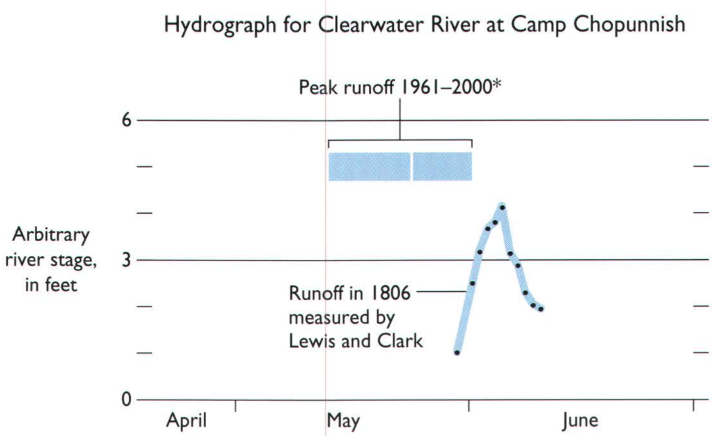
and later they recorded in their weather logs (below) the snowmelt runoff firsthand while waiting at Camp Chopunnish on the Clearwater River for the snow to melt in the Rocky Mountains during June of 1806:

...the river raised 6 inches in the course of yesterday and 1 foot 5 I. in the course of the last night. it is now as high as there are any marks of it's having been in the spring 1805.— at 10 A. M. it arrived at it's greatest hight having raised 11/ 2 inches from sunrise to that time. in the ballance of the day it fell 7 inches. the natives inform us that it will take one more rise before it begins finally to subside for the season and then the passage of the mountains will be practicable...29 May 1806

...from sunset on the 31st of May untill sun rise on the 1st of June it rose Eighteen inches and is now as high as any marks of it's having been for several years past...31 May 1806

...the Indians inform us that the present rise of the river is the greatest which it annually takes, and that when the water now subsides to about the hight it was when we arrived here the mountains will be passable. I have no doubt but that the melting of the mountain snows in the begining of June is what

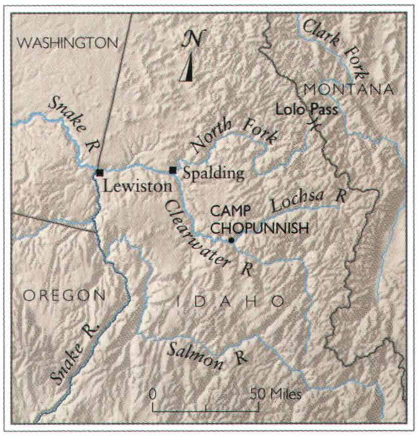
The hydrograph shows the 1806 snowmelt peak occurring two weeks later than the median date of the peak runoff.



*The vertical white bar is the median, May 24. The ends of the box are the 25th and 75th percentiles corresponding to May 13 and June 1. The earliest and latest days for the peak runoff are April 21 and June 20.

causes the annual inundation of the lower portion of the Missouri from the 1st to the Middle of July...2 June 1806

...the river fell 31/2 inches in the course of the day and raised 4 I. last night as [s]tated in the diary. this fluctuating state of the river no doubt caused by the influence of the sun in the course of the day on the snows of the mountains; the accession of water thus caused in the day dose not reach us untill night when it produces a rise in the river...5 June 1806



While they waited, they measured the stage of the Clearwater River from May 30 through June 10 and observed the peak that occurred on June 5. Based on data for 1961 through 2000 (opposite), the average date for the peak runoff at a gaging site (Clearwater River at Spalding, Idaho) downstream from Camp Chopunnish was May 24. Thus, in 1806 the snowmelt runoff was almost 2 weeks later than the present-day median date. This does not reflect a change in climate but simply the variability of the weather. Lewis and Clark encountered a later than usual snowmelt, even for the early 1800s. It is also possible that they encountered a second snowmelt peak (see 29 May 1806 excerpt). This is common for the Clearwater River and may be a result of snowmelt from different elevations within the Clearwater basin (Steve Lipscomb, written communication, 2002).

RAIN ON SNOW

Once again Lewis and Clark made a conjecture about the hydrology based on the character of the river channel:

...passed three streames today which discharged themselves on the Lard. side; the first of these we call little dry creek it contained some water in standing pools but discharged none, the 2ed 50 yards wide no Water, we called it Big dry Creek, the 3rd is bed of a conspicuous river 200 yards wide which we called little dry river; the banks of these streams are low and bottoms wide with but little timber, their beds are almost entirely formed of a fine brown sand intermixed with a small proportion of little pebbles, which were either transparent, white, green, red, yellow or brown. these streams appeared to continue their width without diminution as far as we could perceive them which with rispect to the river was many miles, they had recenly discharged their waters. from the appearance of these streams, and the country through which they passed, we concluded that they had their souces in level low dry plains...that the rains in the spring of the year <in a few day> suddonly melts the snow at the same time and causes for a few days a vast quantity of water which finds it's way to the Missouri through those channels...6 May 1805

These dry channels, in what is now Montana, were features unexpected by Lewis and Clark who, like most Americans of that time, were accustomed to eastern rivers that usually flowed all year and in which the flow usually increased downstream:

...today we passed the bed of the most extraordinary river that I ever beheld. it is as wide as the Missouri is at this place or 1/2 a mile wide and not containing a single drop of runing water; some small standing pools being all the water that could be perceived. it falls in on the Lard. side. I walked up this river about three miles...the bank are low and abbrupt, seldom more than 6 or eight feet above the level of the bed, yet show but little appearance of being overflown...it had the appearance of having recently discharged it's waters; and from the watermark, it did not appear that it had been more than 2 feet deep at it's greatest hight...9 May 1805

...Those dry Streams which are also verry wide, I think is the Conveyance of the melted Snow, & heavy rains...9 May 1805

...this we call Teapot Creek, it affords no water at it's mouth but has runing water at some small distance above, this I beleive to be the case with many of those creekes which we have passed since we entered this hilley country, the water is absorbed by the earth near the river and of course appear dry; they afford but little water at any rate...23 May 1805

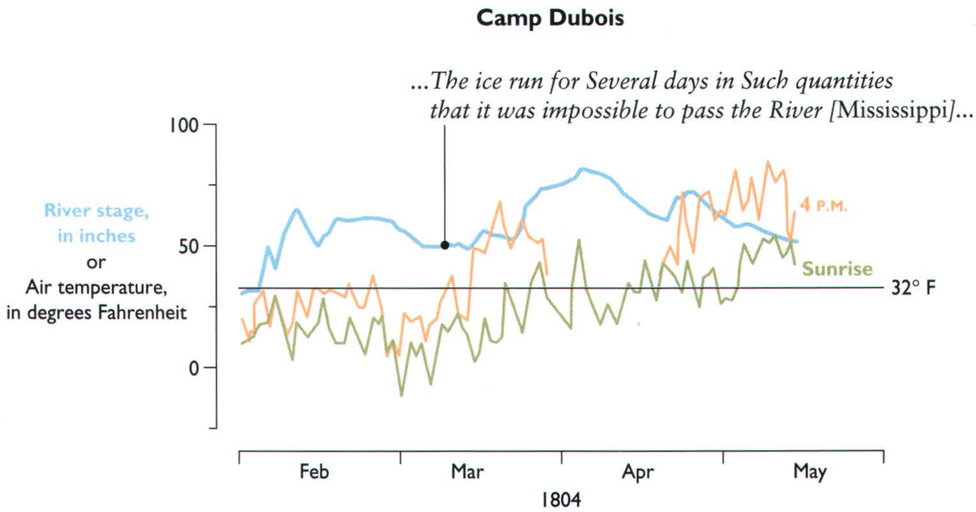
ICE BREAKUP

While the expedition was at Camp Dubois opposite the mouth of the Missouri River, Clark measured air temperature, river stage, and ice conditions on the Missouri and Mississippi Rivers. *Running Ice* was observed on Thursday December 22, 1803, on the Mississippi River, which seems to have been frozen over by January 4, 1804:

...a Cold Clear morning, the river Covered with Ice from the Missouri, the Massissippi above frosed across, the Wind from the West, The Thermometer this morning at 19° below freesing...4 January 1804

This ice jam on the Platte River (February 2003) is probably typical of the ones observed by Lewis and Clark.

Photo: Nebraska Department of Natural Resources



Measurements of air temperature, river stage, and ice conditions at Camp Dubois opposite the mouth of the Missouri River shows how fluctuation in the weather often causes flutuation in river stage and ice conditions.

Temperature measurements were made carefully. The thermometer was put on the N. *Side of a large tree in the woods* and they described their methods in their weather log of January 1804 (Moulton, 1986, v. 2, p. 169):

> *...By two experiments made with Ferenheit's Thermometer which I used in these observations, I asscertained it's error to be 11° too low or additive +- I tested it with water and snow mixed for the friezing point, and boiling water for—the point marked boiling...*

Absolute temperatures are uncertain, but relative temperatures would be reliable. They measured the temperature twice each day, at sunrise and at 4 P.M. In January 1804, they begin to record this and other weather observations and river changes in a weather log for each month. During the last 4 days in January the temperature at sunrise averaged 13.2°F and at 4 P.M. it averaged 18°F. The ice conditions from January 28 to January 31, 1804, were:

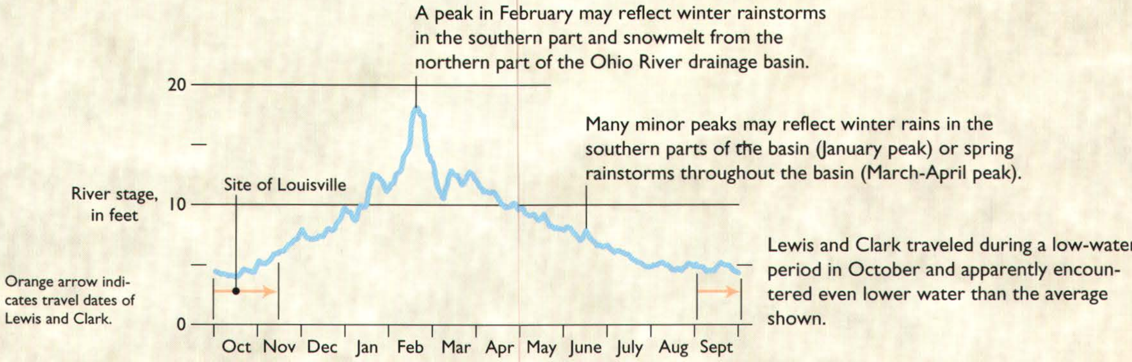
> *...Some floating Ice in the River...*
>
> *...the river rise a little no Ice...*
>
> *...but little Ice running this morng...*
>
> *...some Ice running this morning...*

Based on their measurements, fluctuations in the weather often caused fluctuations in river stage and also the ice conditions (above).

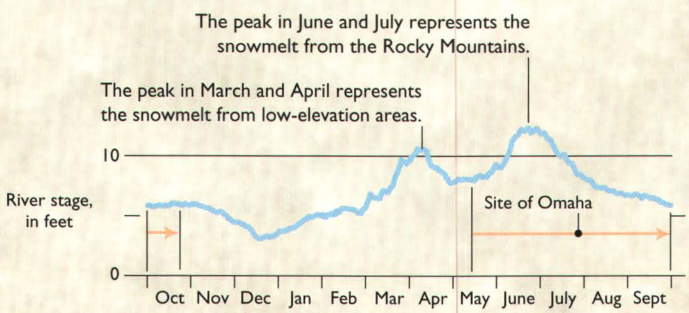
River Hydrographs

The annual hydrograph is a plot of the stage or discharge of the river through the year. The hydrographs for the Ohio, Missouri, and Columbia Rivers are different because they drain different precipitation regimes. Stage is measured above some fixed datum (local or sea level) and indicates the height of the water but is not equal to the depth. In general, the mean velocity of the river is not directly proportional to the depth, but it is proportional to the discharge at a fixed location.

Average annual stage hydrograph for the Ohio River at Louisville, Kentucky (1876–1895)

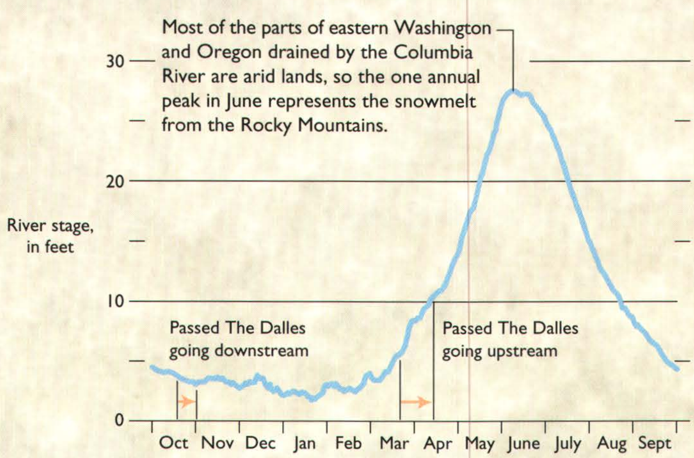


Average annual stage hydrograph for the Missouri River at Omaha, Nebraska (1931–1950)



Lewis and Clark were at Camp Dubois during the first peak, which was associated with the ice breakup. They struggled upstream against the second peak and arrived at Council Bluffs just upriver from what would be the city of Omaha about July 28, 1804. Low water is in October and November, and Lewis and Clark encountered this part of the annual hydrograph while traversing between what are now Pierre, South Dakota, and Bismarck, North Dakota, from about September 15 to October 27, 1804.

Average annual stage hydrograph for the Columbia River at The Dalles, Oregon (1879–1896)



The Dalles is on the eastern side of the Cascades, so the prolonged winter rains that Lewis and Clark endured at Fort Clatsop at the mouth of the Columbia River are not part of this hydrograph. Lewis and Clark entered the Columbia River at the mouth of the Snake River on October 18, 1805, passed The Dalles on about October 24, 1805, and reached the tidewater area of the Columbia River a few days later.

Temperatures rose from the end of January until mid-February, and the river stage rose bringing increasing quantities of ice. They listed the conditions from February 4 through February 6, 1804, as:

> *...the River Covered with large Sheetes of Ice from both rivers...*
>
> *...emmence quantities of ice runing some of which 11 Inches...*
>
> *...river riseing & Covered with Small Ice...*

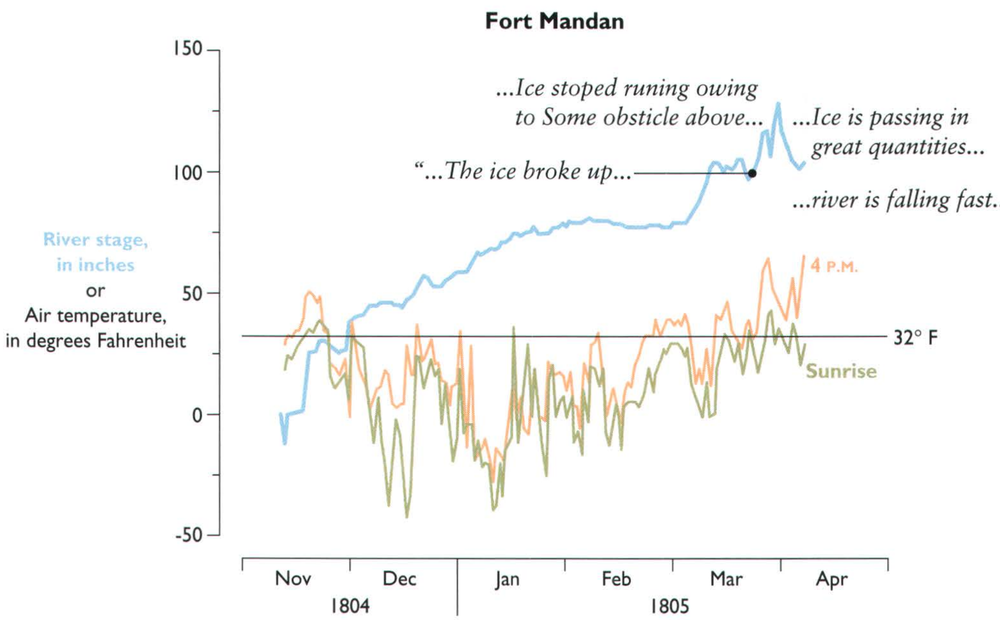
and with the sudden rise on February 9, 1804:

> *...the river raised 2 feet, large quantity of drift ice from Misso*[uri]...

Then the temperature in February decreased, the stage decreased, but no ice observations were recorded in the weather log. An increase in temperature in mid-March probably resulted in the spring ice breakup because the stage reached a maximum and then decreased rapidly (page 67). From the Weather Log on March 19, 1804:

> *...the ice run for Several days in Such quantities that is was impossible to pass the River* [Mississippi]...

Lewis and Clark repeated these ice observations and measurements during the winter of 1804–05 at Fort Mandan. On October 31, 1804, Lewis noted that *the river being very low and the season so far advanced that it frequently shuts up with ice in this climate.* By November 13, *the river has every appearance of closing for winter*, and the weather log again showed daily river changes and temperatures at sunrise and 4 P.M (below). For the Missouri River near Fort Mandan, where the



The following winter measurements were repeated at Fort Mandan on the Missouri River. Starting in late November there is a drop in temperature and unexplainable rise in stage. By mid-March the breakup of the ice corresponds to the temperature rising above 32°F.

temperature was much colder (−43°F at sunrise on December 17, 1804), the river stage does not appear correlated with air temperature. Without knowing exactly where the stage was being measured and how that water was connected to the main channel, one cannot explain why the river stage should increase while the temperature was generally decreasing during January 1805. However, as the temperature rose above freezing, the river stages definitely increased, resulting in the ice breakup followed by an ice jam:

...The ice broke up in Several places in the evenig broke away and was nearly takeing off our new Canoes...25 March 1805

...river choked up with ice opposit to us...the ice gave way in the river about 3 P. M. and came down in immense sheets very near distroying our perogues...26 March 1805

...ice running the [river] *Blocked up in view for the Space of 4 hours and gave way leaveing great quantity of ice on the Shallow Sand bars...27 March 1805*

...the ice Stoped running owing to Some obstickle above...28 March 1805

on March 29, 1805:

...The obstickle broke away above & the ice came dow in great quantites the river rose 13 inches the last 24 hours...

on March 31, 1805, *...not much ice floating...*, and finally on April 2, 1805, Clark noted that *the river is falling fast.*

River Characteristics

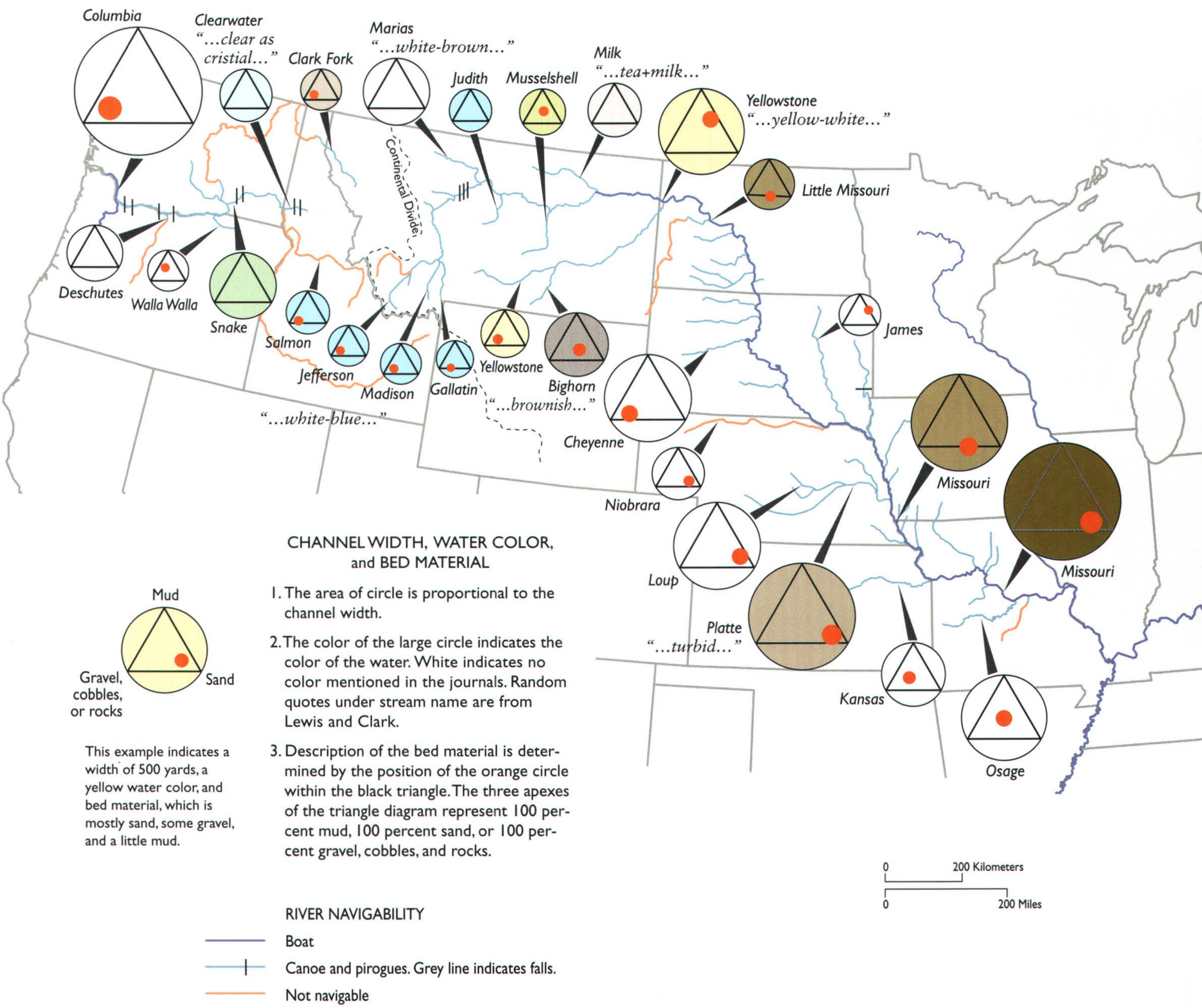
NAVIGABILITY, COLOR, BED MATERIAL

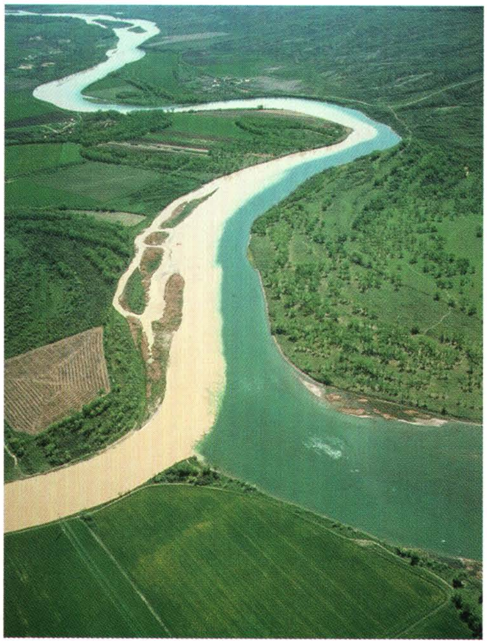
Navigability of the rivers was uppermost in the minds of Lewis and Clark. They described this river characteristic (opposite page) in terms of the type of water craft (boat, bateau, pirogue, or canoe) that could navigate the river; the distance upstream in miles, leagues, or to a landmark; and in some cases the depth of the water in feet.

*...the yellow Stone river is navigable at all seasons of the year, for boats or perogues to the foot of the Rocky Mountains, near which place, it is said to be not more than 20 miles distant from the most southernly of the three forks of the Missouri, which last is also navigable to this point. if Indian information can be relied on, this river waters one of the fairest portions of Louisiana...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 364.

River color was apparently not noteworthy for the eastern tributaries (generally east of 100th meridian), but the color of western tributaries seems to have had

Navigability, channel width, water color, and bed material for some rivers observed by Lewis and Clark.





This view (April 1999) looking downstream shows the confluence of the Milk and Missouri Rivers in Montana. The water of the Milk *"... possesses a peculiar whiteness"*.

Airphoto-Jim Wark

enough variation to have caught their eyes when they passed and explored them. It often gave them clues to the source of a river (page 7, 3 June 1805 and page 9, 29 July 1806).

...the water of this river possesses a peculiar whiteness, being about the colour of a cup of tea with the admixture of a tablespoonfull of milk. from the colour of it's water we called it Milk river...8 May 1805

...the otter are now plenty since the water has become sufficiently clear for them to take fish...12 July 1805

They also noted the location of salt springs and licks. This was again according to Jefferson's instructions to include "Other object worthy of notice will be...salines & mineral waters" (Bergon, 1989):

...this River [Petite Saline Creek in Missouri] *is about 30 yds. wide, and has So many Licks & Salt Springs on its banks that the Water of the Creek is Brackish, one Verry large Lick is 9 ms. up on the left Side the water of the Spring in this Lick is Strong as one bushel of the water is said to make 7 lb. of good Salt...6 June 1804*

...the water of those Springs are not Strong, Say from 4 to 600 Gs. of water for a Bushel of Salt...7 June 1804

...The Waters of this river is Clear, and a Salmon may be Seen at the deabth of 15 or 20 feet...17 October 1805

and the temperature of the water:

...the Fog appears to owe it's orrigin to the difference of temperature between the air and water the latter at this seson being much warmer than the former; the water being heated by the summer's sun dose not undergo so rapid a change from the absence of the sun as the air dose consiquently when the air becomes most cool which is about sunrise the fogg is thickest and appears to rise from the face of the water like the steem from boiling water...1 September 1803

...Verry foggy this morning. Thermometer 63° Ferrenheit, immersed the Thermometer in the river, and the murcury arose immediately to 75° or summer heat so that there is 12° difference is sufficient to shew the vapor which arrises from the water...3 September 1803

...Morning foggy, obliged to wait. Thermometer at 63°— temperature of the river- water 73° being a difference of ten degrees, but yesterday there was a difference of twelve degrees, so that the water must have changed it's temperature 2d in twenty four hours, coalder; at 1/4 past 8 the murcury rose in the open air to 68° the fogg dispeared and we set out; the difference therefore of 5° in temperature between the warter and air is not sufficient to produce the appearance of fogg...4 September 1803

...Thermometer in the air to stand at 71° water 73°—the fogg continued even with small difference between the temperature of the air and water...6 September 1803

In the Rocky Mountains, they used temperature to determine the expedition's route:

...it's [Beaverhead River] *water is much warmer then the rapid fork* [Big Hole River] *and it's water more turbid; from which I conjecture that it has it's sources at a greater distance in the mountains and passes through an opener country than the other. under this impression I wrote a note to Capt Clark, recommending his taking the middle fork povided he should arrive at this place before my return, which I expect will be the day after tomorrow. this note I left on a pole at the forks of the river...4 August 1805*

and the character of the country:

...The water of this river [Tongue River] *is nearly milk worm very muddy and of a dark lightish brown Colour...tho' I believe that the Country back thro'*

This view (May 1999) looking upstream shows the confluence of the Yellowstone and Missouri Rivers in Montana. The Yellowstone is *"navigable at all seasons of the year, for boats or perogues to the foot of the Rocky Mountains"*.

Airphoto-Jim Wark

This view of the Missouri River looks southeast just north of Bismarck, North Dakota.

Photo: USGS, 2001

which this river passes is an open one where the water is exposed to the Sun which heats it in its passage...29 July 1806

Lewis and Clark collected a sample of bed material which was sent back to Jefferson in 1805 (Moulton, 1987, v. 3, p. 472). This sample, along with other mineral samples, may have reached the Academy of Natural Sciences in Philadelphia, Pennsylvania. Over the years, many samples apparently lost their labels; consequently, they were thrown out. Two samples remain: a piece of slag and a piece of pumice (page 57). Lewis and Clark also described the bed material of many rivers. For example, they used the bed-material characteristics to predict the character of the country surrounding the Little Missouri River:

...the colour of the water, the bed of the river, and it's appearance <of this river> in every respect, resembles the Missouri; I am therefore induced to believe that the texture of the soil of the country in which it takes it's rise, and that through which is passes, is similar to the country through which the Missouri passes...12 April 1805

and remarked on the downstream fining of bed material in the Yellowstone River:

...the bed of this river is almost entirely composed of loose pebble, nor is it's bed interrupted by chains of rock except in one place and that even furnishes no considerable obstruction to it's navigation. as you decend with the river from the mountain the pebble becomes smaller and the quantity of mud increased untill you reah Tongue river where the pebble ceases and the sand then increases and predominates near it's mouth...3 August 1806

Clark made the observation but did not conjecture why the size of the material decreased in the downstream direction. Frisi (1762) mentioned that Guglielmini felt the size decreases because "stones, impelled by the impetuosity of the water, rolling over and striking each other, must break and continually wear away." However, Frisi reflects a still-persistent religious opinion in the 18th century "that round stones, gravels, and sands, are substances originally prepared by nature, and spread all over the globe." Later observers of downstream fining of sediment in rivers have also concurred with Guglielmini's idea of abrasion (Shaw and Kellerhals, 1982). Others have proposed the selective transport of finer grains (Paola and Seal, 1995) and finer input by tributaries downstream (Pizzuto, 1995). In the Yellowstone River, however, it is difficult to attribute downstream fining to any process of progressive hydraulic sorting of coarser materials introduced in the upper river basin because of the continual introduction of gravels from the erodible terrace deposits that flank much of the course of the river.

Hydraulic Geometry

Lewis and Clark measured and noted the channel widths of virtually every stream they encountered—many more streams than those for which they listed the navigability, color, or bed material. Their measurements were of bankfull width—the channel width from bank to bank—and not just measurements of the width of the mouth or of the water. Lewis and Clark seemed to have realized that there was a great variability of discharge and perhaps cogitated on which discharge was important in determining channel geometry.

...I measure the river from bank to bank on the ice and make it 500 yards...12 December 1804

Lewis and Clark often explored tributaries some distance upstream to determine their true character:

> *...I walked on shore and acended this river about a mile and a half in order to examine it. I found this river about 100 yds. wide from bank to bank, the water occupying about 75 yard...Cap. C who assended this R. much higher than I did has <thought proper to> call it Judieths River...29 May 1805*

> *...This morning I dispatched Joseph Fields up the yellowstone river with orders to examine it as far as he could conveniently and return the same evening;..the bottom land on the lower side of the yellowstone river near it's mouth for about one mile in width appears to be subject to inundation...the bed of the yellowstone river is entirely composed of sand and mud, not a*

> *stone of any kind to be seen in it near it's entrance. Capt Clark measured these rivers just above their confluence; found the bed of the Missouri 520 yards wide, the water occupying 330. it's channel deep. the yellowstone river including it's sandbar, 858 yds. of which, the water occupyed 297 yards, the depest part 12 feet; it was falling at this time & appeard to be nearly at it's summer tide...26 April 1805*

Often along the Missouri River, they clearly differentiated between flood-plain width, bankfull width, and the width of the water surface:

> *...this river* [Moreau River in South Dakota] *whin full is 90 yards wide the water is at this time Confined within 20 yards...I walked up this river a mile...7 October 1804*

> *...(2) passed the mouth of a River called by the ricares We tar hoo* [Grand River in South Dakota] *on the L.S. this river is 120 yards wide, the water of which at this time is Confined within 20 yards...8 October 1804*

> *...passed the mouth of (1) la Boulet (or Cannon Ball River) about 140 yards wide on the L. S....above the mouth of this river Great numbers of Stone perfectly round with fine Grit are in the Bluff and on the Shore, the river takes its name from those Stones which resemble Cannon Balls.— The water of this river is Confined within 40 yards...18 October 1804*

and along the Yellowstone River:

> *...draw up the Canoes and take Shelter in an old Indian Lodge above the enterance of a river which is nearly dry it has laterly been very high and Spread over nearly 1/4 a mile in width. its Chanel is 88 yards and in this there is not more water than could pass through an inch auger hole. I call it Yorks dry R....after the rain and wind passed over I proceeded on at 7 Miles passed the enterance of a river* [Powder River] *the water of which is 100 yds wide, the bead of this river nearly 1/4 of a mile this river is Shallow and the water very muddy and of the Colour of the banks a darkish brown. I observe great quantities of red Stone thrown out of this river that from the appearance of the hills at a distance on its lower Side induced me to call this red Stone river...30 July 1806*

Of the later writers who remarked on this phenomenon, most notable is perhaps Struthers Burt, who wrote of the Powder River:

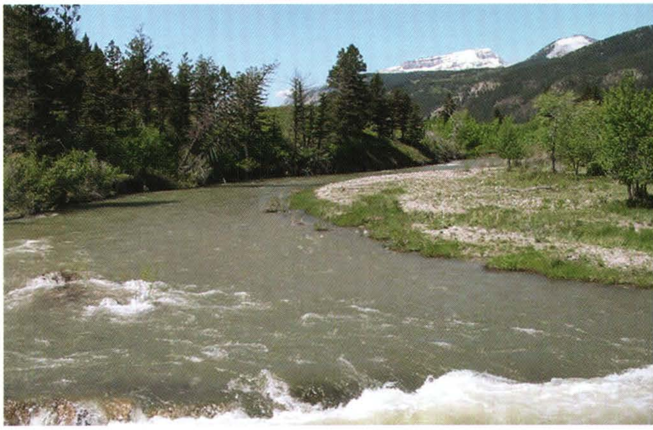
> "A mile wide and an inch deep is the acidly affectionate description used by those who are its intimates, and although the Powder is by no means a mile wide, and although it is considerably over an inch deep, the phrase possesses the exaggerated truth common to folk descriptions; an exaggerated truth conveying a picture clearer than exactness." (Burt, 1938)

Lewis and Clark recognized seasonal effects in the spring of 1805:

> ...*we found that it* [White Earth River or Little Muddy River] *contained more water than streams of it's size generally do at this season. the water is much clearer than that of the Missouri. the banks of the river are steep and not more than ten or twelve feet high; the bed seems to be composed of mud altogether. the salts which have been before mentioned as common on the Missouri, appears in great quantities along the banks of this river, which are in many places so thickly covered with it that the appear perfectly white. perhaps it has been from this white appearance of it's banks that the river has derived it's name...22 April 1805*

and again in 1805:

> ...*passed Dearborne's river at 3 m. this stream comes form the S. W. out of the mountains which are about 5 Ms. to our left. the bed of the river is about 100 yds. wide tho' the water occupys only about 30 yds. it appears to spread over it's bottoms at certain seasons of the year and runs a mear torrant tearing up the trees by the roots which stand in it's bottom...18 July 1805*



The Dearborn River, Montana runs high during spring runoff.

Photo courtesy of Big Sky Fishing.Com

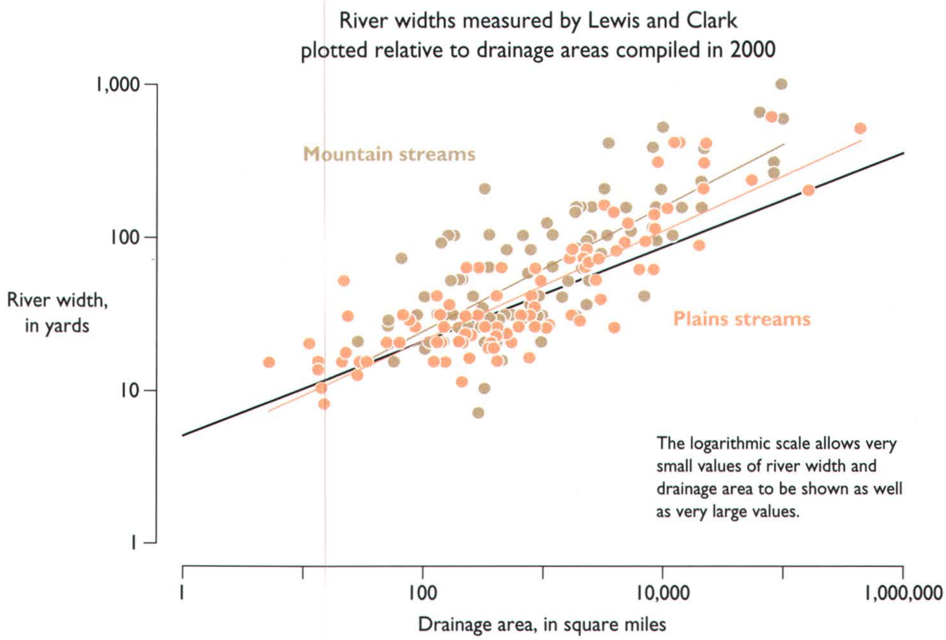
After more than a year in the field measuring and describing river channels, Clark took an evening walk and essentially inferred a relation between the *Size* or width of the rivers he had been measuring and the drainage area of those rivers or the *extent of country*. His observations suggest a relation between the drainage area and the *quantity of water* or discharge of the river:

> ...*I continued my walk on Shore after dinner, and arrived at the mouth of a river on the St. Side, which appeared to be large, and I concluded to go up this river a few miles to examine it accordingly I Set out North 1 mile thro wood or timbered bottom, 2 miles through a butifull leavel plain, and 1 mile over a high plain about 50 feet higher than the bottom & Came to the little river, which I found to be a butifull clear Stream of about 100 yds. from bank to bank, I waded this river at the narrowest part and made it 112 Steps from bank to bank...This river we call Porcupine from the great number of those anamals found about it's mouth....This river from its Size & quantity of water must head at no great distance from the Saskashawan...3 May 1805*

and later a similar inference about the Milk River

> ...*from the quantity of water furnised by this river it must water a large extent of country; perhaps this river also might furnish a practicable and advantageous communication with the Saskashiwan river...8 May 1805*

After a year of measuring rivers, Clark inferred a relation between the width of rivers and the drainage area. His inferences were confirmed 150 years later as shown by the black-line based on data from Leopold and Maddock (1953) and Hack (1957).



Lewis and Clark measured the widths but did not have actual drainage areas to test the relation that they were using to infer the *extent of country*. They made about 275 width measurements of rivers, streams, and creeks ranging from 4 to 875 yards. Some of the larger rivers (Missouri, Yellowstone, and Columbia) were measured in several locations. Drainage areas were compiled in 2000 for 191 of these rivers from published reports and from maps with scales of 1:250,000, 1:500,000, and 1:3,500,000. Some of the smaller streams and creeks could not be identified with present-day streams and creeks, so the drainage area was not determined. The data were divided into two groups: presumably low-gradient or plains channels (downstream from the mouth of the Yellowstone River) and high-gradient or mountainous channels (upstream from the mouth of the Yellowstone River and those rivers in the Columbia River Basin). The relations for the plains and mountainous channels were basically the same (see graph above). The relation for plains channels was

$$\text{width} = 4.0 \times \text{drainage area}^{0.36},\ R^2 = 0.71$$

and the relation for the mountainous channels was

$$\text{width} = 3.6 \times \text{drainage area}^{0.41},\ R^2 = 0.60$$

where the width is in yards, the drainage area is in square miles, and R^2 is the coefficient of determination. About 150 years after Lewis and Clark's measurements, Leopold and Maddock (1953) and Hack (1957) confirmed these inferences with published data. Leopold and Maddock (1953) list 105 measurements (some of which were the same channels measured by Lewis and Clark) and Hack lists 91 measurements (for mostly small streams in Virginia and Maryland). The plot of their combined 196 measurements is similar to the plot of the Lewis and Clark data (black line in graph opposite); the relation for their combined data is also similar:

$$\text{width} = 4.8 \times \text{drainage area}^{0.31},\ R^2 = 0.75$$

Velocity Measurements

The velocity of the Missouri River was an immediate concern to Lewis and Clark as they worked upstream against the current created by the annual spring runoff. Many journal entries give qualitative measures of the velocity of the current. They begin on May 15, 1804, as Lewis and Clark entered the mouth of the Missouri River, and no two entries are identical:

> *...the water excessively rapid...verry hard water...the water excessively Swift to day...the Currents verry Swift...the current exceedingly rapid...Some Swift water...we found the water excessively hard for 12 Miles...the Current exceedingly Strong...the immence Current & falling banks on the S.S...water very swift...15 May to 15 June 1804*

Clark made the first quantitative measurements of the velocity while some of the expedition were making tow ropes at Rope Walk Camp:

> *...The Current of the River at this place is a Stick will float $_4$8 poles 6 feet in the rapidest part in 23 Seconds, further out is 34, Still further 65—74—78 & 82 are the Trials we have made...17 June 1804*

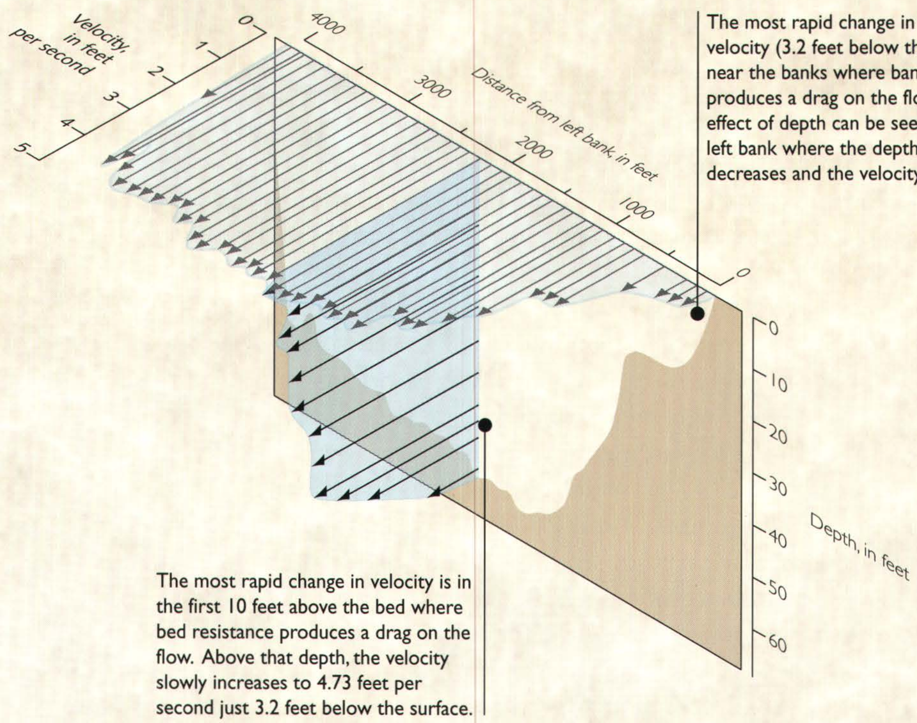
Unfortunately, it is not entirely clear if he meant 48 pole and 6 feet or 4.8 pole and 6 feet or perhaps 48 fathoms as mentioned below. If the first option of 48 poles 6 feet is used, then the total distance would have been 798 feet and the velocity would have been 23.6 mph (miles per hour), which is unreasonable even for the Missouri River. Clark in previous measurements would write the tenths of a pole as 8/10; however, if it is 4.8 poles and 6 feet then the velocity of the river is 3.7 ft/s or 2.5 mph, which is reasonable but perhaps on the slow side. If one assumes the third option, 48 fathoms (and the 6 feet was meant to define a fathom), then the velocity is 18.4 ft/s or 12.5 mph. Later measurements were made by the U.S. Geological Survey at Waverly, Missouri (1928–30), which is near the site of Clark's measurements (Dale Blevins, written communication, 2002). The maximum velocity was 12.5 ft/s corresponding to a discharge of about 230,000 ft^3/s so that the third option seems possible. A possible argument against 48 fathoms is that Clark mentions *a Stick will float* rather than using a logline (as he does later), so he may have made measurements from the shore where he would probably measure in poles (a land unit of measure) rather than in fathoms (a nautical unit of measure). We will

River Velocities

River velocities depend upon the slope of the channel, the depth of water, and the roughness of the bottom material. The velocity is slowest near the bottom and increases as the distance increases above the bottom. The maximum velocity is not necessarily at the surface, but somewhat below the surface. This subsurface maximum was carefully measured on the Lower Mississippi River by Humphreys and Abbot (1876) in the 1860s repeating many measurements using drift buoys, which were timed as the river velocity carried them downstream for a specific distance. Normally, velocity is only measured at one fixed location relative to the bottom of the river. However, Savini and Bodhaine (1971) made a unique set of simultaneous measurements of velocity at 12 fixed locations above the bottom. These measurements provide a good example of the vertical and horizontal structure of river velocities. The depth-averaged velocity is approximately equal to the velocity at 0.6 of the water depth below the surface. It is also approximately equal to the average of the values at 0.2 and 0.8 of the water depth. This is the method used by the U.S. Geological Survey when measuring and calculating the discharge of a river (Rantz and others, 1982). Sometimes only surface velocity measurements can be made and the depth-averaged velocity is estimated to be 0.86 times the surface velocity (Rantz and others, 1982). The mean velocity of the entire river is calculated by dividing the calculated discharge by the cross-sectional area of the river.

Velocity structure for the Columbia River.

(Measurements were made at the Hood River Bridge, Oregon, on June 5, 1961.)



NOTE: The vertical scale for depth is exaggerated relative to the horizontal scale for distance across the river from the left bank. Rivers are really very thin ribbons of flowing water. Data from Savini and Bodhaine (1971).

probably never know what he meant, but he seems to have been making the measurements at different distances from the shore along the outside of a bend where the velocity would be greatest. The velocities decrease with distance away from him and are only 1 ft/s or 0.7 mph (assuming the 4.8 pole option) at the farthest location, which may have been in shallow water over a point bar (see opposite page). Later, on July 17 and 18, he made additional measurements:

> *...The Common Current taken with a Log runs 50 fathen in 40"—Some places much Swifter in 30" and even 20 Seconds of time...17 July 1804*
>
> *...Measured the Current and found that in forty one Seconds it run 50 fathoms...18 July 1804*

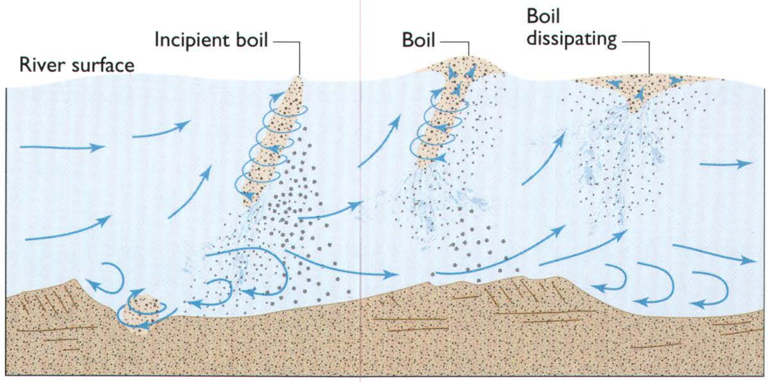
These measurements give surface point velocities ranging from 7.3 to 15.0 ft/s or 5.0 to 10.2 mph. This set of measurements appears to have been made from a boat using a log line (page 12, "Instruments"), probably while the boat was anchored in the river. However, if they made the measurements from a moving boat, then the velocity of the boat needs to be subtracted. At this time the expedition was making about 18 to 20 miles per day upriver. Assuming that they spent about 12 hours on the river, then an estimate of the average boat speed would be 2.2 to 2.5 ft/s or 1.5 to 1.7 mph so that the surface velocity would have ranged from 4.8 to 12.7 ft/s or 3.3 to 8.7 mph. They continued these surface velocity measurements at different locations along the Missouri River, and the table below summarizes these results.

These were measurements of the surface velocity at different locations along the river. They did not have instruments to measure velocities at different depths

Surface velocity measurements made by Clark

River reach	Velocity (miles per hour)	Velocity (feet per second)
Mississippi River	*4*	*5.9*
Missouri River between the Osage and Mississippi Rivers	*5.5 to 6*	*8.1 to 8.8*
Missouri River between the Kansas and Osage Rivers	*6.5 to 7*	*9.5 to 10*
Missouri River between the Platte and Kansas Rivers	*5.5*	*8.1*
Platte River	*8*	*12*
Missouri River between the Cheyenne and Platte Rivers	*3.5*	*5.1*
Missouri River above the Cheyenne River	*3*	*4*
Columbia River below the Narrows*	*1 to 1.5*	*1.5 to 2.2*
Yellowstone near Clarks Fork of the Yellowstone	*(4.5)*	*(6.6)*
Yellowstone between Clarks Fork and Bighorn Rivers	*(3.5)*	*(5.1)*
Yellowstone between Bighorn and Tongue Rivers	*(3.0)*	*(4.4)*
Yellowstone beween Tongue River and Wolf rapid	*(2.75)*	*(4.0)*
Yellowstone between Wolf rapid and the Missouri River	*(2.5)*	*(3.7)*

*Velocity of the Columbia River is given near the Cascade Rapids on October 30, 1805, just upstream from the tidewater. Velocities given inside parentheses were indicated in the journals (on August 3,1806) as estimates.



Boils (or kolks) occur when fast currents propel water and sediment to the surface.

Modified from Matthes (1947)

below the water surface (page 80, "River Velocities"), nor did Lewis and Clark have instruments specialized to measure turbulent velocities. Nonetheless, Lewis observed and described the macroturbulence of the confluence between the Platte and Missouri Rivers. One feature of this turbulence is boils (or kolks), and Lewis's description seems to fit Matthes's (1947) diagram above of macroturbulence many years later.

> *...Thirty two miles higher up, and distant 630* [blank] *from the confluence of the Missouri and Mississippi, the great river Platte disembogues on the S. side. The steady, regular, and incessant velocity of this stream, is perhaps unequaled by any on eath; notwithstanding it's great rapidity the surface of the water continues smooth, except when occasionally interrupted by a boiling motion, or ebullition of it's waters. this motion of the water, is also common to the Missouri, and Mississippi, below the mouth of that river and always takes place in the most rapid part of the current; in this manner the*

This is a downstream view of the White River near the confluence with the Mississippi River in Arkansas. The boil near the bank is dissipating and can be identified by its smooth, glassy surface surrounded by rough water moving outward from the center.

Photo: John Moody

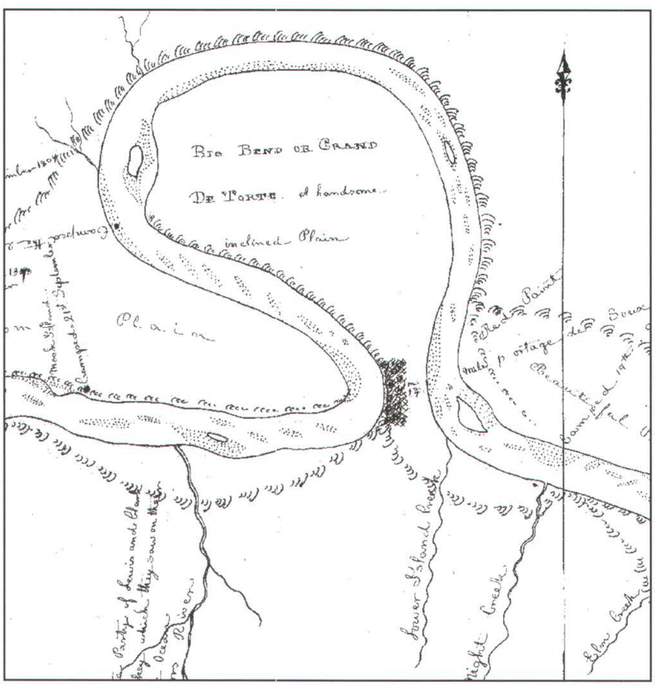
> *water, is seen to rise suddenly many inches higher than the common surface, then breaking with a rappid and roling motion extends itself in a circular manner in every direction arround interrrupting the smooth, tho' rappid surface of the water for many yards. this ebullition of the water of those rivers, is a singular phenomenon, nor do I know to what cause to attribute it, unless it be, the irregular motion of large masses of sand and mud at their bottoms, which are constantly changing their positions...*Fort Mandan Miscellany, Moulton, 1987, v. 3, p. 347.

These observations of Lewis and Clark predate many hydrologic studies in the United States. Their stage and velocity measurements are probably the first for these rivers. It is unfortunate that the journals were not published until the late 1800s because these asute observations and simple measurements may have spurred others into similar investigation that would have provided us with, perhaps, 50 to 70 years of additional historical data on which to better understand the hydrology of western rivers. Desire to control the Mississippi River resulted in comprehensive measurements of velocity in the Mississippi River published by Humphreys and Abbot (1876). Even so, it was not until John Wesley Powell recognized and promoted the importance of the western water resources beyond the 100th meridian in the 1870s (Stegner, 1954) that any serious effort was made to map and measure the water resources of the Louisiana Purchase.

IV

Geomorphic and Hydrologic Changes in 200 Years

THE WESTERN expansion of the human population soon followed the expedition of Lewis and Clark and changed the landscape adjacent to the river corridors they traversed. We have Lewis and Clark's written descriptions of *immence level and fertile plains and meadows, in which, no timber is to be seen except on it's own borders and those of it's tributary streams*. Now, interstate highways cross and towns spread over the *immence level plains*, and farms systematically divide the fertile plains and meadows. Agriculture has modified most of the semiarid and arid regions drained by the Missouri River. Among the most striking features in aerial photographs are the center-pivot irrigation systems that leave the characteristic circle of green vegetation on the ground that might otherwise have been dry and yellow throughout the summer (below). To produce these irrigated fields, the landscape can be leveled by laser-guided earthmoving equipment—doing in a few days what took erosion and deposition centuries to complete.



Clark's map (1804) of the Big Bend of the Missouri is located in what is now central South Dakota. River flow is to the east.

Aerial mosaic (August 1991) of the Big Bend of the Missouri River shows the numerous center-pivot irrigation circles covering the Big Bend and operated by the Lower Brule Indian Tribe. Today's wider river is in the backwater of Lake Sharpe reservoir, impounded by Big Bend Dam.

In 1833, Karl Bodmer painted watercolors of the landscape as he traveled up and down the Missouri River with Prince Maximilian of Prussia. To fit the immense landscapes of the West onto paper, Bodmer often compressed the dimensions of the scenes he painted, giving them a slight vertical exaggeration. The details of most of his landscape paintings, however, were so accurately rendered that his scenes can be relocated today. These paintings provide a visual description of the landscape that complements, 30 years later, the written descriptions of Lewis and Clark. Some of the scenes that Bodmer painted from the riverboat "Yellow Stone" have been located and photographed to provide a visual record of change since the expedition of Lewis and Clark. Some landmarks have been significantly changed by human activity (below and opposite). Some landmarks have been changed because the river has moved several miles from its location in the early 1800s. For example, the Missouri River is no longer present to maintain erosion at the base of the bluff on which Fort Atkinson was built (page 88, top). Consequently, trees have established themselves, and the old riverbed has filled in and been converted to farm land and an access road has been built running down from the low spot in the bluff. Some landmarks have been changed only by a few homes and planted trees (page 88, bottom). In less accessible locations, the landmarks are unchanged by humans and appear much as Lewis and Clark observed them (page 89).

"View of Pittsburgh" painted by Karl Bodmer in September-October 1832.

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

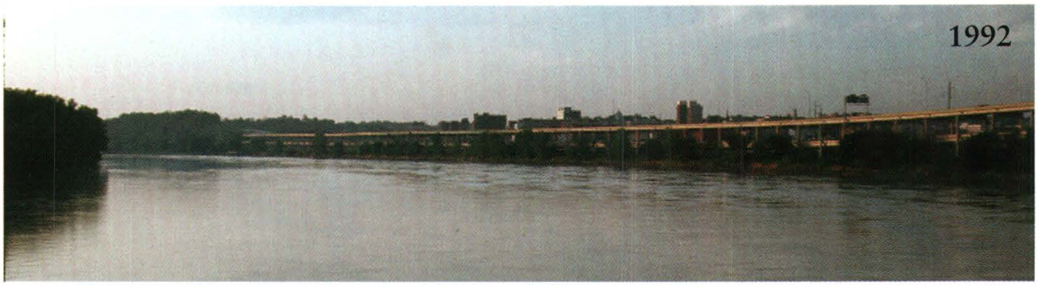
This view taken in November 1993 shows the Allegheny River on the left joining the Monongahela River on the right to form the Ohio River.

Photo: Bob Lindholm

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

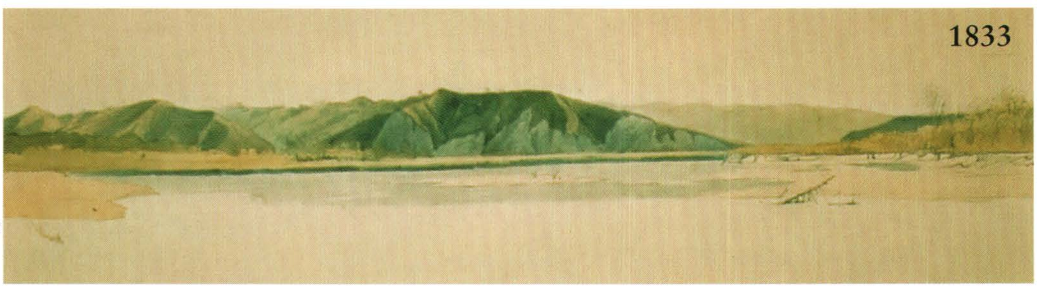
"Blacksnake Hills, Roubidoux's House" painted by Karl Bodmer on April 24, 1833. Joseph Roubidoux built a trading post which eventually became the site of St. Joseph, Missouri.

Photo: Bob Lindholm



This view taken in July 1992 shows Interstate 29 along the Missouri River with St. Joseph, Missouri, in the background.

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

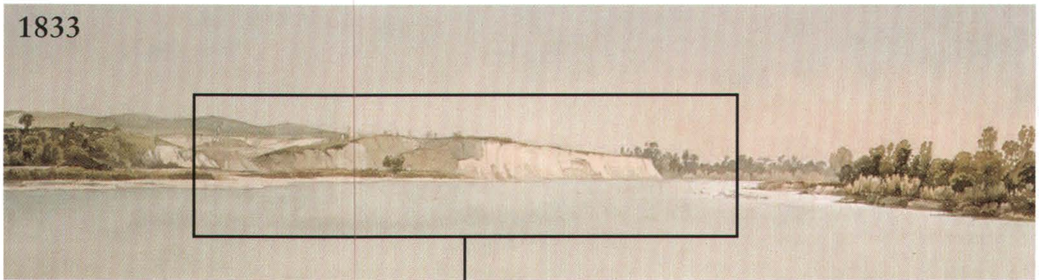


"Missouri in the Morning below Council Bluffs" painted by Karl Bodmer on May 3, 1833. The view is across the Missouri River with the loess bluffs on the eastern side of the Missouri River.

Photo: John Moody

This view of Eppley Airfield in Omaha, Nebraska, was taken October 2002. The airfield occupies land created when the Missouri River changed course. The loess bluffs are still on the eastern side of the river in Iowa.

"Ruins of Fort Atkinson" painted by Karl Bodmer on about May 5, 1833.



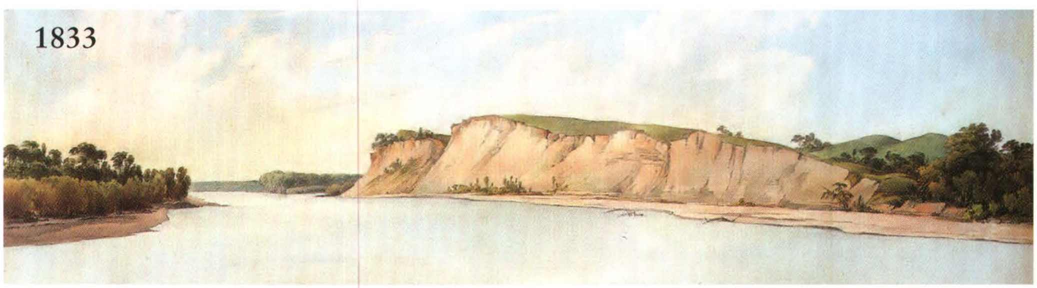
Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

This photograph taken in June 2002 represents the area shown within the rectangle on the Bodmer painting above.

Photo: John Moody

This site is just east of Fort Calhoun, Nebraska, about 10 miles north of Omaha. The Missouri River is now at least 1 mile east of the foot of the bluff shown in the painting. The agricultural fields in the photograph are now where the river was in 1833. Trees now grow on and cover the bluff face, which is about 30 to 40 feet high. The road occupies the low area between the bluffs in the painting (upper left corner of the rectangle on the painting).

"Mouth of the Big Sioux River" painted by Karl Bodmer on May 8, 1833. The view is looking upstream into the mouth of the big Sioux River where South Dakota, Nebraska, and Iowa now meet.



Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

This same view was taken October 2002 on the west side of the Missouri River.

Photo: Bob Lindholm

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

"Bijoux Hills on the Missouri" painted by Karl Bodmer on May 22, 1833. The view is looking toward the east with the river flowing from left to right.

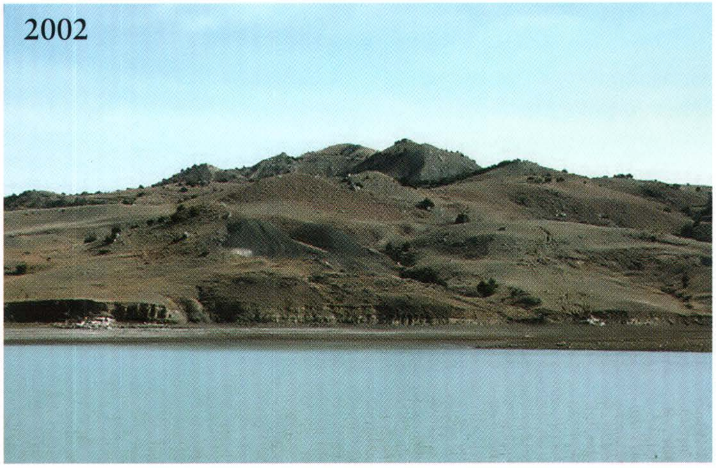


Photo: Bob Meade

These hills, photographed in October 2002, are known as Twin Butte and are the western part of the Bijoux Hills. The Francis Case Reservoir is in the foreground and is upstream from the Fort Randall Dam in South Dakota. The water level is now 20 to 30 feet higher than when Bodmer made his painting. The wide reservoir is conducive to the generation of waves, which have apparently eroded the outcrops of bedrock that appeared at the water level in Bodmer's painting.

Copy provided by Joslyn Art Museum, Omaha, Nebraska; gift of Enron Art Foundation

"View of the Stone Walls" painted by Karl Bodmer in August 1833.

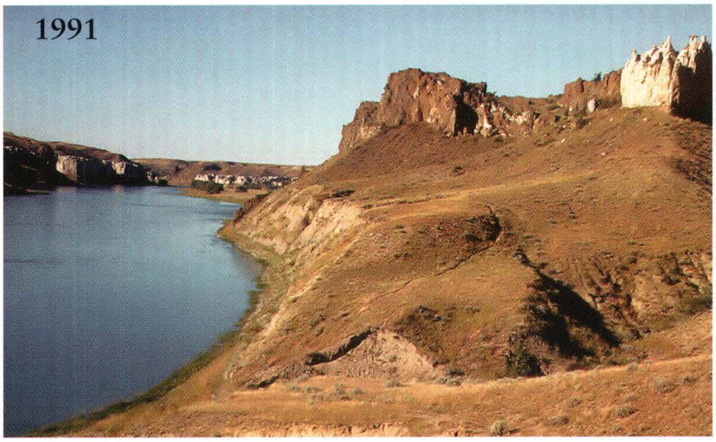


Photo: Bob Lindholm

This upstream view taken in August 1991 shows the white cliffs on the left and Castle Rock to the right. The campsite of Lewis and Clark on May 31, 1805, is at the mouth of the tributary (Eagle Creek or Stonewall Creek) coming in on the right just upstream from the point of land jutting into the river.

This 1920s photograph was taken looking east at the future site of the Bonneville Dam located just downstream from the Cascade Rapids (*Great Shute*).

This view was taken after the construction of the Bonneville Dam.

Photos: Courtesy of the U.S. Army Corps of Engineers and the Bonneville Power Administration

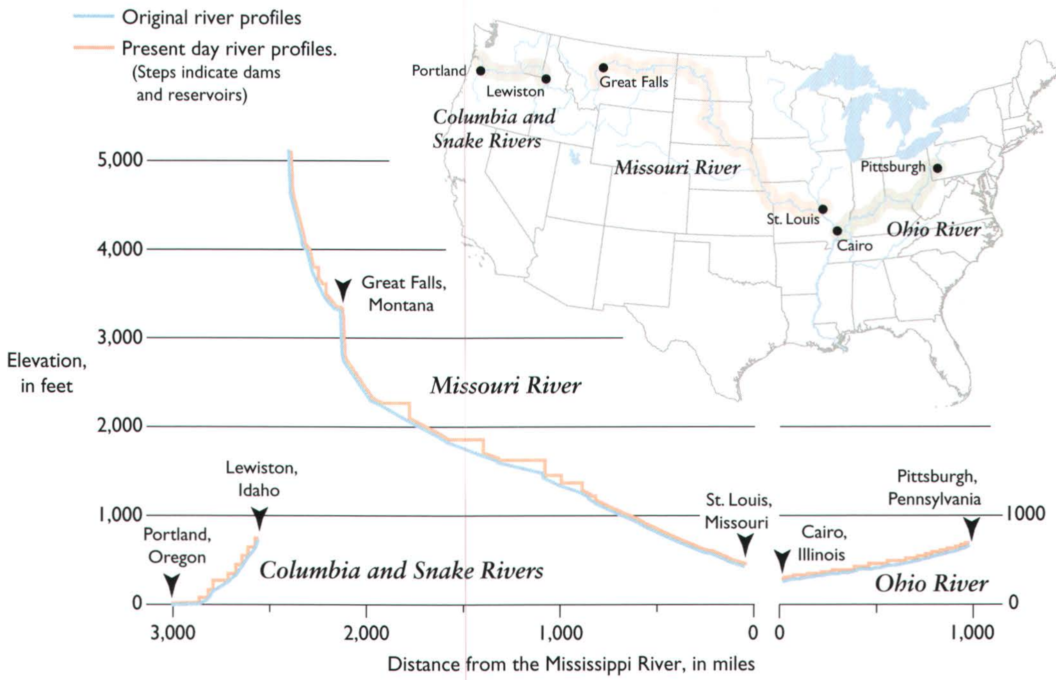
Karl Bodmer traveled westward only as far as Fort McKenzie on the Missouri River near Loma, Montana, at the mouth of the Marias River and did not paint scenes of the Columbia River landscape. However, Arthur Piper, a ground-water hydrologist for the U.S. Geological Survey, did photograph landscapes in Oregon and Washington and some scenes of the Columbia River during the 1930s, and these provide some idea of the area that Lewis and Clark traversed in 1805 and 1806. Once again, the major change on the Columbia River has been the construction of dams and their associated reservoirs. Cascade Rapids (opposite) and Celilo Falls (below) are now permanently under the water backed up by the Bonneville Dam and The Dalles Dam, respectively.

Photo: Arthur Piper

This photograph was taken in 1930 of Celilo Falls (*Great Falls of Columbia River*) on the Columbia River looking north.

Photo: Jim O'Connor

This view taken in 1994 shows the same area of Celilo Falls but is now covered by the reservoir created by The Dalles Dam.

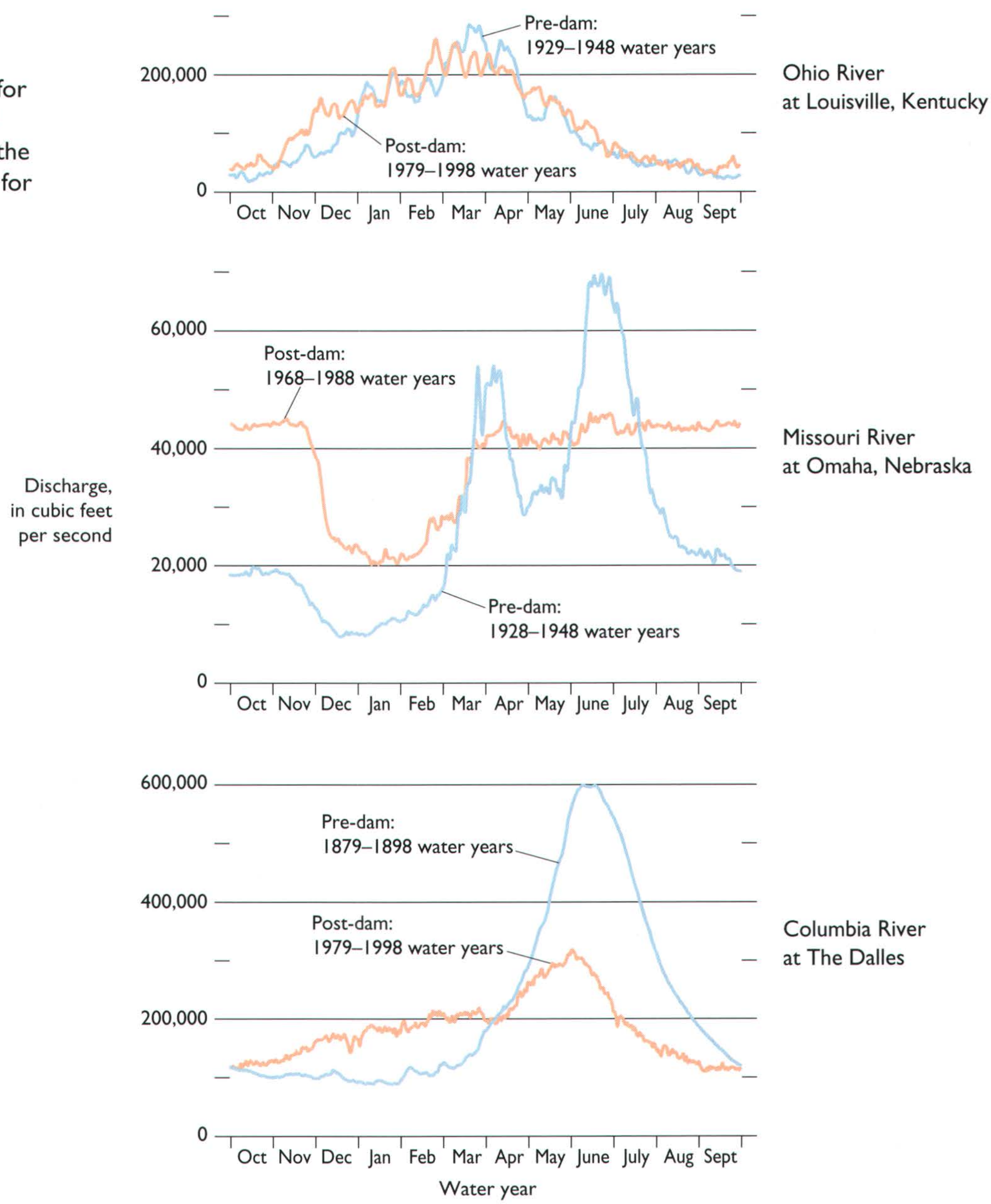


Since Lewis and Clark traversed the three major rivers—Ohio, Missouri, and Columbia—engineering modifications have significantly altered the flow characteristics, the channel cross sections, and the longitudinal profile of the rivers (above). Most of these human-induced changes were designed to make the rivers easier to navigate, to control floods, to make water available for crop irrigation, or to generate electricity. Dams have been the most common means of controlling these rivers.

Navigability of the Ohio River began to be controlled in 1885, when the first of a series of wicket dams was completed to maintain a year-round water depth of 6 feet in the river near Pittsburgh. By 1929, 52 more wicket dams had been installed to regulate the depth of the full length of the Ohio between Pittsburgh, Pennsylvania, and Cairo, Illinois. Wicket dams were allowed to lie on the river bottom during average-to-high flows and were raised into place only during low flows when they were needed to keep the river depths from falling below 6 feet. Beginning in the 1920s, the wicket dams were systematically replaced by a smaller number of larger concrete dams that maintained navigation depths at 9 feet or more. After completion of Olmsted Lock and Dam near Cairo in 2003, 19 of these larger structures will control the Ohio River. These concrete dams serve no function in flood control (gates are opened wide during high water), but they hold back the waters when the Ohio River is low (Johnson, 1991). Comparison of the pre- and post-dam discharge hydrographs (opposite) illustrates that the dams have no flood-control function because the flood peaks are essentially the same. The differences in the hydrographs are more apparent from October through December, when the Ohio River flow is kept higher to maintain sufficient navigational depth.

Engineering of the Missouri River began in earnest during the 1930s when the first massive dam was completed on the upper river at Fort Peck, Montana, for irrigation and flood control, and the middle and lower reaches were channelized. Following World War II, during 1953–63, the construction of five more dams left

Pre-dam and post-dam discharge hydrographs for the Ohio, Missouri, and Columbia rivers. Note the different vertical scales for water discharge.

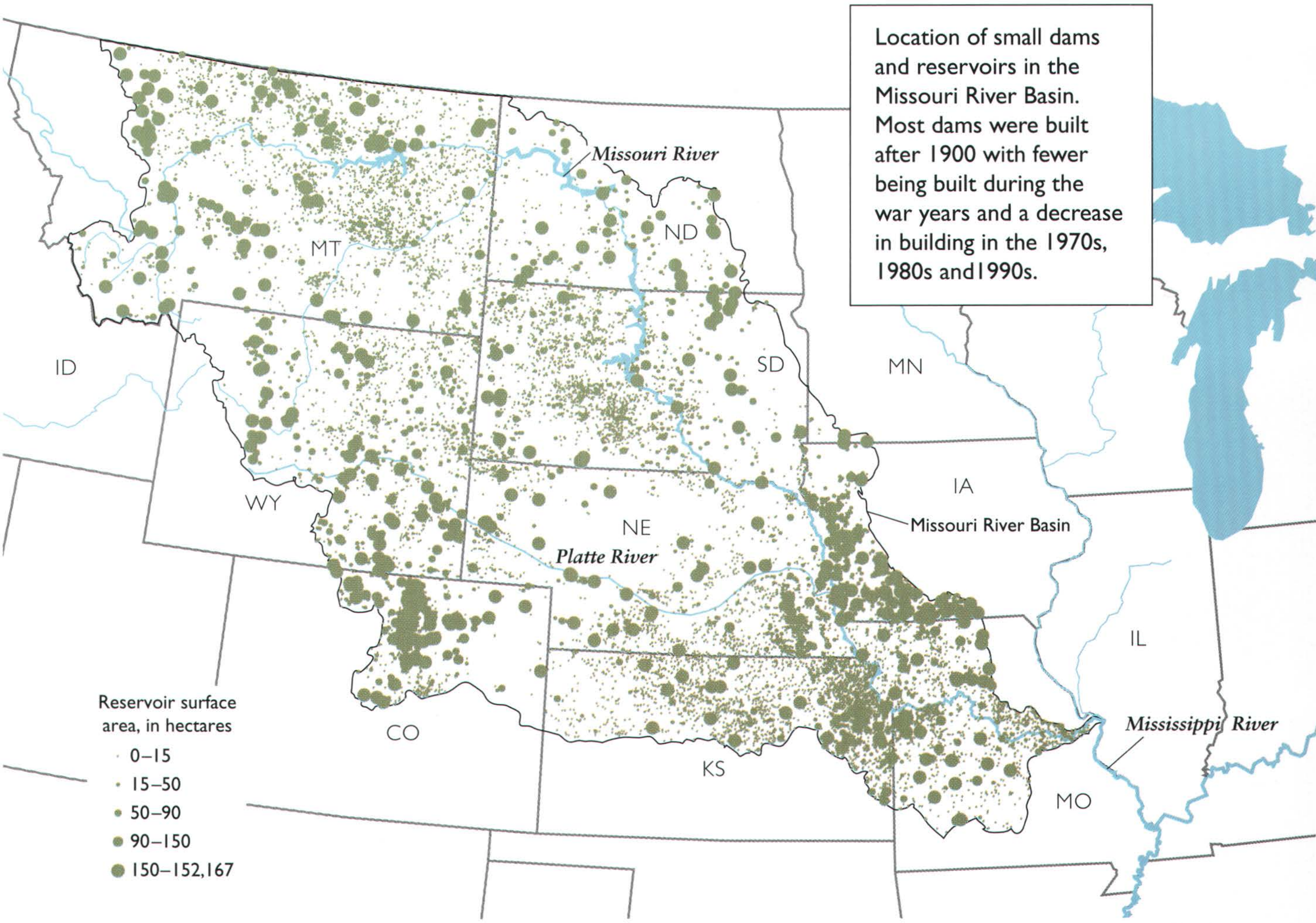


only a few unimpounded miles of Missouri River in the States of North and South Dakota. Schlosser (1987) reports that 35 percent of the length of the Missouri River is impounded, 32 percent has been channelized, and 33 percent is unchannelized. Because one purpose of the dams on the Missouri River is flood control, their effect is rather different from that of the dams on the Ohio River. The two seasonal flood peaks are truncated, and a steady flow is released from the dams to maintain sufficient depth for navigation of the lower Missouri River from March through mid-November (page 68 and 93).

Hydropower was the principal reason for the series of large dams constructed during the 20th century on the reaches of the Snake and Columbia Rivers that Lewis and Clark had traversed in 1805–06. These dams also are equipped with large navigation locks, capable of lifting barges and their towboats as much as 100 feet, to permit the shipment of agricultural products and other commodities between Lewiston, Idaho, and the Pacific Ocean. Beginning with the Bonneville Dam in the late 1930s, eight such structures have converted the former Snake and lower Columbia Rivers to a continuous series of slowly moving "lakes." These dams, along with the many large and small dams that control the middle and upper Columbia in the United States and Canada, have substantially reduced the single flood peak of the Columbia River by storing the water and releasing it later for power production and navigation (page 68 and 93).

Although many dams were built for flood control, their reservoirs can be thought of as permanent floods that affect the river system upstream from the dam in a

Construction of reservoirs caused a large reduction of sediment in the Missouri River between 1700 and 1990. In contrast, sediment loads in the Ohio River have increased as results of deforestation and rowcrop farming. (Meade, 1995)



Provided by David Mixon and Deborah Martin

quite different way than the annual floods, which lasted for only a few weeks or perhaps a month. Reservoirs now cover many of the meanders, riffles, rapids, and falls encountered by Lewis and Clark. Dams trap sediment in the upper reaches of reservoirs where tributaries enter the relatively quiet water of the reservoir and deposit sediment to create deltas and wetlands, which can have effects on the environment that are both positive and negative. Dams also affect the river system downstream (Williams and Wolman, 1984; Collier and others, 1996). The closure of the downstream-most dam at Yankton, South Dakota, in 1953 caused extensive changes in the sediment transport and other characteristics of the flow of the Missouri and Mississippi Rivers that could be observed all the way to the Gulf of Mexico. The suspended-sediment load of the lower Missouri River during the time of the Lewis and Clark expedition is estimated to have been about 320 million tons per year. Today, 200 years after Lewis and Clark, the lower part of the muddy Missouri transports only about 86 million tons per year (Meade, 1995). This is not enough to replenish the marshes and islands at the mouth of the Mississippi River.

The dams that trap sediment are not all large. Many smaller dams almost cover the landscape in some areas, and their combined effect may rival that of the large dams (page 95). Each dam traps sediment and organic material and regulates the hydrologic regime downstream. Sediment that was once *thrown out* by tributaries has been reduced, and a *river full of Sand bars* and *riffles* has largely disappeared in many places.

While the Missouri River did not carry the most water, it was perhaps the most dynamic river traversed by Lewis and Clark. Most of the Missouri's length, greater than that of either the Ohio or Snake-lower Columbia River reaches traversed by the Corps of Discovery, was not confined in narrow canyons or valleys and was truly an alluvial river forming and reforming its own channel and flood plain. Subsequent channelization for purposes of navigation has caused many of the changes in the Missouri River. Using Clark's river distances as the basis for comparison, channelization has probably shortened the Missouri River by about 21 percent during the last 200 years. Nearly all of this shortening of the river was in the lower one-third below the Gavins Point Dam in South Dakota. Meander bends were artificially cut off, and wing dikes were built to channelize the flow. Pile dikes were built to trap sediment, bank revetment was installed to stabilize the banks, and levees were built to keep floodwaters off the flood plains. These engineering activities, designed to improve commerce and support agriculture, have resulted in narrower channels but wider flood plains as the *great number of islands* have been connected to the bank by the deposition of sediment between the pile dikes (photos on opposite page). Channelization has eliminated those shallow braided reaches of the Missouri where Lewis and Clark were *at a great loss to find the Channel of the river.*

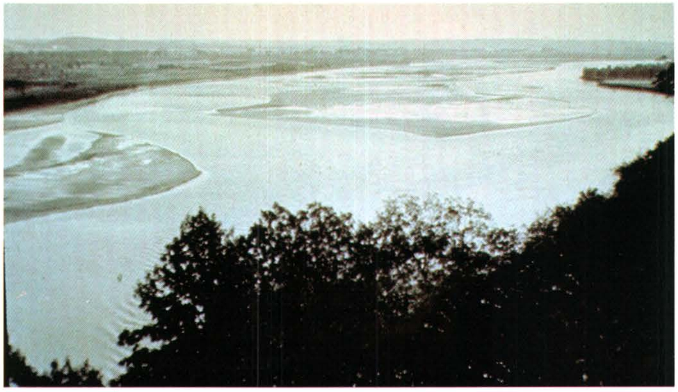
It is notable that Lewis and Clark never commented on overbank flooding during their trip up the Missouri River, which according to hydrographs on page 68 was made near the crest of the annual snowmelt flood. This may illustrate the consequence of channelization and confining a formerly wide river to a narrow channel. The river must now rise much higher vertically to overflow its banks, while previously it could spread out over wide areas of islands and flood plain at a relatively shallow depth.

Vegetation has encroached on and grown into many rivers of the west as a consequence of projects designed to control rivers. The annual floods and ice-jam floods in the spring and dry river channels in the late summer, observed by Lewis and Clark, were natural ways to keep some channels free of vegetation. Now dams decrease the magnitude of floods and provide water in the summer. The encroach-

Engineering projects have eliminated most of the braided reaches of the Missouri River.

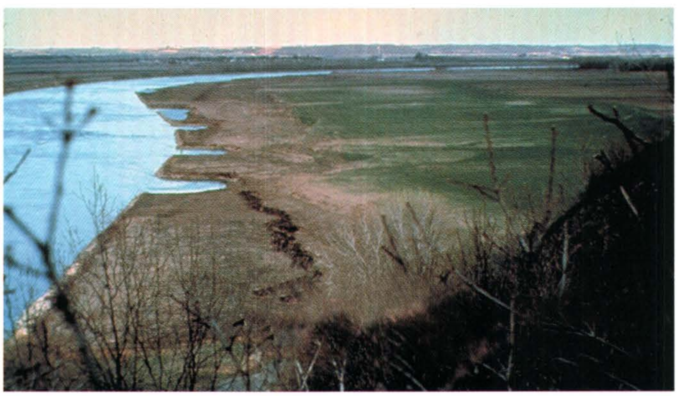
This series of photographs was taken at Indian Cave Bend Point on the Missouri River near mile 517 about 18 miles upstream from Rulo, Nebraska. The view is downstream, from Nebraska (near bank) into Missouri (far bank). The 1934 photograph was taken before the construction of wing dams.

Photographs provided by Norm Stucky



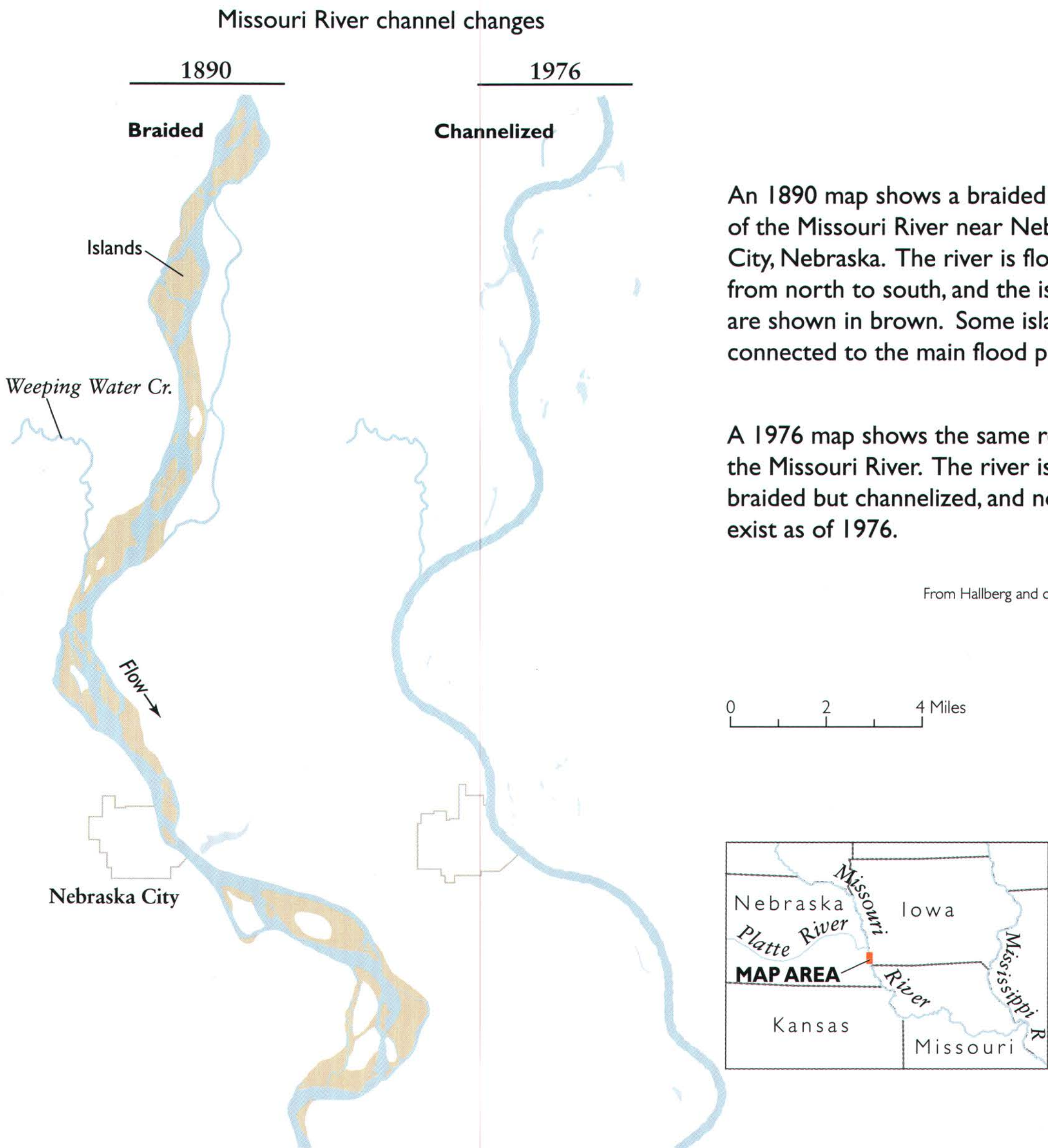
September 1934

September 1935



March 1977

ment of vegetation into the channel also traps and stores sediment, changing the geomorphic configuration of the river (Friedman and others, 1998). The combined effects of damming, channelization, and vegetation encroachment has changed the character of the Missouri River relative to when Lewis and Clark struggled upstream. It has caused the water-surface area of the Missouri River to decrease by 49 percent, the channel area to decrease by 41 percent, and the number of those formidable sandbars and unconnected islands to decrease by 99 percent (Funk and Robinson, 1974; Hallberg and others, 1979).



An 1890 map shows a braided reach of the Missouri River near Nebraska City, Nebraska. The river is flowing from north to south, and the islands are shown in brown. Some islands are connected to the main flood plain.

A 1976 map shows the same reach of the Missouri River. The river is not braided but channelized, and no islands exist as of 1976.

From Hallberg and others, 1979

The change in channel-surface area is relatively easy to determine from maps and aerial photographs. However, the thickness of sediment on the flood plains is not as easy to determine. This stored sediment also contains large amounts of stored carbon, which is of current concern to many research scientists interested in the global carbon budget (Stallard, 1998). Some idea of the thickness can be seen in the photograph series on the opposite page, but the thickness probably varies from inches to many feet. Two examples of perhaps the upper limit for thickness were determined when two steamboat wrecks were excavated out of the

Steamboat *Arabia* found in 1987 north of Kansas City, Missouri, was buried under about 45 feet of flood-plain sediment. The paddle wheel is 28 feet tall.

Photo: Arabia Steamboat Museum, Kansas City, Missouri

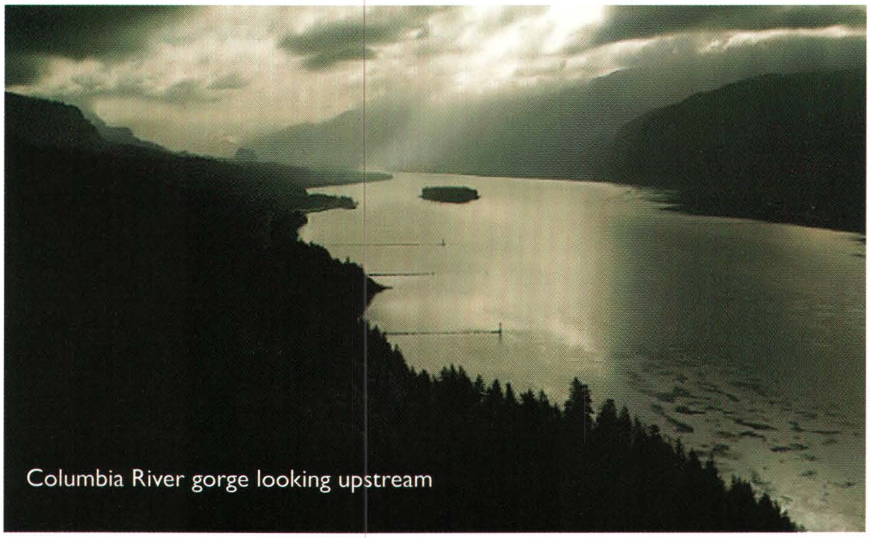
flood plain. One, the *Arabia,* which sank in 1856, was found buried in a cornfield near Kansas City, Missouri, covered by as much as 45 feet of sediment. Another, the *Bertrand,* which hit a large snag and sank in 1865, was found a century later buried under about 30 feet of sediment north of Omaha, Nebraska.

The changes on the Ohio, Missouri, and Columbia Rivers illustrate similar changes on other rivers in the United States. Very few, if any, rivers have escaped the human desire to control nature. Today's Missouri River is not the dynamic river observed by Lewis and Clark that annually built and recycled its flood plains. However, there has been a growing interest in river restoration in the United States. Because so few natural rivers remain, the observations of Lewis and Clark provide some insight into the character and processes of natural rivers that may help guide river restoration efforts. This is especially true for the Missouri River, which for the most part was an alluvial river, unconfined, and forming its own channel and flood plain. Besides making direct observations of the river itself, Lewis and

Steamboat *Bertrand* found north of Omaha, Nebraska, was buried under about 30 feet of flood-plain sediment.

Photo: John Fulton, National Geographic Society

Clark recognized the interconnections between the river and the vegetation and animals that lived on or next to it. Beaver, for example, whose importance Lewis and Clark observed as being *very instrumental* in the morphology of the Missouri River, is recognized today 200 years later, as a *keystone species* (Outwater, 1996) that affects other species by engineering rivers and creating wetlands. The legacy of the keen observations in all scientific fields left by Lewis and Clark needs to be continued today, and into the future, to discover the complex but important interconnected relationships in riverine ecosystems.



Columbia River gorge looking upstream

Photo: Lyn Topinka, 1987

Glossary and Abbreviations

azimuth	horizontal angular distance from a fixed reference direction, which commonly is north
bearing	horizonal angle measured from north toward a landmark
chain	100 metal links, each link is 7.92 inches such that 1 chain equals 66 feet
eolian	pertains to wind
fluvial	pertains to river and streams
E.	East
grs.	grains (1 grain equals 0.065 gram or 0.002285 ounce)
Gs.	gallons
I	inch or inches
lb	pound
league	equals 3 miles
L.S.	lard., larboard, port, or the left-hand side of a vessel
median	middle value, 50 percent of the values are less than this value and 50 percent are greater than this value
mes.	miles
mph	miles per hour
ms.	miles
N.	north
Opsd.	opposite
po.	pole
pr.	per
pt.	point
R.	river
S.	south
thro'	through
S.S. or Stard.	starboard or the right-hand side of a vessel
yd.	yard
yds.	yards
transport	movement of soil or sediment by air or water in a specified time
tho.	though
W.	west
&c	et cetera, and so forth
"	seconds

Rivers, Creeks, and Sites Alo

e Lewis and Clark Corridor

This map shows the hydrologic, geomorphic and cultural features mentioned in the text. Also shown are the many dams which now cross the rivers traversed by Lewis and Clark.

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