A VIEW OF THE RIVER

by Dennis Kalma, BRASS Laboratory Director

In 1964, the young geologist Luna Leopold was the lead author for a new book about rivers. The title was Fluvial Processes in Geomorphology, a fancy way of saying that the book is about how rivers go about their business of forming the landscape. The geologist (son of the famous conservationist Aldo Leopold) summarized the scattered knowledge about rivers, and ushered in a new era of research. His overview inspired several others to enter the field. At the time he wrote the book, the field was in its infancy. Most of the book can be read by anyone with - or willing to pick up - a little background in differential equations and fluid mechanics/dynamics. Now, thirty some years later, the field has matured through the attentions of hundreds of other workers. Unfortunately, the field has also become much more complex. Some knowledge of math through matrices' algebra level and some fairly sophisticated fluid dynamics has to be the starting point if you really want to appreciate the research.

Although I applaud the advances made in these studies, there is an unfortunate side effect. The scientists who study rivers now have a hard time making non-scientists appreciate the significance of their discoveries. That's a shame, because sometimes decision-makers and the public who sway them lack the scientific training needed to understand river dynamics.

Luna Leopold is now an emeritus professor, at the end of a long and distinguished career. In a new book he has tried to do something about this gap between scientists and administrators. In *A View of the River* (Harvard University Press, 1994), he tries to distill some of the main findings of the last 30 years. It is packed with information, but not an easy book to read.

I seem to progress by reading a paragraph at a time. Once I've read that much, I have to stop and absorb it. Although the writing style is clear and information presented as simply as possible, the book lacks a clearly stated overview and cohesion. Each of the chapters contains sections and the sections deal with interrelated topics, but sometimes the nature of the relationship is unclear. Relating one chapter to another is often even more difficult. However, the material in the book makes it worth the trouble.

Did you know that of the average annual rainfall of 30 inches which falls on the United States, only about 9 inches gets into the rivers; so that in a year in which preciipitation varies only 1 inch (about 3% from the average), stream flow is likely to alter by about 10%?

Since about 1980, our weather has become more variable. Although average rainfall is about the same, we see more periods that are either wetter or drier than the norm. As explained above, this means there is more variation in river flow.

One theme seems to underlie all of Leopold's discussion of rivers. He pictures them as being determined by small scale random events, say at the level of raindrops or small parcels of water in the river itself. They act randomly in the sense that no one can predict just which way one of these small parcels of water will move in the next instant of time.

What is interesting is that one of the counter-intuitive properties of all types of random events is that if you consider enough of them together, they add up to something perfectly predictable. For example, when a coin is tossed in the air, whether it comes down head or tails is a random event. But if we toss the coin in the air many times, we can confidently predict that the coin will come up heads about one half the time and tails the other half. This is what we mean when we talk about the paradox that random events are predictable.

In Leopold's view, the river is a tantalizing mixture of predictability and unpredictability. For example, if you know the area of land a river drains and the region of the country in which it is located, you can make some very accurate predictions about the river. You can predict the annual discharge, how often the river will overflow its banks, or how often it will flood to a certain height. You can also predict the width, depth and shape of the river channel, the velocity of the river, the size and shape of bends in the river, and the spacing of rapids and pools in mature sections of the river.

The velocity of flow at any point in the stream channel is nearly inversely proportional to the logarithm of the depth. (BRASS always takes velocity measurements at 0.6 of the depth which is where the mean speed of flow occurs.) The rate of flow decreases rapidly at the bottom.

Unfortunately (the other side of the paradox), you cannot predict just when some of these things such as floods will occur - only that they will occur, on the average, every so often. If you build on a flood plain, you can be sure you will experience flooded property at intervals that are, on the average, predictable. Not to expect flooding is to be like an ostrich hiding its head in the sand.

Another aspect of this randomness relates to the way a river does its work. In Leopold's view, a river is a system for moving water and sediment. Because of physical laws, such as the second law of thermodynamics, a maturing river will always tend to arrange itself into the most efficient shape to perform that transport. The most efficient shape is the meander, with its seemingly unplanned and uncontrolled wandering loops. In seems paradoxical that such acasual shape should actually be the preordained shape.

Not much of the Boquet is geologically mature; the continental ice pack retreated only a few thousand years ago. Although the Boquet has been eroding at the land since then, it has a long way to go. But, most sections show the ripple and pool sequence that will someday lead to meanders. In a few places there are meanders, like above Wadhams (see illustration). The river swings back and forth in smooth loops. The small ponds, cut off by the changing river, are oxbows and are characteristic of a meandering river.

For all the apparent randomness of the meander system, the physical principles operating there create a very predictable situation. The shape of a meander approaches that of a sine-generated curve. The water in the channel flows as two great helices converging in the center of the river, slightly bowing up the surface of the water. At the bends, these helices get squashed to the outside of the curve. One result: the maximum erosion occurs on the downstream edge of the outside curve of the meander. All these phenomena - and many more - result from the compromises between two partially opposing physical principles. The first is that the river will tend to arrange itself to do a minimal amount of work. The second is the river will arrange itself so it is expending power as evenly as possible. Although neither of these principles is intuitively obvious, Leopold makes a strong case that understanding these principles and how they interact is the key to understanding rivers.

What is the practical significance? If we change the river channel, the river immediately begins to respond by changing other of its aspects in order to restore the minimum work/even power expenditure balance. Many times engineers make problems worse when they change a river. An example is the Mississippi; floodwaters have lately backed up in upstream areas because of man-made levees. Studies also show that the volume of water in the 1973 flood was the same as the flood in 1908, but the peak for the 1973 flood was 8-feet higher. King Canute rebuked flatterers by showing them that not even a king, appointed by God, could turn back the waters of the sea. Perhaps we, too, should know a little humility and realize we need to work with the river, not against it.

I confess that before I read Luna Leopold's book I thought I had a certain intuitive sense of how a river behaved. The effect of discharge, currents, and stream morphology all made a certain sense. I am less confident now. The river is both simpler and - in that simplicity - more complex than I imagined. There are parts of Leopold's book that make perfect sense to me, and parts that seem counter-intuitive when I think about them. I'm about to start reading the book a second time.

For the Budding Mathematician or Engineer

For any size stream or river, there is a relationship between the length of channel and the area drained. About 1 sq km is a sufficient area to maintain about 1.4 km of river channel . The formula for this is:

$$L = 1.4\,A^{0.6}$$

where L = length of channel and A = drainage area

Where streambeds are of coarse gravel, riffles tend to be spaced at regular distances of 5 to 7 stream-widths apart. Larger substrate particles of gravel, stones, or boulders tend to congregate on the bars that form the riffles, and the bars lope first towards one bank and then the other. This creates sinuosity of flow even in a straight channel.

Riffles do not move, although the stones that make them up migrate individually downstream. Furthermore, the largest stones in a riffle are always on the upper layer, even though smaller stones migrate too. The fact that large stones lie on the surface is of great importance to the stream biota.

The wavelength of meanders is related to the width of the river, being 7 - 10 times the width, and the path measured along the channel itself is 11 - 16 times the width.

A river channel is an almost infinitely adjustable complex of interrelations between discharge, width, depth, rate of flow, bed resistance, and sediment transport. Change in any one will be countered by adjustments in the others.
