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New Perspectives on Braided Rivers

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Abstract. A short history of braided rivers is presented, from the time Peale (1879) first noticed them during a U.S.G.S. survey, down through the late 1960's when quantitative fluid mechanics models began to be built. Several of these are described in modest detail. Starting in 1977, Mandelbrot, the discoverer of the fractal, began to apply that concept to hydrological systems. Subsequent discoveries on the self-organizing behavior of single river channels, river networks, and braided systems are presented. Recent work by Richardson and Thorne (2001) along with flume studies are tied together with Parker's (1976) fluid dynamic models to present the hypothesis that mid bar formation in a braided river system is a flow driven phenomenon rather than a sediment driven one. Energy considerations of the braided system and several morphological changes are then considered.

I. Background

A.C. Peale first recognized braided rivers as being a distinct morphological type in the 1877 Hayden Survey of Western Wyoming. One of the tributaries of the Green River, known as Horse Creek, did not join it as a straight channel, which was characteristic of the region. In his own words, " [Horse Creek] flows out into a broad valley in which it is side by side with the Green, and finally, to use an anatomical term which exactly describes it, joins the latter by anastomosis. There are at least five islands formed by the two streams in the lower end of the broad valley." (Peale 1879; Leopold and Wolman 1957).

The term "anastomosis" was first used in the literature as a descriptor of river morphology by Jackson (1834), and as used by both him and Peale (1879), was really referring to reaches of braided river systems. (Leopold and Wolman 1957). Leopold and Wolman (1957) note that in their survey, 80 years later, that there and been no substantial morphological changes at the river confluence. Figure (1) is a diagram taken from their report which shows one reach of Horse Creek slightly headward of the confluence. Upon inspection, one can see that it resembles a very stable braided configuration. The mid-channel islands with willow trees growing on them are indicative of just how stable this bar has been. They note that “the islands shown by Peale [in 1879] still exist with but minor changes in form [today in 1957].”

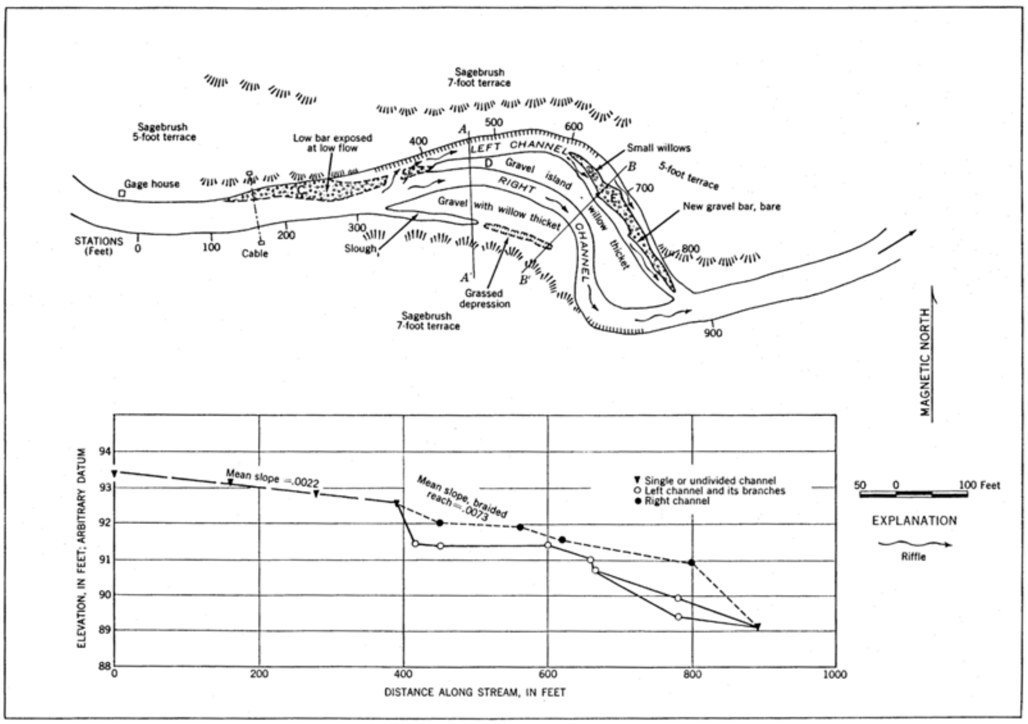

FIGURE 29. Plan and profile of Horse Creek near Daniel, Wyo., an example of a braided river. (Section shown in fig. 32.)

Figure 1

This type locality represents one end member of what the author has called the “Braided River Family”, as shown in Figure (2). It is similar to the Yangtze River in China, as the structure is very stable. The opposite end of the continuum is the so-called wandering braided river, of which the Yellow River in China is a type example. Of wandering braided rivers, one flume study notes that “Individual channels and bars in such rivers can evolve, migrate, and switch position within days or hours of competent flow, so that the overall pattern is bewilderingly variable and complex.” (Ferguson, Ashmore et al. 1992)

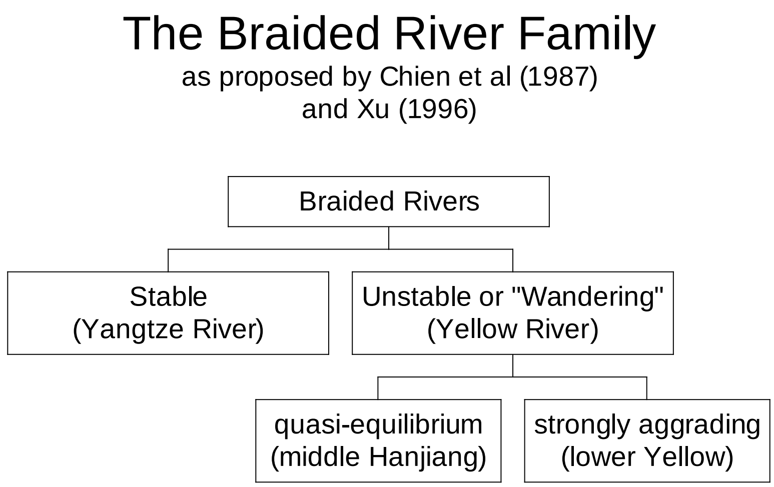

Figure 2

Between Peale’s work in 1879 and that of Leopold and Wolman (1957), most of the work done on braided rivers was largely qualitative in nature. Although, several studies such as Melton (1936) began developing the empirical relationships that have become the staple of modern fluvial geomorphology. In 1952, Rubey brought the prospect that the braided condition may represent an equilibrium state to the forefront of geomorphic inquiry. In some measure, that discussion has continued to the present.

With the advent of modern computing technology, geomorphologists along with physicists began to use the equations of fluid dynamics to model flow in river systems. This novel approach rested upon the assumption that the transition between straight, meandering, and braided rivers was governed by a stability problem in which energy was minimized (Hansen 1967; Callander 1969). River flow began to be framed as more of a wave, energy, and momentum problem than anything else. Both Hansen (1967) and Callander (1969) took a two-dimensional approach, and assumed that sediment transport was always parallel to the local velocity vector. Hansen's (1967) study was unavailable, but Callander (1969) was fairly inaccurate owing to its only calculating linear solutions to the partial differential equations. The only conclusion that he felt that he could make was that it was possible to create realistic estimates of the wavelengths of the phenomenon.

The next major step forward was when a three dimensional treatment of the system was published (Engelund and Skovgaard 1973). One significant improvement was that it considered transverse variations in slope, which was found to have a significant impact on the results (Fredsoe 1978). In addition, owing to the higher dimensionality, helical motion caused by the non-uniform vertical flow was considered in its entirety. The two major studies to follow this (Parker 1976; Fredsoe 1978) stepped back from this accurate approach and preferred the two dimensional treatment. It is significant to note that Fredsoe was in the same institute as and even under the tutelage of Engelund. They did not specify why they felt this change was appropriate.

Perhaps the most significant result of Engelund and Skovgaard (1973) is that "for a given hydraulic resistance and depth the river will exhibit meandering if the width is smaller than some threshold value B_*, while a wider river will braid in two or more courses – the more the wider it is." (Engelund and Skovgaard 1973). They go on to state that these results "seem" to agree with those of Leopold and Wolman (1957). The problem with rigorously validating their analysis was that they were concerned with the problem of when a straight channel just begins to meander or braid, and these data were largely unavailable at that time, and are somewhat sparse even today.

Parker (1976) based his work directly on that of Hansen (1967) and Callander (1969). It is intended primarily for *shallow* rivers, thus the necessity for a full three-dimensional treatment is unnecessary. Other notable assumptions include the presence of uniform erodible or non-erodible banks and the absence of a suspended load. Furthermore, dynamic pressure variations are ignored (i.e. hydrostatic pressure is assumed), and helicity effects are only partially accounted for. Parker states that, “This theoretical model river is realized in solid-walled tilting flumes of the recirculating or sediment-feed type.” (Parker 1976). The balance equations used in the model are given as Equations (1 - 4), where d is the channel depth, h is the river stage, (u, v) is the stream velocity vector, (q_x, q_y) is the bed load vector, (τ_x, τ_y) is the bed stress vector, ρ is the density of water, and λ_p is the bed porosity.

$$\begin{aligned}
&\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial h}{\partial x} - \frac{\tau_x}{\rho d}, \\
&\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial h}{\partial y} - \frac{\tau_y}{\rho d}, \\
&\frac{\partial}{\partial x}(ud) + \frac{\partial}{\partial y}(vd) + \frac{\partial d}{\partial t} = 0, \\
&\frac{\partial (h-d)}{\partial t} + \frac{1}{1-\lambda_p}\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y}\right) = 0
\end{aligned} \tag{1 - 4}$$

The larger question Parker (1976), and indeed many of the fluid dynamics studies, is trying to answer is whether instabilities in flow are intrinsic to the nature of fluid flow, or is a sediment driven phenomenon. Several studies have suggested that meandering is a property of the flow with sediment playing a passive role (Leopold and Wolman 1957; Karcz 1971; Gorycki 1973; Gorycki 1973b). There are many examples in which meandering is observed in alluvial and non-alluvial settings with no sediment present. These include supra-glacial melt-water streams, millimeter scale laboratory streams, and even the Gulf Stream (Parker 1976).

There are also several studies that have concluded that resistance has a minor role and emphasized the importance of sediment in generating river meanders (Werner 1951; Schumm 1963; Hayashi 1970). Note that meandering and braiding are postulated to be two ends of the same instability phenomenon (Parker 1976). Parker's (1976) results indicate that it is a property of the flow, and these results have been observed in later flume studies (Germanoski and Schumm 1993). This will be returned to later in this paper.

Fredsoe (1978) takes much the same approach as that of Parker (1976). It includes, however, several important enhancements. Firstly, suspended load is considered in addition to bed load. Secondly, "The linearized equations are solved numerically without introducing further approximations, such as the perturbation methods applied by Parker and to some extent by Callander."(Fredsoe 1978). Thirdly, as in the work of Engelund and Skovgaard (1973), transverse slope is again considered. Without going into excruciating detail, the result of his analysis which is the most germane to the study of braided rivers is that the river will braid if its width is larger than about 60 times its depth.

Colombini, Seminara *et al.* (1987) did an excellent numerical study of alternate bar formation in braided rivers, but it is not considered here, as the main focus of this paper will be mid-channel bars. The reasoning for this decision is that while mid-channel bars are a very prominent cause of river braiding, they are also very poorly understood (Ashworth 1996). While it is impossible to say that no more numerical studies of river stability phenomenon and how it impacts river braiding have been done, there are none that present themselves prominently in the literature.

As the surge in computational modeling of flow stability began to wane, another major phenomenon present in braided river systems was recognized. Mandelbrot, the discoverer of the fractal, was the first to apply this concept to hydrological systems in Mandelbrot (1977), and again in Mandelbrot (1982). His approach was reproduced later in Hjelmfelt (1988). In Nikora (1991), it was found that those studies were flawed in the details, but the idea still remained accepted by the scientific community.

The concept of the fractal and its application to rivers will be briefly reviewed here. Qualitatively, they can be described as follows. “The presence of scaling phenomenon means that statistical properties of the phenomenon at one scale relate to its statistical properties at another scale via a transformation which involves only the ratio of the two scales. This implies a certain invariance of the phenomenon under magnification or contraction (scale invariance).” (Sapozhnikov and Foufoula-Georgiou 1996) In river systems, the scaling parameters are anisotropic, they are different in the x and y directions. These are known as self-affine fractals.

There are self-similar fractals whose scaling is isotropic in all directions, but these are never found in braided river systems (Sapozhnikov and Foufoula-Georgiou 1996). The so-called “internal fractal exponents” of self-affine fractals are expressed as (v_x and $v_{y)}$. These are the parameters of interest in conducting a study of river braiding. According to theory, each must be less than two, which would represent the total area being covered with water (Bras and Rodriguez-Iturbe 1990). Note that to ascertain the magnitude of the anisotropy, one can look at the ratio of v_x / v_y (Sapozhnikov and Foufoula-Georgiou 1997).

Self-affine behavior is caused, simply enough, by the effects of gravity. It forces the streams to scale differently in the direction of the gradient and in the perpendicular direction (Sapozhnikov and Foufoula-Georgiou 1996). It is important to note that this behavior only manifests itself in a statistical sense, thus one is not likely to see what we usually think of as a self replicating fractal (such as make popular screen savers) when looking at a river in plan form (Nikora 1991). Each part of the object displaying self-affine behavior is a complete image of the whole scaled differently in the x and y directions. Equation (5) expresses this mathematically, and demonstrates the role of v_x and v_y. Note that M is the mass of the object within a rectangle X,Y. (Sapozhnikov and Foufoula-Georgiou 1996)

(5) $M(X,Y) \sim X^{1/v_x} \sim Y^{1/v_y}$

To ascertain how densely a fractal fills space, one can look at the fractal dimension, which is given by equation (6) (Sapozhnikov and Foufoula-Georgiou 1997).

(6) $D = \frac{(v_y - v_x + 1)}{v_y}$

The general equation which determines whether something is a fractal is given as Equation (7), where M is the number of objects similar to the given one and having b times smaller spatial scale (Nikora 1991).

(7) $M = b^D$

If D is a fraction, the system is a fractal (fractal is derived from the Latin ‘fractus’, meaning fractional). Nikora (1991) goes on to explain that fractal scaling will only occur across a limited spatial range determined by the average object size and the length of correlation. The former is called the internal scale, which is what is of interest in river systems, while the latter is external scale. For a more complete discussion, see Mandelbrot (1977, 1982), Nikora (1991), or Sapozhnikov and Foufoula-Georgiou (1995, 1996, 1997)

One of the first applications of fractal analysis to hydrologic systems was in river networks. These seemed like a natural application, and indeed it was here that Mandelbrot (1977, 1982) applied his energies. Work has continued from then until the present day on several fronts (Tarboton, Bras et al. 1988; Nikora and Sapozhnikov 1993; Rinaldo, Rodriguez-Iturbe et al. 1993; Nikora 1994; Peckham 1995). Peckham's (1995) work in particular brings very abstract mathematics to bare on the problem in the form of modeling river networks using a semi-infinite class of trees based on the Strahler ordering scheme. This is beyond the scope of this paper and will not be discussed further.

The next major step in this line of inquiry was taken by Tarboton, Bras *et al.* (1989). They began investigating the question of whether channel slope in a river drainage network also displayed self-organizing behavior by analyzing data from digital elevation model (DEM) data sets. Amazingly enough, even this aspect of river systems displayed fractal behavior with the area serving as the scaling parameter. Note that self-similar, not self-affine organization was observed in this case. River discharge has even been shown to exhibit self-organized behavior (Rodriguez-Iturbe, Ijjasz-Vasquez et al. 1992).

It was not until the 1990's that work began in earnest to determine how fractal geometry manifested itself in braided river systems.

The last major topic discussed in this paper is mid-channel bars. This is not to say that it is the only method by which braids formed. Ferguson (1993) lists five: chute cut-off, chute-lobe, lobe dissection, avulsion, and mid –channel bar formation. Ashworth (1996) notes that mid-channel bar formation is extremely common, and remains the least understood of all the methods for braid genesis, thus it has been chosen for analysis here. Along with it, energy considerations associated with braiding will also be examined in modest detail.

II. Braiding and Energy Considerations

Before proceeding to more complicated matters, it is necessary to briefly review what governs whether a river will meander, braid, or remain in a straight channel. Equation (8) gives this relation.

(8) [illegible]

Where ε = braiding parameter, m = braiding index, U = velocity, B = channel width, d_0 = flow depth, g = gravitational acceleration, τ_0 = bed shear stress, and ρ = water density. ε can be thought of in several ways. Physically, it is simply the ratio of work done on the bed to available energy from both kinetic and potential sources. An alternative perspective that is useful when considering braided rivers is to think of ε as a measure of "the ratio of the work that must be done to maintain a mode of oscillation [for] m braids" (Parker, 1976).

If ε is much less than one, the river will dissipate its energy via extreme bank erosion. It if is much greater than one, it will do so by extreme braiding. If it is approximately equal to one, then it is likely to be a straight channel. This configuration is obviously only quasi-stable as a little change either way will send it to a meanding or braiding flow regime.

The next question to be addressed is ‘why do rivers braid?’ Classic geomorphic wisdom holds that it is the result of situations in which there is a lot of sediment, a high gradient, and generally just a lot of excess energy to be dissipated.

In 2001, Richardson and Thorne published a study in which, for the first time, researchers were able to measure the three-dimensional velocity fields in braided river flows by using an acoustic Doppler current profiler (ADCP). As their field site, they chose the Brahmaputra-Jamuna River in Bangladesh. They hypothesize that channel bifurcation is *physically* caused by the division of a single channel flow stream into two or more threads of high velocity within the channel which constitute entirely separate flow systems. This happens *before* any depositional changes, and independent of the magnitude of sediment load. Figure (3) shows cross sections of different reaches from their study.

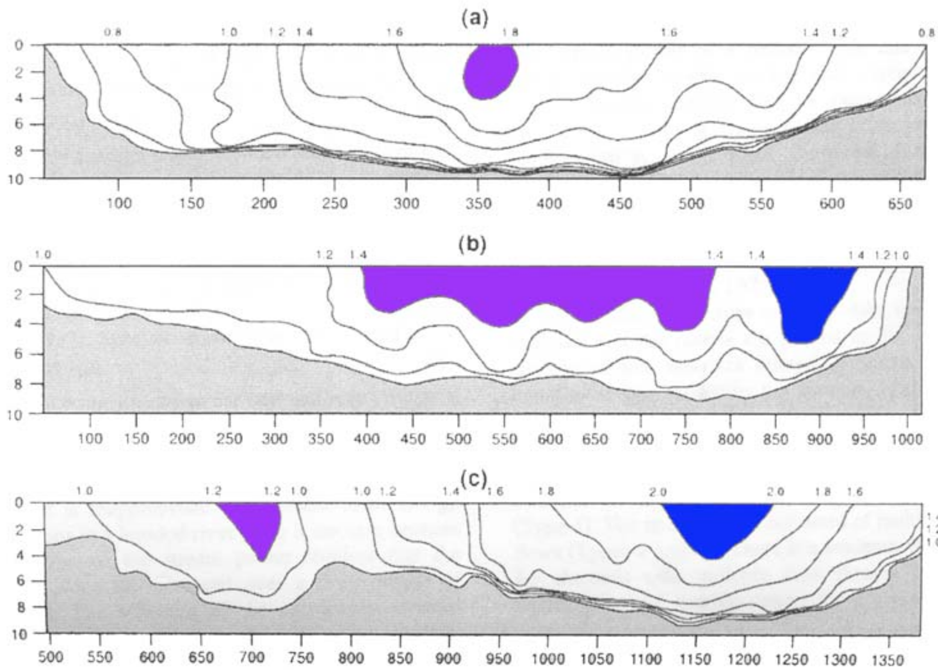

Fig. 3. Primary isovels for: (a) section 5 in May 1994; (b) section 2 in May 1994; (c) section 5 in August 1994.

Figure 3

The figure has been altered in that high velocity threads in the flow have been shaded in. In 3(a), one can see a single channel, single thread flow system. This reach of the river, if fluid mechanics studies are to be believed, will not bifurcate. 3(b) shows a situation in which the flow regime has just divided into two high velocity threads with equal magnitude. 3(c) shows another system in which two threads exist, with different magnitude. For this reach, it is not obvious whether the topographic high in between them represents a mid-channel bar forming, or whether it is a pre-existing variation in the river bed.

They assert that it is in these low velocity spaces in between high velocity threads, such as in Figure (3b), where sediment will begin to be deposited. Eventually, it will accrete into a mid-channel bar.

Experimental evidence from 34 flow data points suggest some interesting physics. Figure (4) is another diagram from their study.

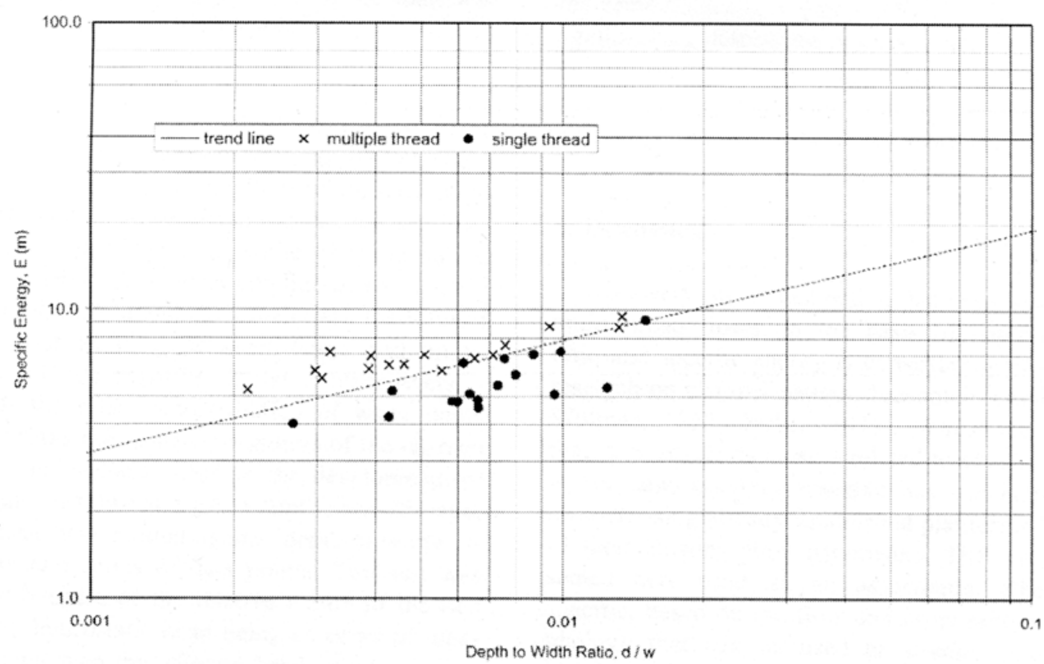

Figure 4

On the vertical axis is specific energy, which is given by Equation (9), where v = the flow velocity, g = the acceleration due to gravity, and d = the depth of the channel.

(9) $$E = \left(\frac{v^2}{2g}\right) + d$$

Specific energy can be though of as representing "the kinematic and hydrostatic energy of the flow at the cross-section." (Richardson and Thorne 2001) On the horizontal is the width to depth ratio. When graphed on a log-log plot, it reveals the startling relationship of a line of demarcation above which the river has multi-thread flow systems and will bifurcate, and below it only single thread. They caution that the numerical value of this relationship is unlikely to transfer between rivers, while the form is. As discharge increases, the velocity of the water will increase quadratically and, once it passes the threshold, start dividing into multiple flow systems.

These results appear to be in agreement with the predictions of Engelund and Skovgaard (1973). They predicted that for a given depth, the river would braid when it had gotten wider than a certain threshold. Thus a point on the graph would move to the left until it had crossed over the line of demarcation. Fredsoe's (1978) predictions offer further insights into the relationship. According to his treatment, the river will braid when its width is larger than about 60 times its depth. This also means that if the width to depth ratio lands it to far right on Figure (4), that there will be no braiding manifested. This would appear consistent with the results of Howard, Keetch, *et al.* (1970) who noted specifically that the degree of braiding increases with the product of discharge and gradient.

As mentioned earlier, the role of sediment runs contrary to traditional geomorphic thought. Parker (1976) showed that sediment is required to initiate an instability in the flow, but to the first order, the (Anderson) wavelength of the instability and numbers of braids are not dependent on the amount of sediment present. In addition, helicity was found to not be required for instability formation.

This immediately brings to mind the systems that were noted above in which flow does meander and there is no sediment present. Parker (1976) addressed this seeming contradiction by explaining that sediment is not the only thing that will disrupt a flow field and cause instability. In the case of alluvial streams, it is sediment transport. In oceanic systems, along with the Gulf Stream, the perturbing force is the Coriolis effect. In supra-glacial melt, the heat differences. In the millimeter scale systems of Gorycki

(1973, 1973b), surface tension disrupts the flow field. Thus, his conclusion is that for meandering or braiding to occur there must be a second condition to disrupt the field beyond friction, and in most alluvial systems, this was done by the presence of a sediment bed-load. The flume studies of Germanoski and Schumm (1993) showed that "changes in sediment load had no tangible influence on the fundamental kinematics of braided channel behavior." The flume studies of Warburton and Davies (1994) found a "weak" to "good" similarity between bedload transfer rate and braiding intensity. This likely is because the water is moving faster and can thus carry more sediment. Since it is moving faster, it has more specific energy, and would cause a vertical movement on Figure (4). These results seem to validate in some measure the fluid mechanical predictions.

Not all studies do agree with these predictions, however. Xu (1997) found that on the Hanjiang River in China following the construction of a reservoir, that there was a relationship between sediment supply and formation of mid-channel bars. As erosion increased, thus supplying increased sediment; he observed an increase in the quantity of mid-channel bars.

We will return briefly to ε, and the energy relations which govern braiding. Most researchers have noted the fact that braided streams are straighter than meandering ones. Remember that ε is "the ratio of the work that must be done to maintain a mode of oscillation [for] m braids" (Parker, 1976).

Consider a river with a high degree of braiding. In a degradation scenario, the ratio becomes smaller, and there is less work available to be done. Consequentially, the first thing that will happen is that the braiding index will be reduced since that mode of oscillation can no longer be maintained. As it continues to degrade, the braiding will keep on reducing, until the point when the braiding index is equal to one. At that point, the number of channels can not be decreased any more, so energy is dissipated via massive bank erosion. This process eventually causes meanders to form.

Aggradation is, of course, just the opposite. Since it causes an increase in braiding, there is a corresponding increase in channel complexity (Germanoski and Schumm 1993). In the flume experiments of Ferguson, Ashmore *et al.* (1992), when mid-channel bars grew, sediment was slowly added to the upstream side of the bar. However, when the water broke around the bar and moved to its side, it would often deposit its sediment there. These neighboring bars would eventually grow until they had coalesced with the original bar. This supports the conclusion that most bars are actually compound structures.

Furthermore, Germanoski and Schumm (1993) showed that, contrary to intuition, while the number of braid bars did increase in aggradation, their size did not. Size actually increased due to degradation because small channels were abandoned, thus forming more composite bars.

III. Fractal Geometry of Braided Systems

The group at St. Anthony Falls Laboratory at the University of Minnesota has done much of the major work in this area. In 1996, Sapozhinikov and Foufoula-Georgiou published a study that had examined three very different braided river systems for self-organizing behavior. As their study sites, they chose the Brahmaputra River in Bangladesh, the Aichilik River in Alaska, and the Hulahula River also in Alaska.

These were chosen because of their vastly different scales and physical properties. They remark that “The Brahmaptura is one of the world’s largest rivers. It starts at Tibet and joins the Ganges near the Bay of Bengal. It is a very dynamic sand-bed river, with intensive bank erosion, mobile sand bars, less mobile islands, and frequent shifting of anabranches and switching flows between anabrances. The braid plain width… reaches 20 km. The mean discharge is around 12,200 m^3/s.” Its annual sediment load is approximately 500 million tons.

In contrast, the other two rivers chosen are both on the North Slope in Alaska. They are gravel-bed rivers, and both are fed by snow, glacial and permafrost melt. The physical properties of all three are summarized in Table (1).

	Brahmaputra	*Aichilik*	*Halahula*
Reach width (km)	15	0.5	0.7
Reach length (km)	200	6.4	20
Mean channel depth (m)	5	1	1
Slope	0.000077	0.001	0.0007
Braiding index	3.8	6.8	5.2
Prominent type of bed material	Sand	Gravel	Gravel

Table (1)

Note that the braiding index was taken to be the average number of channels in cross sectional profiles of the river.

Aerial photographs and satellite images were obtained, and the river channels were traced. This is, of course, the largest source of error. The digitized images are shown as Figure (5)

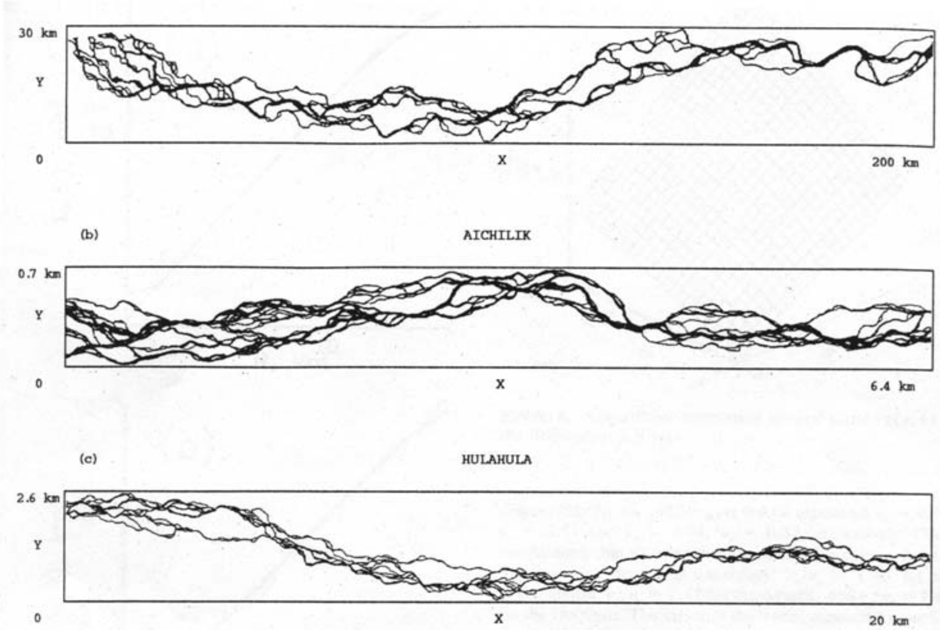

Figure 2. The digitized images of (a) the Brahmaputra River (Bangladesh), (b) the Aichilik River (Alaska), and (c) the Hulahula River (Alaska).

Figure 5

With the x-axis taken to be along the river and the y-axis perpendicular to it, the internal fractal exponents were found to be $v_x = 0.72\text{-}0.74$ and $v_y = 0.51\text{-}0.52$. This is an amazingly small range for rivers which are so different in scale and physical properties.

In 1998, Nykanen, also at St. Anthony Falls, collaborated with Sapozhinikov and Foufoula-Georgiou in doing a similar study of the Tanana River in Alaska, just outside of Fairbanks. This time, they used synthetic aperture radar (SAR) imagery instead of aerial photographs. SAR excels at seeing the difference between rough and smooth ground, along with wetness or dryness of the soil. For a thorough discussion of SAR technology in scientific imaging, see Oliver (1991).

They were able to use several automated techniques in combination with manual steps to map the channel pattern. This is very likely to be more accurate than the approach taken in Sapozhinikov and Foufoula-Georgiou (1996). Its braiding index varied from 3.14-5.35. Other physical data were not given.

One of the most important results found was that self-affine spatial scaling only occurred when there were no topographic constraints placed on the river. Mountains in particular forced the river into a certain path, not allowing it to form the braidplain freely. In addition, if there was a predominant, pre-existing channel, several tens of times the width of the other channels in the braidplain, water would preferentially take that path, again not allowing self-organization to take place.

With the exception of these constraints, self-affine behavior was observed over many different flow regimes and times of year. The internal scaling exponents were found to be $v_x = 0.74\text{-}0.77$ and $v_y = 0.47\text{-}0.50$. This displays a remarkable correlation with the values from Sapozhinikov and Foufoula-Georgiou (1996), $v_x = 0.72\text{-}0.74$ and $v_y = 0.51\text{-}0.52$.

Taken together, the results from these studies offer preliminary results that this behavior may be fundamental to all braided river systems.

IV. Unanswered Questions

In considering the fluid mechanics of braided river systems, fairly accurate models have been developed with both two and three-dimensional treatments. However, in none of the five models discussed has the fundamental question of how slope, width and depth are physically determined been addressed. Parker (1976) mentions this deficiency, and remarks that he has made no attempt to answer it. This would seem to be a major gap in our physical understanding of the systems, and an excellent opportunity for future studies.

While the study of Richardson and Thorne (2001) is quite revolutionary in its allowing us for the first time to examine the three-dimensional flow system of a braided river, the data are still somewhat coarse. Higher resolution would provide a window into the precise physics and circumstances involved in the perturbations of the flow system prior to bar formation. They relied heavily upon the results of fluid dynamics studies, most notably Parker (1976), and all of these required several significant approximations to reality in order to solve the systems of equations. It is very unlikely that they have captured the truth in a precise way. Higher resolution flow system data would prove to be an invaluable tool in ascertaining the fine scale behavior of these systems, which is missed because of the approximations.

It would be interesting to see if the underlying physics were determined well enough, if one could predict channel morphology based upon physical parameters. At present this is beyond the realm of possibility. Mosley (1983) noted that "…prediction of likely changes in the channel character of braided rivers due to changes in discharge does not appear to be feasible"

It has been shown here that many braided systems exhibit self-organizing behavior. Further studies must be done to determine whether this is truly a physical property of the flow, or is caused by some other circumstances which have not yet been identified. From v_x, v_y, and D, it can not be determined exactly what these physical processes might be. If it is fundamental to braided systems, the possibility exists that it might serve to help predict changes in channel morphology.

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