F-R-6

PROCEEDINGS OF

RIVER MECHANICS SEMINAR

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PROCEEDINGS OF RIVER MECHANICS SEMINAR

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The format of the seminar was a panel presentation and discussion. The panel members consisted of three professors from Colorado State University, a potamologist from the Corps of Engineers, and a professor from Montana State University. Each expert gave a short presentation on his particular field of expertise. Questions were encouraged at all times. Following each presentation there was a short period of questions and answers. The last portion of the seminar was devoted to answering specific questions concerning Montana rivers.

Panel Members

Dr. Morris M. Skinner (panel moderator)	Expert on Remote Sensing Applied to Rivers, Colorado State University, Civil Engineering Department.
Dr. Daryl B. Simons	International expert on river hydrology-hydraulics, Colorado State University, Associate Dean of Engineering Research.
Dr. Stanley A. Schumm	Expert on river mechanics from geologic point of view. A geomorphologist with both the Earth Resources and Civil Engineering Department at Colorado State University.
Mr. Brien R. Winkley	Expert on river behavior. Head of special potamology section for the Corps of Engineers, Vicksburg, Mississippi.
Dr. Donald Reichmuth	Civil Engineer at Montana State University doing a study on the Gallatin River and Baker Creek.

INTRODUCTORY REMARKS

FLUVIAL GEOMORPHOLOGY - SCHUMM. A geomorphologist in other parts of the world is a physical geographer--in the U.S. he is a geologist. A geomorphologist is interested in long spans of time. Therefore, we look at rivers from a historical perspective, and we try to interpret past changes and past events. What's happening in a particular bend in the river today isn't of too much interest to us except as these changes can help us to interpret the history of the river. Perhaps my comments will be of less interest to you with regard to practical problems, but they may give you a somewhat different perspective of rivers.

Geologists and ecologists know that there have been dramatic climatic changes during the last million years of the earth's history. This also means that there have been spectacular hydrologic changes, and so we intuitively feel that the morphology of most rivers has changed dramatically during this time. One of the best examples of such changes that I have ever found is the Murrumbidgee River in New South Wales, Australia.

Here is an aerial photograph of part of the alluvial flood plain of the Murrumbidgee River. The river flows across the alluvial plain and has a very sinuous and relatively narrow, deep channel; on the same slide we see a paleochannel that was functioning perhaps 10,000 years ago. The conclusions that we would draw from this slide is that there have been dramatic changes in the morphology of this channel.

Here we have an example of river metamorphosis. The sediment and the runoff source area was unchanged , but there were some pretty dramatic hydrologic changes that have caused complete changes in the morphology of the Murrumbidgee River. The modern channel is 200 feet

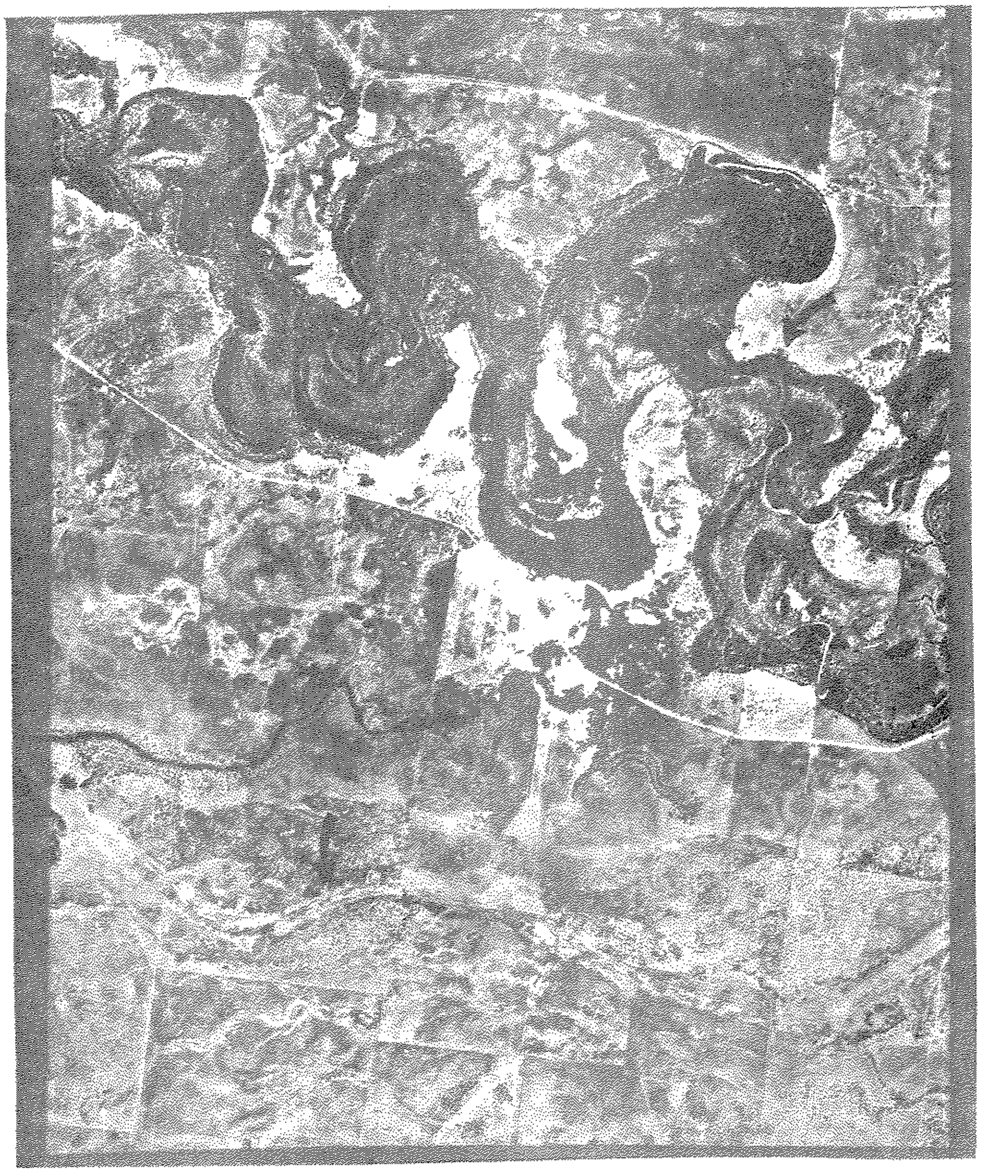


Figure 1. The Murrumbidgee River is shown by the upper arrow. The middle arrow shows young paleochannel and the lower arrow identifies old paleochannel.

wide, 20 feet deep, and very sinuous. The paleochannel is 500 feet wide, about 10 feet deep, and relatively straight. So the climatic changes have caused the system to go from a very wide, straight river to a very, very sinuous river. I think that it is important to note that this river is flowing across an alluvial plain that slopes one and one-half feet per mile. The modern Murrumbidgee River is quite sinuous, with a sinuosity of about 2. This means it is traveling twice the distance it needs to get to the same point; it also means the gradient of the new river is one-half the gradient of the old river. So with climatic changes and the change in sediment load and discharge this river decreased its gradient by developing a very, very sinuous course. This seems to be one way in which a river responds geologically to change in sediment yield and runoff. A river doesn't have to scour because it can change its pattern; in this case, from relatively straight to relatively sinuous.

The present North Platte River near Scottsbluff, Nebraska is another example of a changed river. A very dramatic change has occurred during the last 70 years in the morphology of the North Platte River.

Figure 2 shows the North Platte River near Scottsbluff, Nebraska in 1890. The entire valley floor was the floor of the stream channel in 1890, but since that time dams have been built in Wyoming; the great snow melt floods of the past no longer occur, and discharge has been decreased somewhat due to diversions for irrigation. In effect, man has created a new floodplain in this valley. In fact Scottsbluff City Park now occupies a position that once was in the middle of the 1890 channel. The North Platte River has narrowed from about three quarters of a mile wide to about 200 feet wide in less than 100 years as a result of reduced flood peaks.

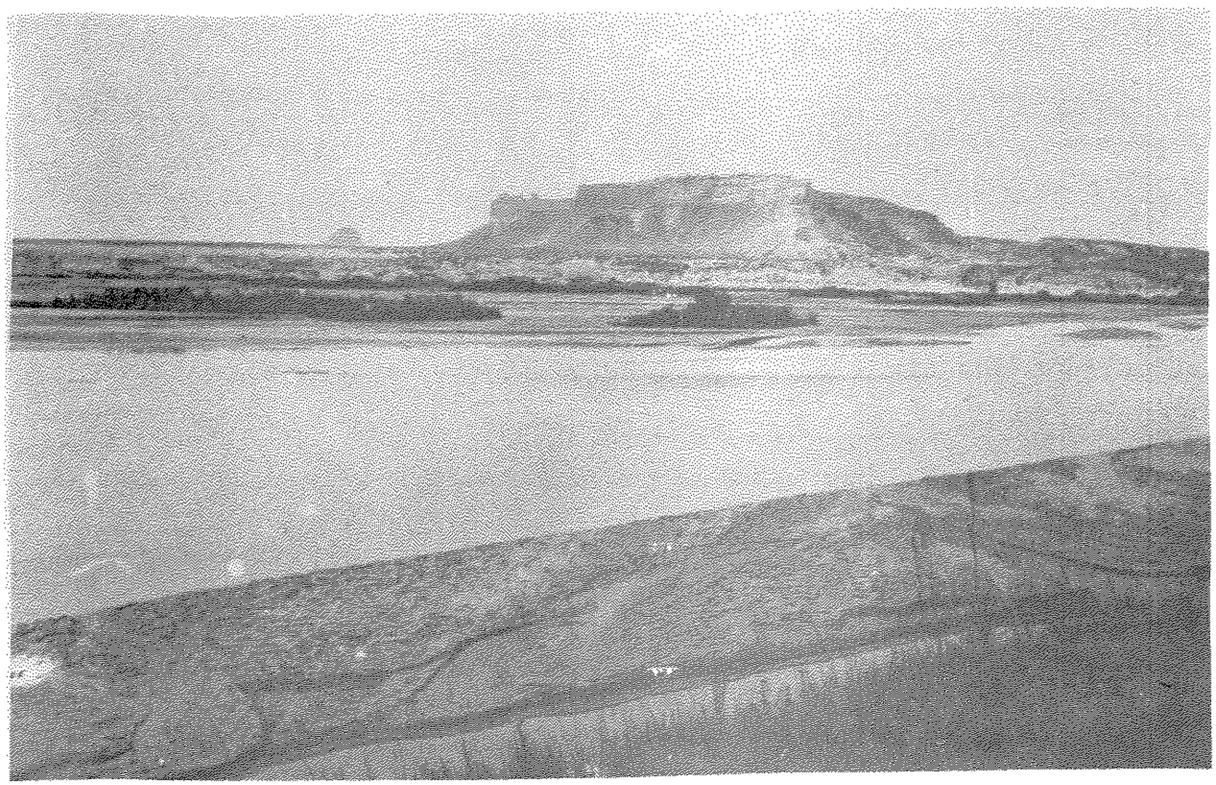


Figure 2. North Platte River near Scottsbluff, Nebraska in 1890.

A good example of the same type of thing, but in reverse is the Cimmaron River in northwestern Kansas, which had a sinuous and relatively narrow and deep channel in about 1890, Fig. 3. At this time the river seemed to be fairly stable, and the wide floodplain produced hay. Note the stacks in the photograph.

Figure 4 shows the Cimmaron in 1942: The average width of the river during the Land Office survey of the latter part of the 19th century was 50 feet. In 1942 the average width was 1200 feet. The entire valley floor had been converted from floodplain to channel, and apparently this was due to a climatic fluctuation. During the 1930's large floods moved downstream and destroyed the meander pattern and floodplain. The end result was that the entire valley floor was converted to a wide, sandy, braided stream channel.

By 1960, the Cimmaron River was much narrower. In 1890 and probably up to about 1915 the river was about 50 feet wide. In the 1940's, the river progressively widened until in 1942 it was an average of 1200 feet wide. Now it is back to about 500 feet wide. So a new floodplain has been constructed in this valley due to climatic fluctuation.

The above examples illustrate how dynamic river systems are and how they adjust to change. Through observations of natural rivers and laboratory models, we have determined that there is a threshold slope below which a stream will not meander and above which it begins to meander. In addition, as we continued with the experiments and progressively steepened the slope of the flume, we found that another critical zone or threshold was reached above which the stream became braided. For example, if sinuosity (ratio of channel to valley length) is plotted against the slope of the surface on which the stream is

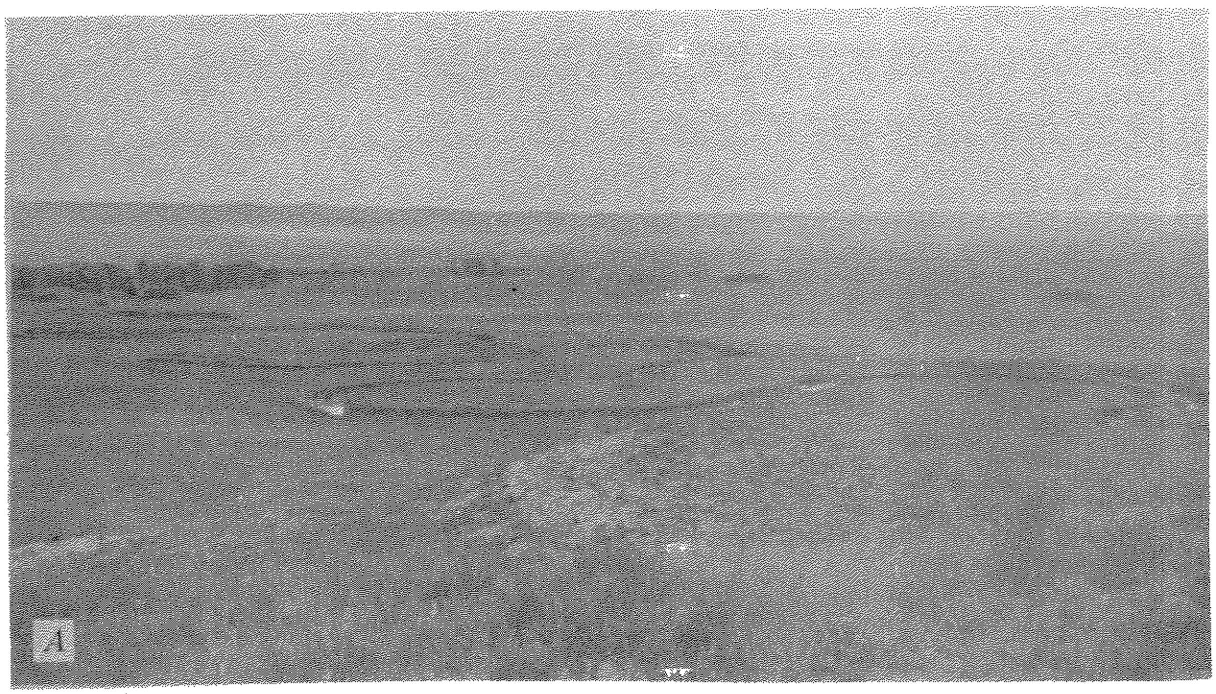


Figure 3. Cimmaron River, 1890.

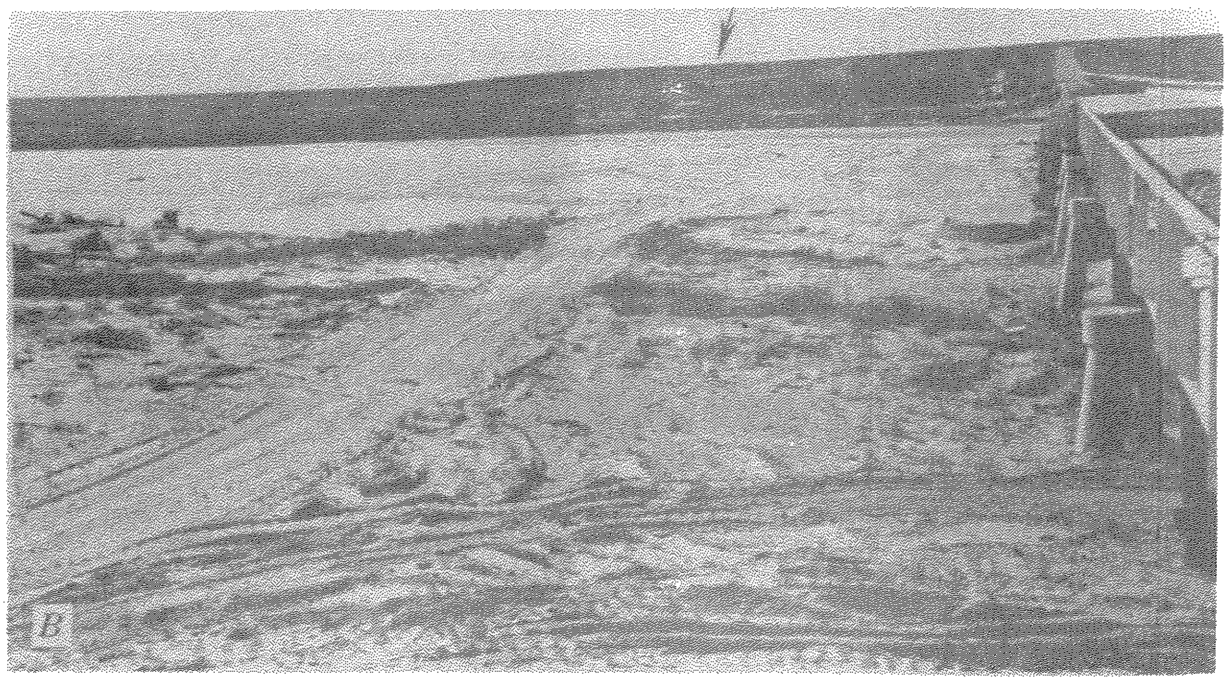


Figure 4. Cimmaron River, 1942.

flowing at one discharge (.15 cfs), we find the channel is straight at relatively low slopes. A slope threshold exists above which the channel becomes progressively more sinuous and at a higher threshold it becomes braided. This is quite interesting geomorphically, as an explanation of the variability of river patterns in a downstream direction. In terms of river control this relation is also important. If these thresholds exist in nature then they have some very practical implications. For example, if you find that you are somewhere near one of these thresholds, you better be careful about what you do to the channel.

This slide is courtesy of Bob Winkley and it looks quite a bit like the previous slide except that it is of the Mississippi River. The valley slope has considerably less slope than that of our model. The discharge is considerably greater, sinuosity is as high as 2, but it shows that for Mississippi River, as the valley slope changes in downstream direction, there are marked changes in river pattern. It is on the steeper reaches of valley slope that the more serious problems of river control occur. These relations show that some rivers may be inherently unstable and susceptible to change.

Question--Did you do anything on velocity and slope?

Answer (Schumm)--Our experiments show that as slope and sediment load increase, velocity increases. In fact, you can plot not only slope but also sediment load versus sinuosity and get the same relationship. In terms of our experiment, slope and the quantity of sediments fed into this system were very closely related. But from a geologic point of view I'd say, the independent variable is really the quantity of sediment moving through the system. The valley slope adjusts and then channel sinuosity adjusts.

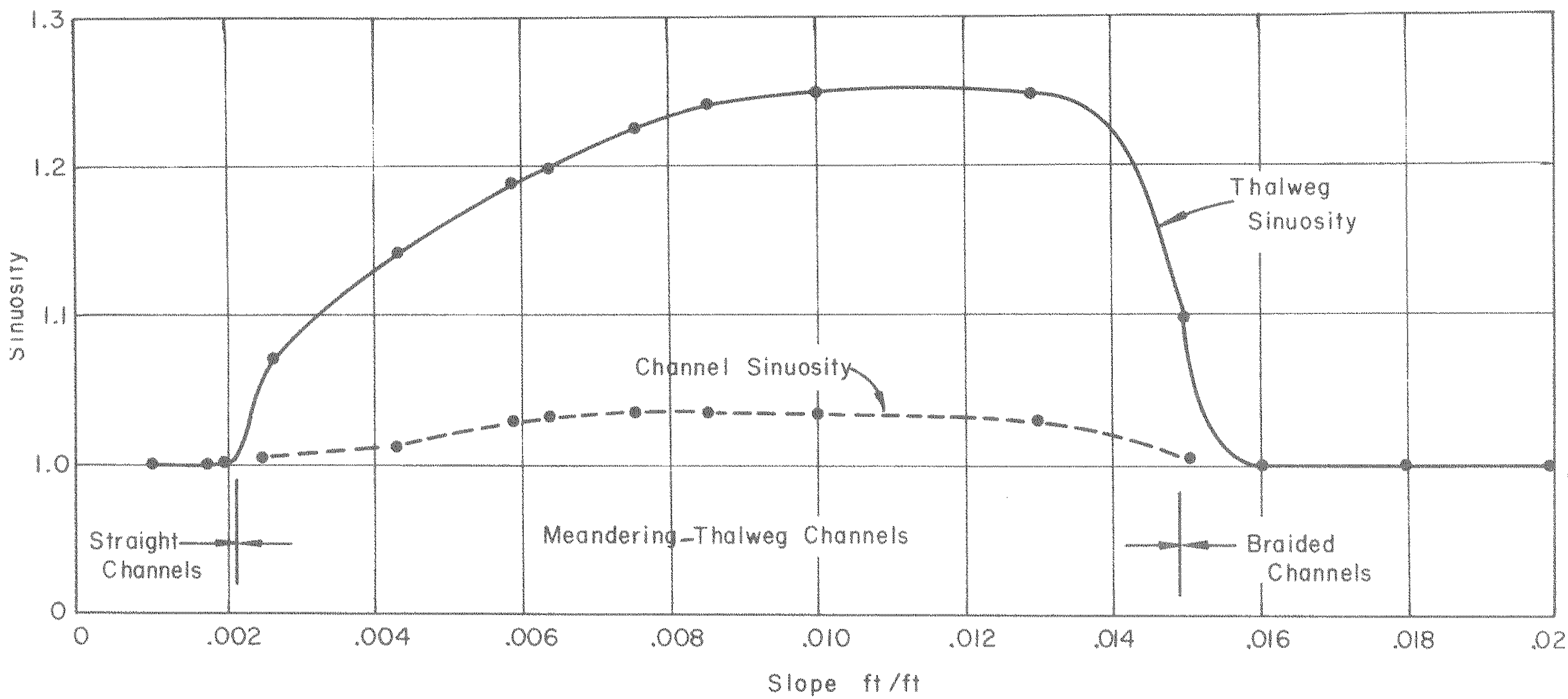


Figure 5. Relation between "valley" slope and sinuosity (ratio of channel length to valley length or ratio of valley slope to stream gradient) from experimental studies.

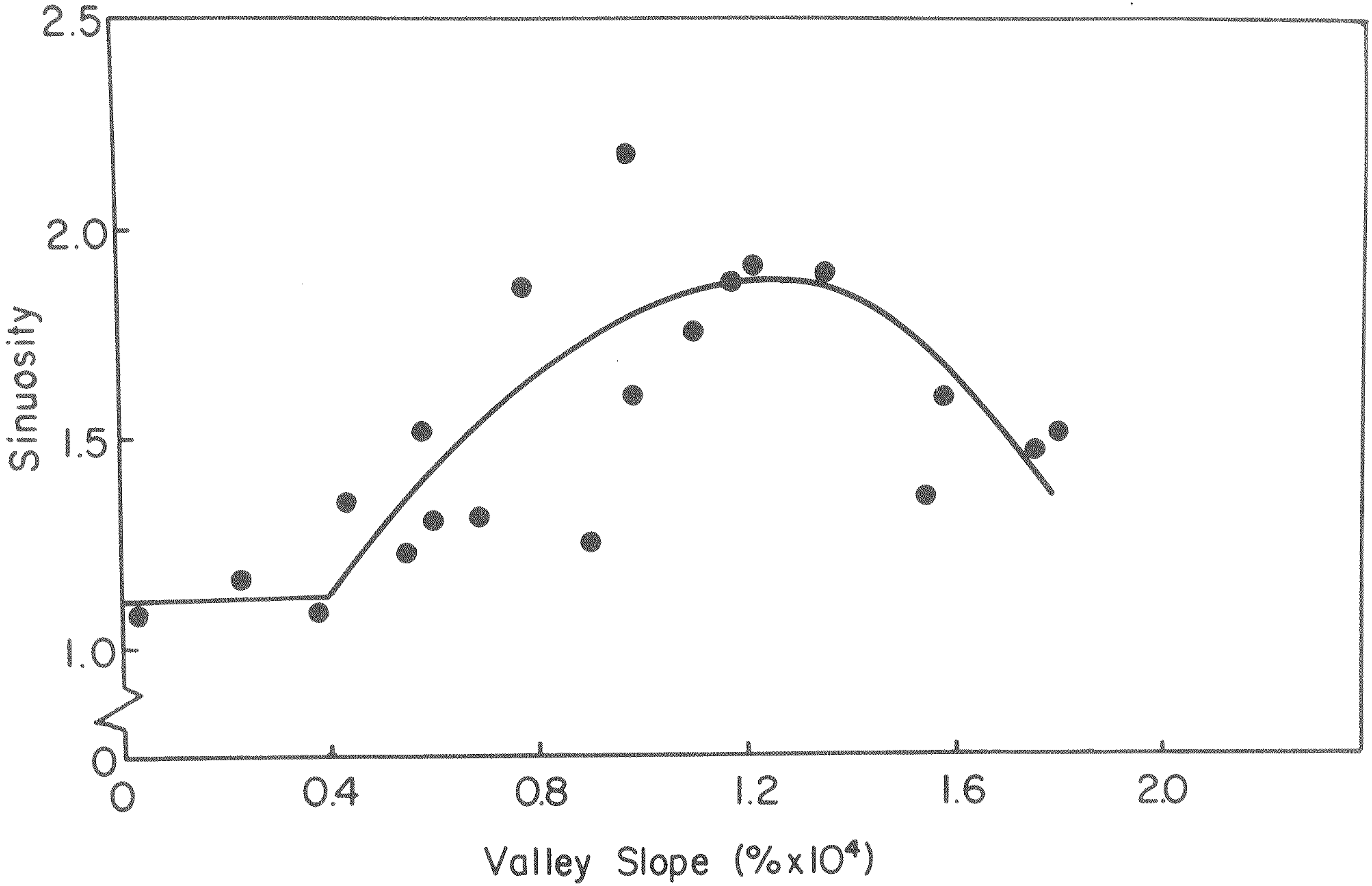


Figure 6. Relation between valley slope and sinuosity for Mississippi River between Cairo, Illinois, and Head of Passes, Louisiana. Data from Potamology Section, U.S. Army Corps of Engineers, Vicksburg, Mississippi.

Question--Are channel changes predictable for given flow conditions?

Answer (Schumm)--In our experimental studies we are now looking at different discharges, and so we are developing a family of curves. The thresholds, of course, are going to shift as the discharge changes. All I can say is that I'm sure that for each river there are these two thresholds--one between straight-meandering, and one between meandering-braided. However, I also want to mention E.W. Lane's work, in which he considered not only laboratory models but also major rivers, which were both braided and meandering. E.W. Lane has complied the available data for a number of rivers. Leopold and Wolman have a similar graph in one of their professional papers which shows for a given discharge and given slope where this threshold should be. Using their relationships (Leopold and Wolman) and other published relationships, perhaps we could roughly estimate where the thresholds are for a given river in Montana or anywhere else in the world.

Question--You had your slope plotted in feet/feet terms. Do you have any idea where those thresholds could be in feet/mile?

Answer (Schumm)--Well, again we were dealing with model in a 100-foot long flume and the gradients are very steep, and I think where the channel began to braid the slope was about 1.5 feet per 100 feet. I doubt if you could find an alluvial stream transporting sand with a gradient that steep.

Winkley. To give you another side of it from the situation on a large river like the Mississippi, the difference between a braided and a meandering stream occurs at about 0.6 foot mile fall in the valley slope. Critical point, if the river maintains less than 0.6 foot per mile fall of valley slope, we have a meandering stream. But, when a channel is straightened, the critical point may be exceeded then a braided stream develops.

Schumm. In a natural situation we felt that the major variable was sediment load. From a geologic point of view (a long time span) the channel patterns are related to valley slopes, and stream gradients are related to quantities of sediment and water moving through the system. You can look at the same problem from a shorter time span, say engineering time, and you can obviously change the slope of the river by realignment. So it depends on the time span you are dealing with. Where we changed the slope in our experiments we had to change the quantity of sand we fed into the system at the upper end. I prefer to think that the quantity of sand was the independent variable. If we had introduced more sand into our system the slope would have gradually steepened and the patterns would have changed as we crossed these thresholds.

Question--What is the reaction or adjustment of a valley stream to an increase in sediment load caused by over grazing or logging? How would the stream adjust to this?

Answer (Schumm)--Well, obviously it will aggrade and the sediment will deposit. New Zealand rivers, for example, changed from meandering to braided streams as a result of vegetation destruction. It may wipe out the meanders and then the river will be straight with a steeper gradient.

RIVER MECHANICS - SIMONS. I want to start out by emphasizing the tremendous variability of rivers; you find some areas totally unvegetated, some densely vegetated, some low rainfall areas, and some high rainfall areas. You find very extreme changes over a relatively short period of time which sometimes makes us wonder about trying to nail a river down or argue against nailing it down, because in many instances old mother nature will override some of the other factors that exist. For example, a channel may only flow a few days of the year, but when it flows it has a velocity somewhere on the order of 10 to 15 feet per second and carries tremendous quantities of sediment that certainly effect the channel on downstream. I think the main point to make is that we've got to look at the problem that exists and decide as a group what we want and then decide upon some measures that we're going to take; and, know that we'll never make anyone, or any single group completely happy. This slide shows that over geologic time the river has been over the total width of the river valley. It never has been possible for us to nail it down in precisely one position and hold it. Naturally, all of these streams, whether they be in cobbles, gravel, sand, or clays, have this tendency to be live dynamic things that are changing with time. Certainly things like major droughts, periods of extreme wetness, and major floods can give us extreme changes...completely change the characteristics of the stream, irrespective of what we would like it to be. As Dr. Schumm pointed out, how these rivers behave is very intimately related to the amount of sediment that they carry. This sediment can come in as a consequence of overgrazing, it comes in as a consequence of steep channels, and/or instability of the bank. It could be due to drought, it could be due to forest fires. But, there can be a tremendous range in the quantities of sediment that can be introduced into these streams, and if you get too much there is a tendency for the stream to "aggrade," then steepen and go to the braided situation. The banks are unstable and you've got a mess.

On the other hand, you might go back another way. Maybe we've controlled the river (dams, diversions, etc.) so that it goes from the wide paleochannel, that Dr. Schumm talked about, to an extremely narrow one. Maybe that is what happened on the North Platte River that Dr. Schumm showed. Years ago there was little upstream development. There was no well-vegetated overbank or floodplain area. Subsequently, as a consequence of river control, the thing has narrowed down and where it used to be a quarter of a mile to a mile wide, it is now a few hundred feet wide. But, I think one of the keys to controlling what happens is to bring in all of the variables and consider these in a realistic way as possible and at the same time realize we probably don't have an opportunity to completely control them.

For example, rather interesting things can happen in rivers. In an instance where "degradation" (cutting down of the channel bed) was encouraged and estimates as good as people could make were made to determine how deep this particular channel bed would scour. They overlooked just a small amount of gravel, less than 2%, in the sand mixture. They'd anticipated this channel bed would degrade downward 15 feet. By the time it had gotten 6 feet down, it had armored itself beautifully and they have not been able to budge it in any way, shape or form to get it to go any deeper. This is sort of an engineering problem, but they are losing 9 feet of head on their turbines. Looking at it from their viewpoint it is sort of a disaster, in terms of power development. But, little things like this can have a big effect on what happens to these streams.

There are a variety of ways that people can attempt the control of channels. In what is called the Miracle Mile, on the North Platte River, not too far from you here, in Wyoming, the Bureau of Reclamation, the U.S. Geological Survey, and the Corps of Engineers did a tremendous amount of experimental work with all types of jacks and controls and planting vegetation to see how these actual control measures would work. They found out that all of these types of structures were almost totally useless unless there was a lot of debris in the water that would hang up on the wires on the jacks. The stream simply moved under the jacks. But, again, I don't know how well acquainted you are with that study, but the Bureau has done a rather tremendous job of documenting the early system, measures that were taken, and the long term response. There were about 20 years of records, several hundred thousand dollars spent. For those of you interested in channel stabilization, it is a worthwhile reference document.

In another example in order to avoid water losses in an irrigation canal they have underlain the gravel with impermeable plastic membrane and laid gravel over it. Of course they control the gradient so that energy in the system is not big enough to move the material. And as long as no sediments were coming in that might deposit, it would stay stable for an extremely long period of time. If you tried to do this in a river, though, as soon as you got flows large enough and velocities high enough that you exceed the critical forces that are required to move it, it starts to slough the banks, slides down, moves it into waves, roughness changes, and you can completely destroy the total effort.

Another example is the use of common rock in a natural channel to make a lined channel; practical in irrigation, not so practical in a natural channel. But, under certain circumstances where the flow only varies between certain limits, it can be used very effectively. We all know from experience with rivers that the outside of the bends generally come under more attack than maybe other positions along the streambank.

In an irrigation canal in West Pakistan, they literally are laying in by hand rocks up to 100 pounds, one on top of the other, like some of the old work done back in the depression days. And again, if you don't have big variation in discharge, for example, in a canal, it may be totally successful. If you try to use that technique in a river where you can go from very low flows to floods, it is difficult to devise a scheme where it is going to stand up indefinitely.

Another type of stabilization that is often used is "gabions" and probably some of you have had more experience with them than I have. This slide shows a classical example of what I think is wrong utilization of them. This particular channel, prior to a very large flood, was a beautifully meandering stream lined with pine trees. Now it is a mess. Now the low flow is developing a meander along here. Instead of trying to get it back to a long-term average condition, they simply straightened and riprapped the side of the road that leads down to the stream (with the gabions). I think one of the tremendous difficulties with this is if they get a flood of any size the larger rocks will start to move. The wire that is holding this relatively small rock in the gabions is going to be just like putting a piece of wire on an anvil and hitting it with a hammer. It is going to cut loose and you're going to dump the rock and it's failed. So depending upon what you wish to achieve, this type of thing might work and in other cases it might not.

Drop structures are another example which are used in getting a big flow from high elevations down into the river. Bank stabilization made out of gabions was used extensively, for example, in Spain and Italy. In this natural stream in Italy, the outside of the bend was unstable. They've actually got little jetties built of rock in here to roughen it up. They think it is a great idea. And, depending upon your views, your objectives, this may work. Considering perhaps other objectives, from the viewpoint of a fisheries biologist, maybe this would not be satisfactory at all, but it is a technique that is used.

Another type of common technique used in the world, if you are dealing with rivers or canals that are carrying relatively large quantities of fine sediment, is to put in temporary roughness along the banks. This has been put in with local vegetation, weeds, shrubs, anything you can get. It slows down the velocity enough so the silts and clays build a berm. The berm is sufficiently resistant to erosion, considering the velocity of the system, that it might hold for 20, 30, 40 years or more before they would have to do something else. In terms of our streams, such as you have, such as we have in Colorado, and other places, we're continually subjecting our streams to change.

Here is a case where, prior to about 1920, this was a small meandering Colorado stream, very stable. Subsequently, through transmountain diversion, more water was brought into this system, and you can see what it has converted it to. The channel bed was degraded on the order of 15 to 20 feet, down to its present level. It left raw banks and carried tremendous quantities of sediment on downstream. It doesn't have the natural pool-riffle-pool sequence. It's basically just a raw channel. Any time that we get significant discharge changes, particularly upwardly, in the magnitudes of discharge in this system, we've got some extremely serious problems.

Question--Are you talking about the overall means or peak flood?

Answer (Simons)--Well, in this instance the channel may have carried maximum flows on the order of several 100 cfs with the mean on the order of 100 cfs.

Question--Where was this stream?

Answer (Simons)--This runs into Long Draw Reservoir, up the Poudre River above Fort Collins. But, then, through the transmountain diversion, an additional several 100 cfs comes in and the gradient is too steep for that much flow. The channel suffers deterioration. This flow has sufficient energy to start to entrain the materials from the bank and the bed and you end up with something of a mess.

Another situation which is comparable is along the Colorado River above Glenwood Springs. In the early 1920's - 1930's they built the highway on the one side of the river and the railroad on the other in order to minimize construction costs. A high berm was built out which encroached on the river from the highway side and another berm was built out from the railroad side. This converted the river into a raging channel not suitable for anything except maybe looking at it. From the viewpoint of fishing, certainly its quality has deteriorated, probably 90 percent compared to what it was formerly. But, now, as you know, with the pressures to obtain wider highways, they are contemplating building the berm out still further. In fact the restriction is how far can you build out to make room for a four-lane highway without getting the level of the water in the river so high that it inundates the railroad on the other side. These types of things, the more you encroach, the bigger the rocks you have to use, and even then we are going to get maximum flow events for which that large material is not going to be stable. It is going to require continual maintenance and in the event of very large floods maybe total replacement.

This slide illustrates additional data facts that can result from a trans-mountain diversion. This slide shows the North Fork at South Boulder Creek in Colorado. Prior to the trans-mountain diversion this was a beautiful little mountain stream meandering with trees along its banks and it supported a reasonably good fisheries considering the quantity of water. However, in terms of Colorado fishing, pressure in many areas is sufficiently great that most fishing is done on a put and take basis. This change in the system was brought about by a diversion of additional water from the Western slope of the rockies through the pilot bore of the Moffet Tunnel that was constructed by the railroad many years ago. The Denver Water Board simply obtained permission to use the old pilot bore to transport several hundred cubic feet per second of additional water from the Western slope through the tunnel to the Eastern slope. The additional water diverted through the Moffet bore was dumped into the North Fork of South Boulder Creek without making any special preparations for its impact on the channel. The addition of a relatively large quantity of water in a rather small system literally gutted the original river valley. There was degradation in the stream on the order of 15-20 feet in some places and huge quantities of sediment were transported downstream to be intercepted by reservoirs. The Denver Water Board is currently attempting to restore the North Fork of South Boulder Creek to a stable useful form by building control structures and stabilizing the banks. They are not attempting to reestablish the sinuosity of the channel. The major effort is to flatten the gradient using control structures and riprap of the banks to withstand the velocities that the banks will be subjected to. In addition, some special efforts are being made to encourage the growth of vegetation along the modified alignment. Even with this effort on the part of the Denver Water Board it will be a long period of time before the scars of erosion disappear. In fact, they probably never will disappear in terms of engineering time.

Another important factor that affects stream systems is the constructing of reservoirs. These reservoirs intercept the sediments and essentially clear water is released downstream of the dams. This results in a change in the water sediment balance of the stream and the stream responds to this change. When we trap the sediment and release clear water we encourage degradation in the channel subjected to the clear water flow. Degradation may be on the order of several feet. It must be emphasized that whatever we do we should take a look at the total system and carefully analyze the effects of our efforts not just on one part of the river system but on the total river system. As a minimum we certainly must consider the hydraulics, the availability of sediment, the capability of the river system to carry sediment and its response to natural and man induced changes. All of these areas are interrelated and interact. If we make a mistake in the assesment of one factor it's possible for us to cause a stream to deteriorate from something of high standards to something of relatively poor quality.

This slide illustrates the effects of gravel operations along our river systems. Often large areas are torn out in gravel mining operation. These large scars if not properly controlled can contribute large quantities of sediment to adjacent streams. The introduction of more sediments into the adjacent streams can cause them to agrade as Dr. Schumm has point out. This increase in sediment stream gradient is capable of changing the system from a meandering one to a graded one. Certainly from the engineering viewpoint the braided channel is much more difficult to control and develop than a meandering one.

This slide shows a relatively large meandering river in the dashed area. Here I wish to emphasize the importance of natural fluctuations on a river system. This river will overflow its banks to a depth of as great as 20 feet annually. Conversely during the dry period the river may be essentially dry. The slide shows the river in the dry state. One can see the pool and the crossing between the two pools. When rivers are subject to such great variations in flow it is difficult to design stabilization techniques that will hold such a river in a given position.

This slide illustrates the effects of unusually large flows on bridges and related structures along river systems. In 1965, we experienced some extremely heavy rain storms in Colorado. The results in flooding caused failure to approximately 42 major highways and railroad bridges over a period of two days. Prior to this extremely high flow many of the channels were quiet meandering streams with vegetation down to the banks. When these rivers were subjected to the raging flood flows even for a short period of time we ended up in many instances with major changes in the river systems with sand, gravel and rocks strewn over the landscape and with the failure of many man-made structures. In other words, man certainly can effect the behavior of river systems by his actions but we must not lose sight of the fact that old mother nature can impose conditions which probably have greater effects on the system than man's effects.

This slide shows where the discharge has cut around one end of an old abutment on a small tributary. Certainly our highway bridges effect rivers large and small and conversely the rivers can have very devastating effects on highway crossings. All aspects of river engineering should be considered when designing any type structures associated directly or indirectly with the river.

This slide shows a cross drainage structure; more specifically, a culvert passing beneath the highway. The stabilization provided downstream of the culvert was not adequate. The stabilization failed and the channel simply headcapped back through the highway embankment and you see the consequences. Such failure certainly emphasized the necessity for adequate design. This slide illustrates the extent to which erosion has extended upstream into the highway despite the fact that supposedly effective measures were taken to prevent such an occurrence.

Our rivers are an extremely valuable resource and are used throughout the world for a multitude of purposes. Certainly one of the major ones is navigation, particularly when large streams are involved. The development of rivers for navigation is not always popular. The discussion of navigation brings up some interesting controvercies. This area of river development for navigation and flood control particularly for large rivers will be treated in more detail by Mr. Winkley. However, whether we deal with large or small rivers we see similar phenomena and can learn a great deal about large rivers by working with small rivers and we can learn a great deal about both by making laboratory studies.

One issue that has been intriguing to me is our lack of ability to recognize what is natural in the river system and what is unnatural. This often causes confusion, especially where the environment is concerned. For several years I have served as a consultant for groups and agencies working on the Rio Grande. If you study the history of the Rio Grande in its natural form prior to man's entrance on the scene the Rio Grande had little or no vegetation along its banks and when it flooded it ran from valley wall to valley wall. The stream was dry in the dry season. In contrast, when it did flow, it carried not only water but literally thousands of parts per million of sediment. Over time, as a consequence of upstream development, sediment load has been reduced, flows have been stabilized and vegetation has developed on the floodplain and along the banks of this river. Coupled with the stabilization of the system and the growth of the vegetation wildlife has moved in and presently the stream is populated with fish. Many of the people view the Rio Grande in this form as being natural. They have either forgotten what it was in its natural form or simply never knew. It illustrates the point that in many instances man's works can improve river systems in the eyes of those interested in water resources development, those interested in agricultural as well as those interested in the environment. We must all learn to work together in utilizing our valuable water resources to achieve an optimum utilization and we must accept that the environmental considerations is a major factor.

POTAMOLOGY - WINKLEY. I would like to start out by defining the word "potamology." Webster says it is "The Science of Rivers." Several years ago the Corps of Engineers at Vicksburg, Mississippi started a potamology section and the main purpose was to start gathering data; first on the Mississippi River itself to see what should be done; and second to study the other streams. The longer I work with rivers, the more I realize how little is really known about them, and how few people have a good feeling for what goes on in a river.

What I thought I'd do is show you a little bit of what we think you should look at when you start studying a river. Then I'll cover a little bit of the cause and effect of what happens if we don't really look at a river in detail, and some of the things Dr. Simons described as bad effects as well as probably some good effects.

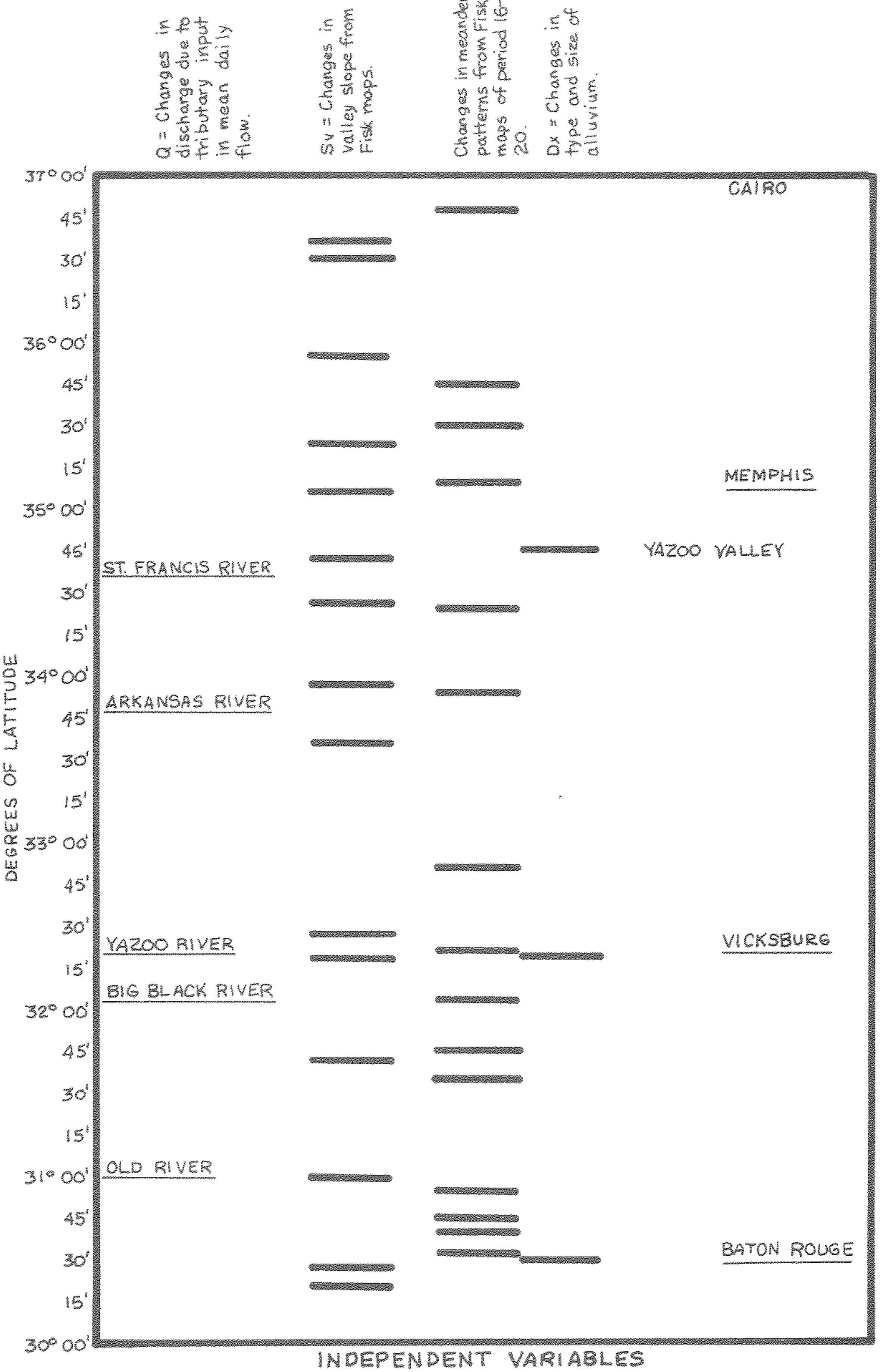
At first, we decided to look at all the variables, but soon realized that we may spend the rest of our lives just trying to list them without ever studying or analyzing them. So we (Corps of Engineers) first decided to take all the variables and put them in broad classifications. From that point, we elected to find out what was the relationship between these broad classifications of variables, and how much emphasis should be put on each variable when studying a particular river. The river will respond very much to the quantity of water, the type of the hydrograph, whether it is a slow undulating flood or one that rises to a sharp peak and falls off, and to the size and type of bed and bank material. In the Mississippi valley, the average size of bed and bank material is 0.4 millimeters. Quite a bit different than I see in Montana. But, we have streams running into the Mississippi valley which have 4 to 5 inches average bed size. So, we have a wide variety of sediments. The rivers range in flow from a few hundred cfs to a million and a half cfs, with slopes from 0.2 of a foot per mile fall to 15 to 20 feet per mile fall; which may still be rather minimal compared to some of your mountain streams. But, still we get enough of a variety so we see how various streams respond.

I think one of the things that we have forgotten in the past, or didn't look at in the past, was the fact that a stream will follow certain natural physical laws and inspite of what we do to it is still going to respond to those particular laws.

Let's start by looking at a river. This is a chart of the Mississippi from Cairo, Illinois down to Baton Rouge. To look at a river of this size, or any size, you start trying to find out what are the basic characteristics of the river. You need to look at where there are changes in flow, where major tributaries come in, where there is a change in the type of bank material, where there is a change in the valley slope and where there is a change in the meandering tendencies of the stream. These characteristics will tell you a lot about how to control a stream in that particular reach of the river.

If you start out and just start plotting points, you may get sort of a buckshot blast graph which will tell you almost nothing.

If you had a constant flow, the river would develop a certain geometry. But, in a river the flow changes. The Mississippi River in low stages flows about 150,000 cubic feet per second. During flood it might flow up to 2 million cfs. You have a change of magnitude on the order of 10 times as much flow at any one time during the year so that the river that is responding differently all the time. But the river, as it occurs in nature, has already responded to all the flows of the previous periods for several years, several decades, or several hundred years, and it is going to tell you something about the characteristics of that river and how you can handle it. Whether you are talking about a river for flood control, navigation, fish and wildlife, good fish habitat, or for something that will handle sediments, it will still say how it is going to respond.



Q = Changes in discharge due to tributary input in mean daily flow.
Sv = Changes in valley slope from Fisk maps.
Changes in meander patterns from Fisk maps of period 16-20.
Dx = Changes in type and size of alluvium.
37° 00'
45'
30'
15'
36° 00'
45'
30'
15'
35° 00'
45'
30'
15'
34° 00'
45'
30'
15'
33° 00'
45'
30'
15'
32° 00'
45'
30'
15'
31° 00'
45'
30'
15'
30° 00'
DEGREES OF LATITUDE
CAIRO
MEMPHIS
YAZOO VALLEY
ST. FRANCIS RIVER
ARKANSAS RIVER
YAZOO RIVER
VICKSBURG
BIG BLACK RIVER
OLD RIVER
BATON ROUGE
INDEPENDENT VARIABLES

Fig. 7

The heavy black line in this sketch of the Mississippi is the meander belt as it was before the Corps of Engineers decided to straighten the river out and control the floods. The dotted line is the top bank of the river today and we'll all lose our jobs (Corps of Engineers) if we don't keep the river within that. We've confined it. We have taken the river out of a 15 to 20 mile wide meander belt and confined it down to something less than 2 miles wide. We have changed the sediment transport. The sediments used to be able to erode at a bendway and deposit on the next bar, then erode the next bendway and deposit on the next bar, and slowly work its way downstream. But, the movement was more lateral than in a down-valley direction. When you confine a river, whether it is the Mississippi River or any other one, you are very liable to increase the down-valley movement of the sediment. Some place along the line you might reach a slope condition that can't carry those sediments so deposition occurs. A building up of the bed of the river occurs and a problem is created.

Normally a river is a combination of pools, crossings, and bars. The pools won't always be nice pools around a bendway with a crossing to a pool on the opposite bendway. Every time you lose a particular curvature in the Mississippi, or any other river, the deep pool will start to deteriorate, the river will try to make a crossing. Now, if there is some other structure or some other control in the river, it may bob back to the proper side again and continue. What I really wanted to show here is that a river will consist of a series of pools and crossings (or riffles). Normally in nature, and in a well controlled river, you'll have a pool on one side of the river and it'll make a crossing, come around the next bendway, make a crossing and continue around the next bendway.

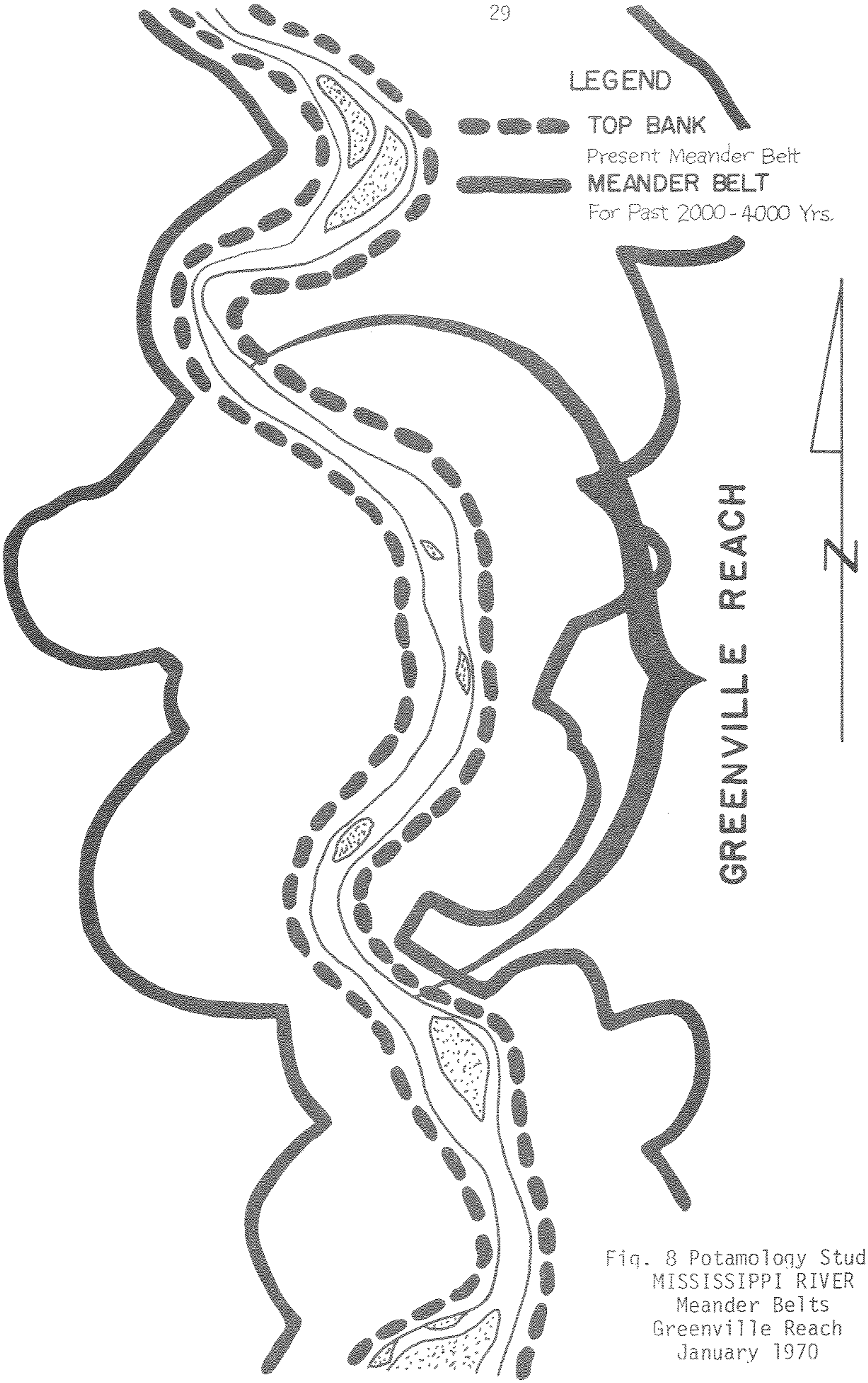


Fig. 8 Potamology Studies
MISSISSIPPI RIVER
Meander Belts
Greenville Reach
January 1970

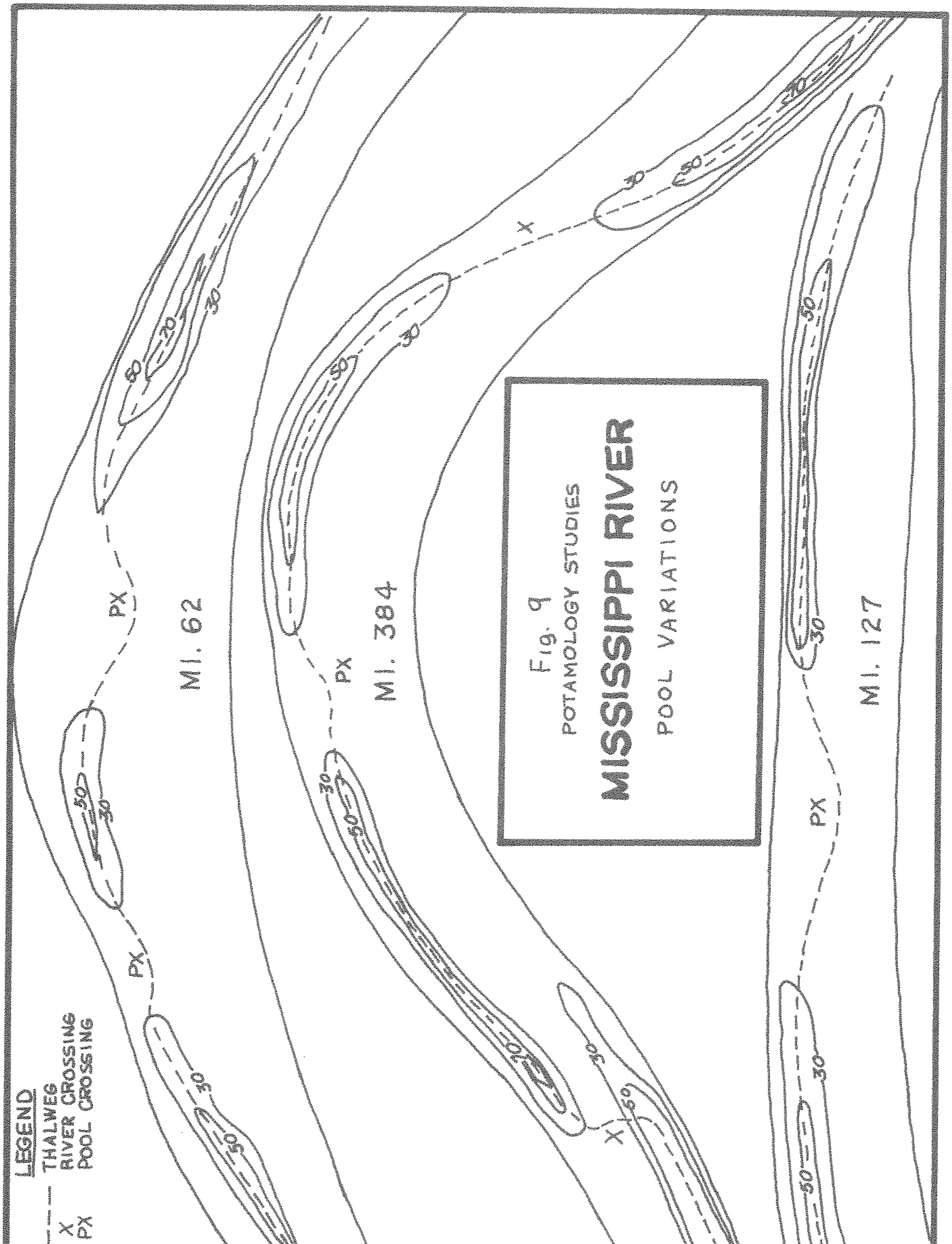


Fig. 9
POTAMOLOGY STUDIES
MISSISSIPPI RIVER
POOL VARIATIONS

Several years ago, some laboratory studies consisted of starting with a straight channel and letting a meander belt develop. It was found that where they kept the bed and bank material the same and where they kept the slope of the channel or slope of the valley or the flume the same, the river would develop a meander pattern. What were alternate bars, would become the meander loops of the river. The distance between the meander loops and the distance between the alternate bars were the same. This interested me and I went back and looked at the "cutoff program" of the Mississippi River which started in the 1930's. The literature on cut offs has always bragged about what a wonderful thing the "cutoff program" was. "It got the water out of the valley faster, it decreased a lot of floods." Momentarily, it did. But, we took a sinuous river and almost made a straight river out of it. It is trying very hard to get back to its original shape again. In the meantime, we crossed over a threshold in many places and made divided flow sections which were poor for navigation, poor for flood control, and poor for sediment movement. In fact, in a 300-mile reach of the river 20 years ago we had 15 divided flow reaches (middle bars); today, with expenditures of some $20 million per year, we have 62 divided flows.

Everybody uses the words straight, or braided or sinuous channel. I personally don't believe there is such a thing as a straight channel. You might have fairly straight channels as far as the top bank is concerned, but the thalweg always has a sinuous course within its own top banks. Now, whether you have a fairly straight alignment or a very sinuous alignment, we found one thing; as long as there was a fairly smooth bend the pool continued. As soon as the radius of bend changed a crossing began. You people are probably interested because of fish

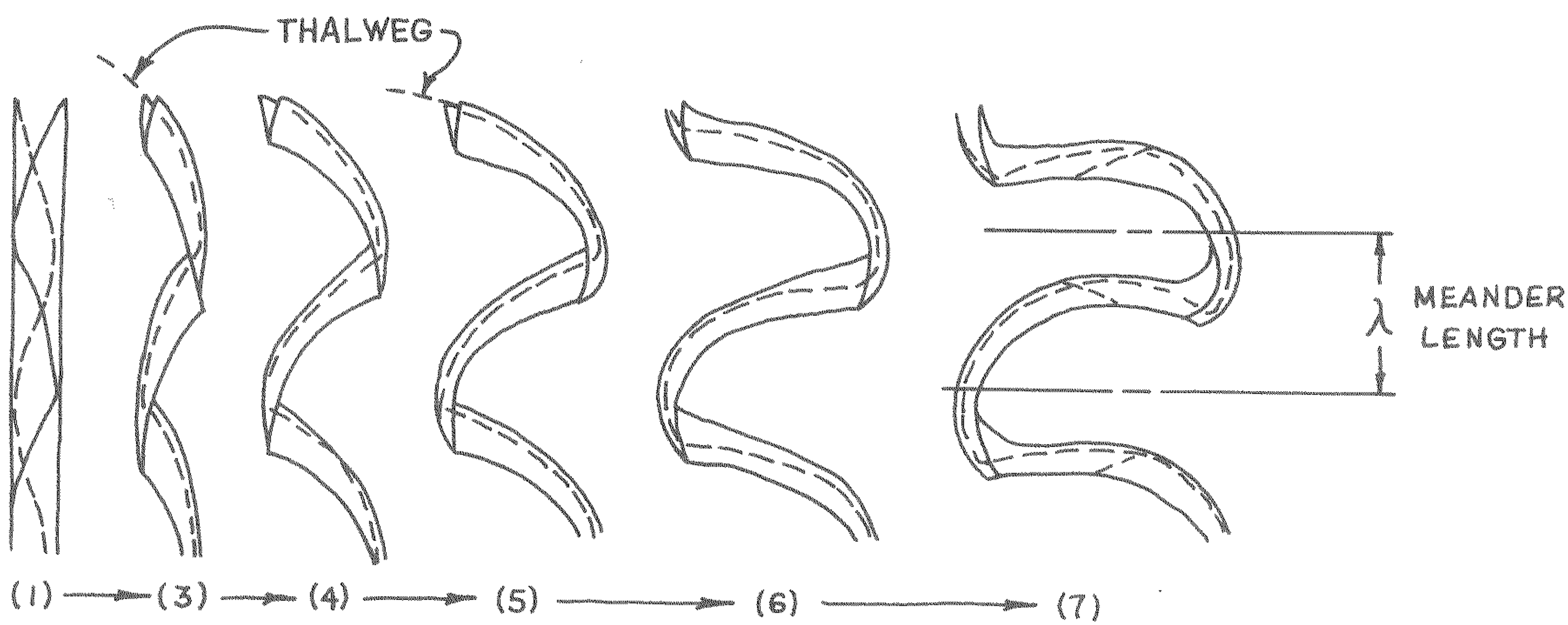


Fig. 10 Potamology Studies
Geometric Stability Analysis

MISSISSIPPI RIVER
The Development of Free
Meandering From Straight
Alluvial Channel
(After Kinosita)
June 1970

habitat to keep these pools in the river and not have a flat, shallow cross section. In order to maintain pools you have to keep good geometry to the shape of the river.

To get an idea of how often you should have pools and bars in a river, we went back and looked at two old surveys of the Mississippi River made in the 1800's and early 1900's to see what the river did under natural conditions before man had a chance to do anything to it. We made a frequency analysis of the occurrence of the distance between the bars in the river and we found that the average distance between pools was around 4-5 miles, Fig. 11, in the Vicksburgs District. Well, that data started to tell us something. We wondered what would happen to the river after you start to straighten it out.

We went back and took some of the old geological maps of the river and measured the distance between the meander loops and found that we got the same sort of frequency. Anomalies occurred in the regions of recent natural cutoffs.

On the Mississippi, the main purpose of straightening was flood control. The farmers were happy because of lower flood levels and lower water tables. In Mississippi we get about 50-55 inches of rain a year. The farmers like to have the water table lowered. It made a lot more usable land. Now, shortly after this staightening the channel built up alternate bars after the first runoff.

Another example of the same thing in the Misssissippi area is where a particular government agency (and I won't mention the name of it) has gone through and taken every channel of every stream and every drainage ditch, and straightened them out. Now the entire country is becoming unravelled. A recent survey states that if this is allowed

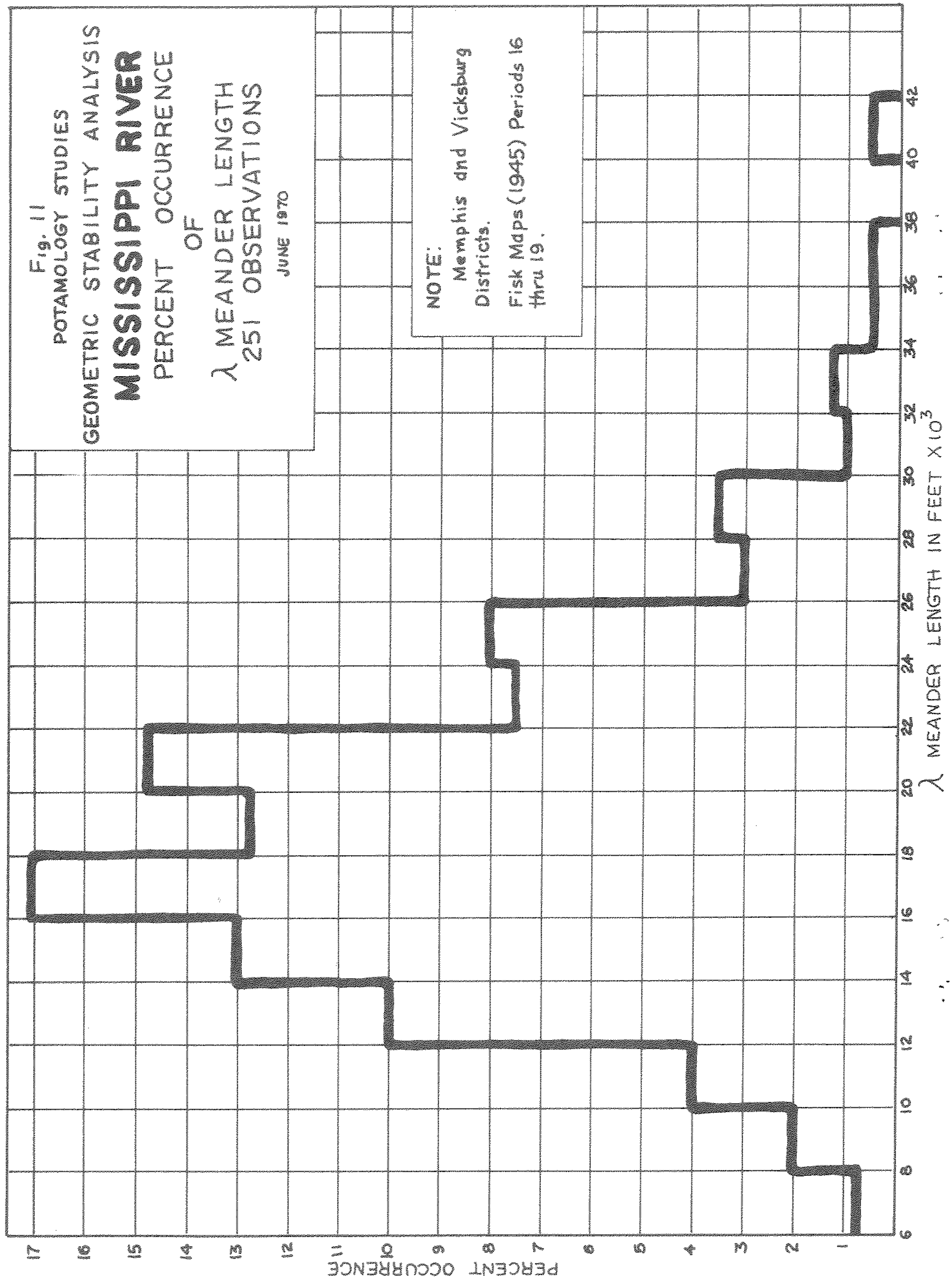


Fig. 11
POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
PERCENT OCCURRENCE
OF
λ MEANDER LENGTH
251 OBSERVATIONS
JUNE 1970
NOTE:
Memphis and Vicksburg Districts.
Fisk Maps (1945) Periods 16 thru 19.
λ MEANDER LENGTH IN FEET X10^3
6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
PERCENT OCCURRENCE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

to continue that within some very short period of time, 50 percent of the farm land they created will be destroyed through erosion.

In the Arkansas River the Corp recently did a large rectification on a section of channel making a navigable stream out of it. The Arkansas at one time was a braided channel and during low water you could drive a car, pickup, motorcycle, or anything you wanted across portions of it. During high water it carried as much as 400,000 cubic feet per second. Upstream reservoirs and a series of locks and dams made a stream that's usable and took out the danger of floods. The Arkansas River used to be the color of coffee, brown, dark, and murky, heavy with sediments. It was unusable for anything. The current meander belt is quite wide. In harnessing the river for navigation they forgot a couple of things. One, the proper geometry of the stream; and two, control of top banks. A series of dikes (stone dikes) were put in to hold the bank at a certain width. The outer bank was revetted with riprap. Now, where the natural banks stop, they can't maintain navigable depths because the flows that flush the sediments through now leave a deposit of material. If you are going to control sediment and water, you have to control the top bank as well as the low water channel.

As the sinuosity increases and as the valley slope increases, you get a point in any river where a braided type stream develops. In the Mississippi valley, at about 0.6 foot per mile, normally a braided, multiple channel exists. At slopes less than 0.6 foot per mile we can do a lot of things to the channel, and the hydraulics will take over and build back a channel like we want. For another river the slope might be several feet per mile. It depends on the particular river. The only way you are going to learn it is to study the stream.

The Corps of Engineers took 632 miles of the Mississippi River in the 1930's and 40's and made 481 miles of it. At this particular location on the river is the famous "Greenville Bends." Forty-five miles of the river were reduced to 12 miles. Today, 35 years after these cutoffs were made, even after we have tried to hold it in this rather strange shape, the river still built back a series of pools and crossings. They are short, but they are exactly oriented to the pools and crossings of the old bendways.

Another example is "The Rodney Cutoff." Today this portion of the river is a problem area and has been since right after the cutoff occurred. Every year for several weeks we dredge to keep the navigation channel open.

Last year on the Mississippi River there was 230 some million tons of freight shipped past Vicksburg, and it has doubled about every 10 years. So the river has to be kept open from a freight problem. But, the main reason I'm showing you these is to show you what happens when you start disrupting a river, and that seems to be the one thing that everybody wants to do; straighten them out, flush the stuff through, build a highway or railway along it, bank the river up against, it, and squeeze it out. Whatever you do be sure you don't forget what the river is going to do by itself.

One good parameter that describes what is going on in a river is the width-depth ratio. The higher the width-depth ratio the less efficient the channel is.

In a typical valley you start out up in the hills, the mountains or anywhere else, with a small stream that gradually grows into a big stream. What I want to do is show that no matter what you do to this system, anywhere in it, you are very likely to cause changes in the entire system. Now the speed at which you will see those changes occur, and the magnitude of the changes will depend on the slope of the valley that the river is running through. Major changes higher up in the valley will probably occur within the first hydrograph. Changes downstream, however, may take 20, 30, or 40 years. Sometimes the changes may be so slow something else will happen and hide or "mask" the response of the first one.

On a particular stream back in the '40's and '50's a lot of reservoirs were put in to control the flood. From '41 to '54 all of the reservoirs were built and we lowered the flow line of these streams roughly 4 feet at all stages.

When working with a river all we have to do is know what the river is going to do and work with the river instead of against it. We don't try to understand a river. Somebody decides they want something done and they don't look at the consequences. They don't consider whether they are helping the farmer and hindering somebody else; or whether they are helping the man that has navigation interests or controlling floods or what other damage they might do. What I'm trying to bring out is that when you do something to a river, look at all aspects of it, consider every possibility before you start doing anything.

West Gallatin River - Baker Creek Stability Study - A Progress Report

By

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I would like to present to you a brief progress report on what I am doing on the West Gallatin River. Figure 12 shows the river and the surrounding area. There are a couple of unusual stream patterns in the area that bear some further examination. First, why do all of these rivers come together at a point north of Three Forks? It seems a little unnatural. Also why does Baker Creek exist? At this point in time Baker Creek has no upstream surface connection with the West Gallatin River. Therefore, Baker Creek is independent, at least at the surface, of the main branch of the West Gallatin.

There are three controlling geologic conditions which explain there patterns. First, the Jefferson, Madison and East Gallatin Rivers are all flowing against north or west sides of their valleys. This is caused by a regional tilting of the entire basin to the northwest. Second, the Madison Plateau region consists of series of fairly young and weak sedimentary rocks which have a gentle northeast dip as is shown in Figure 12. This dip is less than two degrees. Third, at points A & B on Figure 12 the rivers flow over very resistant Precambrian rocks. At these points it is very difficult for the rivers to downcut and local base level control occurs. These base level controls force the rivers to dump considerable bedload above these points.

The channel pattern which develops on a given stretch of river depends largely on the material balance of the alluvium moving through that section

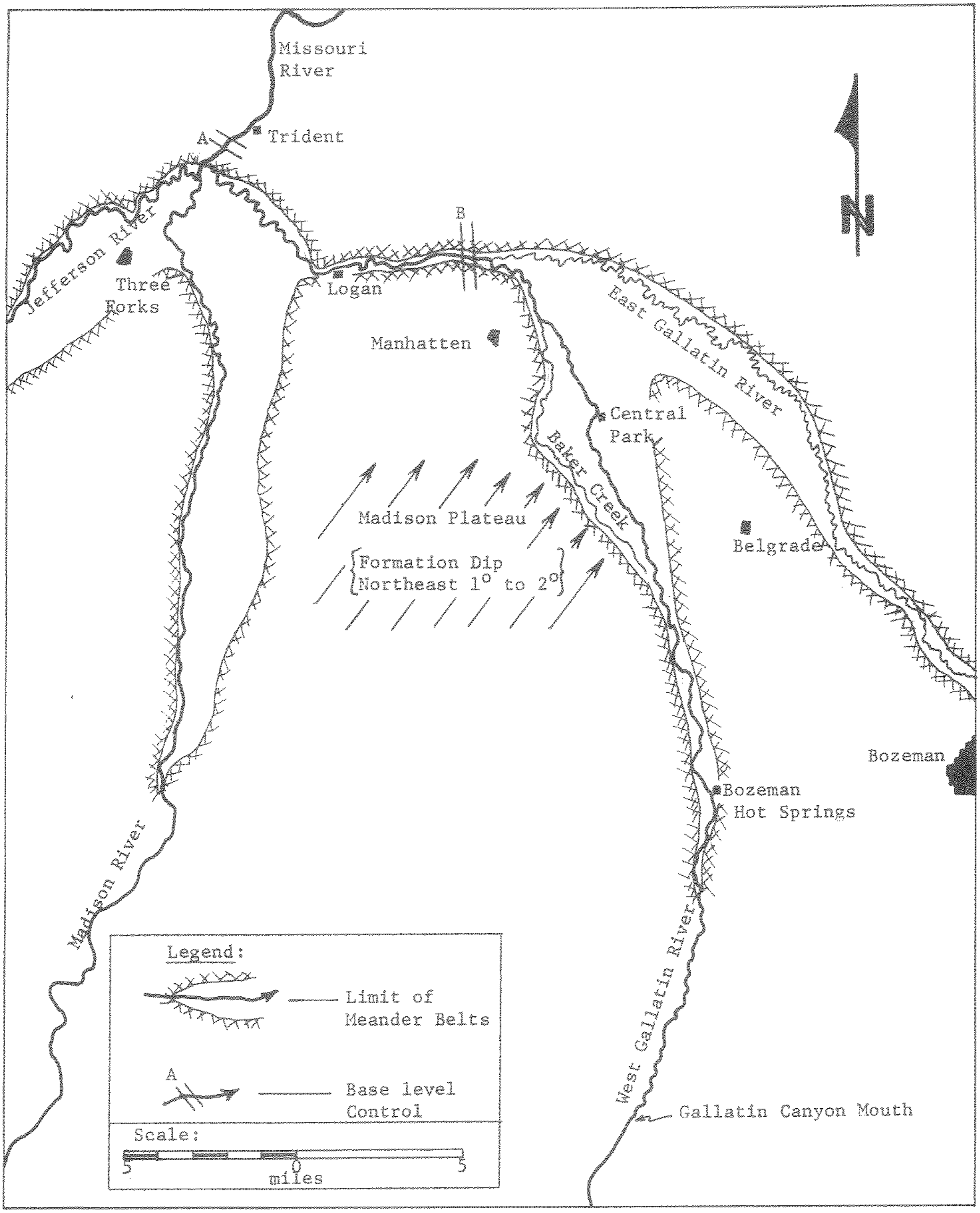


Figure 12 -- Map of the lower West Gallatin River and surrounding area.

of the valley. Figure 13 summarizes the relationship between channel pattern and material balance. The portion of the West Gallatin River shown on Figure 12 has all three of the listed environments. The location of these environments are approximately shown in Table 1.

Approximate Location	Material Balance
Headwaters	
	Gain (Erosion)
Mouth of Gallatin Canyon	
	Zero (Dynamic Steady State)
Bozeman Hot Springs	
	Loss (Deposition Larger Sizes)
Junction of East & West Gallatin	
	Gain (Erosion)
Logan	
	Loss (Deposition Smaller Sizes)
Junction Gallatin & Jefferson Rivers	

Table 1 -- Material balance for the West Gallatin River

The spring flood is almost the entire story on the development of these material balances.

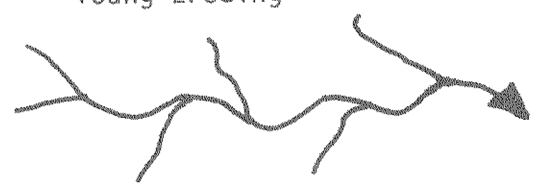
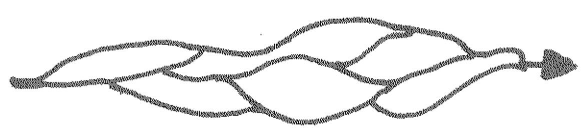
Solids Into Valley	River Type	Solids Out of Valley	Material Balance
None to All Sizes	Young Eroding  Steep Sided, "v" Shaped Valley	Increased Amounts of All Sizes	Gain (Erosion)
Usually Medium to Finer Sizes	Meandering  Narrow to Wide Valley	Size Range Same As Entering Material	Zero (Dynamic Steady State)
All Sizes	Braided  Usually Wider Valley	Finer Sizes Only	Loss (Deposition)

Figure 13. River types showing their associated material balances.

In our situation we have the gradient controlled by bedrock (Points A & B in Figure 12)and the discharge is determined by the magnitude of the spring runoff. Also because the area within the canyon is actively eroding there is large amounts of sediments entering the lower sections of the West Gallatin River.

Now the problem that arises is what is the stability of the lower West Gallatin River? Remembering that the Jefferson, Madison, and East Gallatin Rivers are definitely moving either west or north due to regional tilting. The question arises concerning possible movement of the West Gallatin and if it is moving what are going to be the controlling factors? Presently there is a strong tendency for flood waters to be diverted down Baker Creek (Figure 12). This October I estimated that Baker Creek was carrying in the neighborhood of one-third the water of the West Gallatin River although it has no connection to the river and has very little intake area compared to the West Gallatin River which has an entire mountain range for intake. Also considerable quantities of large sized gravel are being deposited in the Baker Creek section of the West Gallatin. People are in there with bulldozers, trying to clean irrigation diversions, channel straighten, and pull snags out of the river. There are a lot of band aid activities going on, but none of these activities will greatly alter the basic relationships which govern this section of river.

We have a braided agrading stream in the Baker Creek section. There is an influx of solids that has basically all the size ranges to some maximum size of probably 4 to 5 inches. Once you pass through this section you have only much smaller material being transported. This braiding configuration is basically the same mechanism that develops a delta. The only reason that you have a braided stream is the fact that once the water drops its bedload it has to get back into a channel to keep moving. The material is dumped in one channel until it gets too high. A new channel is then formed and the process is repeated. As time passes the channels continue to move. The water simply acts as a dispersing mechanism for the solids. As indicated in Figure 13 this type of an agrading section will certainly behave differently than a meandering or eroding section. In a meandering section, usually you have about the same size and amount of materials moving through the section which then indicates that your material balance basically is zero. This action produces a dynamic steady state where the river basically moves laterally and material that is eroded off of one bend is deposited very close by. At best, we have a slow migration of material downstream.

In an eroding section like in the Gallatin Canyon, there develops a "V" shaped valley and the stream tends to be more straight. Normally all sizes of material are coming in and the net amount of material being carried increases. What happens in general is the material is picked up from an eroding source area, it can be transported through an area of equilibrium, and ultimately gets deposited in an agrading area.

Narrowing our attention at this point to the Baker Creek section, we will see how this small area is being affected. Figure 14 shows a detailed schematic diagram of this area. The West Gallatin in this area is clearly caught in a very shallow trough with the northeast dipping beds of the Madison Plateau (Figure 12) forming the west flank while recent alluvial deposits of the

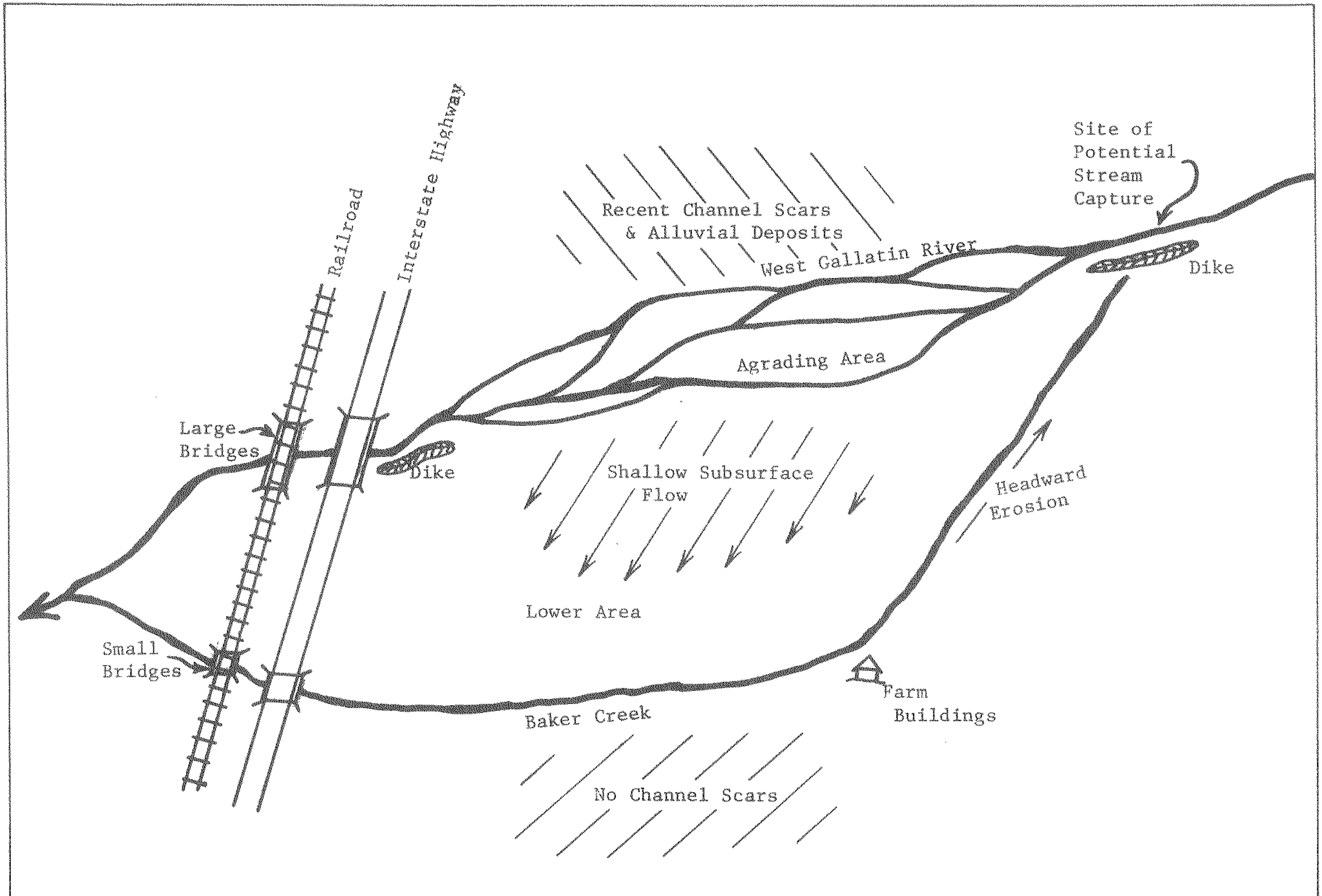


Figure 14 -- Detailed schematic diagram of the Baker Creek area.

river form the east flank. The agradation which is occurring is filling the trough and the northwest regional tilting is slowly forcing the river to migrate westward. At the present time Baker Creek has well vegetated banks and there is very little sign of bank erosion. However, it is tending to lower its channel bottom by headward erosion because of the accumulation of subsurface flow derived from the West Gallatin. Of course as it lowers its bed more subsurface flow will be obtained. This cycle is obviously progressive and without man's intervention Baker Creek would ultimately capture the entire river.

If you owned a farm on Baker Creek you would be awfully unhappy if the West Gallatin River and all this water ended up in your backyard dumping its sediment load. We also have rail and highway structures over Baker Creek which are too small to handle the entire flow. With such complexities, do you keep the river where it is or do you let it divert into Baker Creek?

We still have to determine the rate of material deposition, the rate of stream shifting and what effect man's activities have had on these natural processes. We plan to do the following. First, we will define the historical behavior of the river. A hundred years ago, 1868, the original survey of this area was completed. When streams cross the section lines, their position, width and basic direction of flow was shown. Using these data along with other old surveys and more recent aerial photos, we can get some idea of the long term river stability. How man is starting to modify this stability should also be evident from this historical examination of the records.

Next thing that we will attempt to do is to try to define the agradation rate. If you have a 100 year record of where the river was, hopefully you can find a spot where there have been abrupt channel changes. Hopefully you can dig up the sediments on these old channels and find out what the bed level was at that time. It certainly will be difficult but we should be able to come up with some sort of rate of agradation for the river and a determination of the volume of material that is actually coming in for a given time span.

At some point one must decide what to do with the system. Locally, near Baker Creek, I think we can see a couple of the alternatives that are probably open. You could let the entire river divert to Baker Creek and somehow try to protect the farmers and structures that would be affected or you could attempt to hold the river near its present location. One thing is for sure through, the material which is depositing in this area isn't going to disappear by evaporation. If you get it past the present deposition location who will be the one that lets the material deposit on his land downstream? You've got to make a decision concerning what you are going to do with this material.

You can do about three things as I see it now. You can channelize the river all the way to Canyon Ferry Reservoir, and dump it in the reservoir; or you can move it on down the river to the area near where the Missouri starts; or you can dump it in the Baker Creek area. Certainly if you want to hold it in the original channel you're going to have to somehow levee it, build side boards on the sides, and so you end up having a minature Mississippi levee system. As the river continues to agrade you will have to keep building the levees up higher and higher in the air and, of course, each foot you've raised the river above surrounding ground, the more expensive it gets. The other choice is to let it divert into the Baker Creek area and dump its load there. This undoubtedly would cause the farmers and others in that area problems and you'll have all those people on your back.

Anyhow, someone is going to have to come up with feasible solutions for this deposition. The final choice will ultimately have to be a political decision that does the most good for the most people, taking into account all the interests. I think basically that is where we've been and where we're going. I'll entertain any questions at this point in time.

(Question - Answer)

Question - Boland - Are there still problems upstream where the material is entering the river in the first place?

Answer - Reichmuth - You can try to handle the material influx at the source, but I don't think, short of building a dam across the Gallatic Canyon, much can be done to stop it from entering the system. Now, certainly if you go up there and log extnesively or change land use in the high country, you are going to accelerate the erosion rate. But basically, I would think it would take pretty large changes upstream before you're going to really increase significantly the amount of material in the system. The slopes are so steep already that the area is in active erosion. This material simply will not go away and it is the river's job to move it to flatter areas.

Question - Bianchi - Don't you think that on the West Gallatin probably way over half of it being altered each year by irrigation, altered by man. Don't you think this is increasing the amount of material?

Answer - Reichmuth - It is causing stable deposits to start to move again and it is spreading out the area used to dump the material. In other words, you could probably get rid of the volume of new material in a narrower band. Now again this band isn't static. Once you get the river agraded to a point you either have to spend money to keep it there with levees or dikes, or else you've got to let it shift to another area. Certainly you've got to get rid of that material. Where you do it has to be a political decision. In the case of the Fish and Game they would like to see the river kept from spreading out all over the country so you can at least have a fishery. But, having a fishery doesn't mean the river has to stay static. It can be moved. But when you do move this particular river you've got other problems such as the farmer problem. The other thing you can do is let the material deposit in areas of vigorous vegetative growth. Quite possibly you could at flood stage let this material spread it out and dump on the floodplain. I think the rate of agradation would be slow enough that you could still maintain vegetative cover on it. I would think maybe this would be an ideal solution, if you could somehow keep the brush, trees, and grasses on the area and let the river agrade. But, let it agrade at a rate where the vegetation could keep it covered. Now we're not doing this. It is obvious that the vegetation is being stripped, the river is spreading out and this is bad.

Question - When you talk about the material, you mean the water itself, or the water and material?

Answer - The water in this discussion is almost incidental to the problem. For many years there have been irrigation channels coming off the river between Baker Creek and the mouth of the Gallatin Canyon which have caused fish habitat problems during periods of low flow.

At flood stage what percentage of water is taken out? I don't know for sure but I think its rather insignificant. The problem of getting rid of the gravels which right now is causing the river to spread out, is more dependent on the incoming volume of soilds and the movement of these solids is primarily determined by peak river flows.

Question - Speaking about vegetation on agrading areas and stripping it off - what's stripping it off?

Answer - During high water you're approaching a point where you are trying to run water on top of a hill. Right now you must put dikes or levees on the river to hold it in a reasonable channel. This increased the energy stored in the flow and mades the river more destructive to vegetation. Maybe a better long-term solution would be letting the river divert into the Baker Creek drainage and then this other area would revegetate and you'd regain it.

Question - We just completed a report on the hydraulics of the Gallatin. The volume of the peak flows was about twice what they were in the 1030's. Do you feel that this had anything to do with the loss of stability?

Answer - Certainly, it's bound to. As I said earlier, the curves for solids transport is very dependent on the peak flow and of course if you have a cyclic peak it is going to do more damage than usual. But, ultimately the longer term rate of the agradation is what is causing most of the problems.

Question - If the volume drops back to some normal interval, do you feel that the agradation will continue at the same rate?

Answer - If you look at the agradation during a very short geologic period, say 5,000 years, it has been continuous but there certainly were and are cyclic variations in the rate. I think that the agradation will continue and the rate of materials coming in is pretty constant. Now certainly the material enters the system and sits up in the canyon some place until it gets enough water to move it. So those rocks just lay there in that channel until you get a peak big enough to move them down a little ways or maybe all the way. Now obviously what you think is true, the problem is being made more severe by the fact that you have high peak flows right now. Its tearing up things now that maybe will stablize. If you start having low peaks, there will be a tendency maybe for nature to try to heal the wounds. You will reach a point in time, however, where maybe nature won't be given a chance. Man has pretty well tried to take nature's role away from it and as long as we are in there with bulldozers, diverting, cutting off these meanders, cleaning channels, doing all these things, you are going to have an instability problem. Certainly somebody is going to have to find longterm answers or else you're going to have an awful problem.

Question - Do you find that the channel is progressively shallower?

Answer - The main one? Sure. It's losing some water. The fact that the other one if flowing water is clear evidence of that.

Question - Is the depth of that channel progressively less?

Answer - In those areas where man has been active either in the channels or on the banks there has been a tendency for the channel cross-section to get wider and shallower. Also, the river is definitely agrading. Now it is getting wider based on the records of the original 1868 land survey. Those records give us a definite fix on the width. They didn't even have a braided channel. It was pretty much confined to one channel 100 years ago.

Question - Are you aware that where Baker Creek comes within about 50 feet of the West Gallatin River right now, the bed of Baker Creek was 2 feet lower than the West Gallatin River?

Answer - Now you are trying to keep the river on top of a hill. How long you can do it depends on how much money you want to spend for it.

Question - Have you considered the idea of a whole bunch of small dams in the headwaters? You could keep these reservoirs empty until such a time as you needed them to stop peak flows. This would control runoff and lower erosion.

Answer - No I haven't. At this point in time we have concentrated on the geology of the basic problem. There are many potential solutions that ultimately will have to have some rather broad study. You have the material, you have to get rid of it. This can be done at different places or you can sluice it to another area. You can even dump it in Canyon Ferry Reservoir if you can build a channel big enough, or deep enough that will carry the load. I don't think that would be too good though.

Answer (Simons)--I think we can make hydraulic computations that are accurate with plus or minus 15 percent to predict what happens as a consequence of steepening channels by constructing cutoffs and what happens as a consequence of other types of channelization efforts. Actually it would be very easy to double the velocity locally in a channel by making cutoffs. Another interesting point to keep in mind is sediment transport. The transport of materials increases significantly with an increase in velocity. Transport is a function of size of bed material and a function of the velocity to some exponent. In other words, if you double the velocity in a river system you may quadruple or you may increase transport by tenfold or more. This response, in terms of increased transport when we increase the velocities must be evaluated very carefully. Small changes in velocities can cause significant changes in the channel system. Considering the type of problem that has been described here the approach to date is excellent but whenever possible a quantative approach should be followed. Detailed computations and analysis are required to evaluate the consequences of channel changes on the system. On the other hand, bear in mind that as a consequence of natural effects rivers will be subjected to major flooding. We don't know whether this flooding will occur tomorrow, in 10 years, 100 years, or 1,000 years. One thing that we are certain of is that major flows will occur and when they occur changes will occur in the system. In this case you have braided segment of channel that is acting as a trap for excess sediments. As sediments deposit in the area there is a natural tendency for the channel to break out one way or another from the present alignment. In this case slopes are such that the river has a tendency to break out toward Baker Creek.

You can continue to hold it in this alignment for the time being but sooner or later it will probably break out one way or another. As an alternate you could channelize this reach and carry the sediment on through as stated. However, if these sediments are carried for example into a reservoir area their deposition will deplete the storage capacity of the reservoir. The major point is that whenever we take some action in the particular area it usually causes some new situation in an adjacent area. It emphasizes the necessity to take a look at the total system. One excellent way to gain an idea of the total system is to actually construct a physical or a mathematical model or some combination of both may be used to evaluate the system. Using the mathematical model one can route water and sediment through the system for a drought period, average periods, and flood periods. One can gain an excellent idea about how the characteristics of the channel and the adjacent topography react. The mathematical modeling method looking at rivers is also an excellent procedure when considering alternatives. At this point in time we may argue that mathematical models are not capable of giving precise quantitative values on the other hand, they certainly allow you to see in a general way the many alternatives and to evaluate in a general way the response of the system to different development plans. We have many such cases throughout the United States. For example, Albuquerque, New Mexico, located on the Rio Grande, originally was setting 10-15 feet above the bed of the river. Subsequently a reservoir was built downstream of Albuquerque. As the sediment deposited from the river in the reservoir, aggredation was induced in the channel. Ultimately, this extended on up into the Albuquerque area and presently the river bed is perched in many instances above the city. It is virtually a certainty that some time in the future this perched river will break out of its present alignment and cause serious flooding.

Question (Whitney)--If I understood Bob Winkley correctly, he said a place in the Mississippi braided because it was straightened. Will straightening really help the situation out here?

Answer (Winkley)--The braiding occurred there because we increased the slope of the river and we passed that threshold between a braided and a meandering stream. By straightening the slope, as Dr. Simons was saying here, we increased the sediment transport and the velocity and we actually ended up with a braided type stream. If let go long enough, nature would have cured it, had there been no structures put in to hold it in one particular plan geometry. So anything you do to a stream, unless you forcefully hold it there, is only a temporary thing.

Question (Whitney)--One solution, where there is agrading, is to cut it straight and pass the problem downstream. Would you really pass it on downstream?

Answer (Winkley)--Well it probably depends on downstream conditions and I'm not familiar enough with the area to answer that question. It'll all depend on the slope and the available sediments and no matter what you do with it will respond to them. You'd have to go out and look at actual conditions to tell what is going to happen, and then its just a good calculated guess.

Simons--If you could steepen the channel in the reach it would increase the capacity of the stream to transport sediment. One could increase the ability of the stream to carry sediments by alterating its alignment, by changing its width, depth ratio and so forth. Various combinations of approaches are available. Bear in mind though, that it is sort of a pick up here and dump it there proposition. If we don't properly design for the total system, it has been said before, we may correct the local problem only to create a worse one elsewhere. We are saying that before making any changes in a river system we need to make a complete study, take a total look to determine the alternatives and then attempt to proceed so that the expenditures are minimized and so that the least number of people are hurt. Conversely, we might say that we are developing so that the largest number of people benefit.

Reichmuth--Well this stream is interesting to note that the first trap is taking out the finer sediment materials and then at Canyon Ferry we are taking out the silt. We have basically three traps that are taking out different sizes and so the first trap here at Baker Creek you are passing on, maybe everything bigger than an inch. And you go down there to Trident, around that area near Three Forks State Park and find what comes out there gets down to minus 1 inch to coarse down to maybe sand size and then finer things in there are coming on through to the reservoir. So you have to look at each size range to see what happens at that, when we say at any one size range--holds true, only that size.

Question (Miller)--We are going to get into this problem of riprapping and riprapping on the bends of these channels, and getting to the place now that maybe every other bend of the river, a few thousand feet of riprapping. Now what effect is this going to have on the stream? Are we going to keep fighting this?

Answer (Simons)--There are various answers to this question. Bob has had lots of experience with the Mississippi. Much of our experience has been on smaller systems. More recently we have been doing some studies in the laboratory trying to tie all aspects of the problem together. But bear in mind these streams are live dynamic systems that change with time. Left alone, there is a tendency for them to build up or shift laterally one way or another, depending upon climate and other factors. Whenever we nail a river down at one point or a series of points, the other portions of the river continue to change. As a consequence the total geometry changes. Hence, when we stabilize a particular bend it's often only a temporary relief. The rest of the river continues to change until it may become incompatible with the bend which has been stabilized and subsequently failure within that bend must occur.

Question (Peterson)--Isn't this related to the stabilization of this area? If I were on the inside of the bend I would think my property is more valuable than the guy across the stream. What do you build the structure for? 5-year flood, 50-year flood?

Answer (Winkley)--In time this bank is also going to work back and what you end up with is a good efficient channel up to some point, but beyond some point you may develop a wide, shallow channel. You may actually lose your flood control on it. So you almost have to think about both sides of the river if you are going to do it. That's another problem, what are you going to do with the sediment? Where are you going to put it? Wish all the answers were there.

Simons--I wish to stress again that a river system is dynamic and changes with time. If you decide to fix it in a particular position it serves as a geologic control to some extent. If this point can't move with the river the natural sequence of ripples and pools is affected. Refixed or stabilized points may become a thorn inside the system. The river ultimately may reject it. If one studies river control done on river systems many years ago, such as in Europe you will find incidents where old structures that were put in time and time again are now setting anywhere from thousands of feet to miles away from the present channel. This certainly is a test to fact that these changes in river systems goes on.

Question (Peterson)--If you do stabilize this area, the angle of deflection, and you don't say downstream, you don't stabilize the outside bend, will you then cause accelerated erosion during peak flows on the other side? And if so, what if you have split ownership on both sides of the bank, in other words, a guy on the right stabilizes it, should he be responsible for the other side of the bank?

Answer (Simons)--I don't know what the laws are.

Answer (Winkley)--This is what we've found on many of the bigger rivers. Normally a migrating stream is having new material introduced continuously from this outside bank.

Audience--Are you saying that all riprap is bad then?

Answer (Simons)--Not at all, I am saying we must consider all of the important variables and all of the interests before acting. More specifically I think riprap is an excellent means of solving certain stability problems. On the other hand, its not the solution to all problems. I don't want to imply that riprapping or stabilizing a particular section is bad but we do need to consider the consequences of utilizing it. What is it going to do to the fellow on the other side of the river, what responses will it cause in the river system downstream, and the changes induced may be sufficiently slow so that we may not need to worry about them. However, I stress again that at a fixed point in the river the channel may stretch away or vary with the respect of this fixed point in such a way that the system breaks up and we end up with some new type of formation. This sort of thing is going on continuously.

Question (Spence)--Is there a chance of passing the problem upstream as well as downstream?

Answer (Simons)--The chance is not as great. When you hold this point the whole system tends to compress toward the point and the meander lengths can shorten to such an extent that cutoffs occur and other major changes result. Down here the river tends to stretch away from the fixed point from my limited experience I think that we see more rapid responses downstream of the fixed point than upstream of it.

Winkley--Well, it'll go both directions until some other control take over. The speed and the magnitude of the change there again is going to depend on mainly two factors. The size and type of the bed and bank material, and the gradient of the stream. If it is fairly steep and the material fairly fine, the response will be rather quick. If you have big cobbles, four- or five-inch gravel, and fairly well graded, then it may take many years before you will ever see it.

Simons--On the other hand, you might get the so called 1,000 or 100,000 year flood after having a system stabilized for a hundred years or more. Such a flood may cause the river to change the alignment to a completely different position, so is no total solution.

Question (Miller)--Do these things compound? When you keep nailing them down are you putting a lot of pressure on the areas that aren't creating problems at an exponential rate?

Answer (Simons)--I don't know if I can answer your question adequately. There are certain geologic controls and the river has certain characteristics between these controls. Such geologic controls may dominate the system, if in addition we riprap segments of the river between these geologic controls they serve in a similar way. The river now has to develop some geometry it can live with between these fixed points. If one studies the total system I think it is possible to predict the type of responses that the system will undergo after one places new controls within it. Also, we can give some pretty good estimates on rates of change, on the other hand, as Mr. Winkley stated we may have 100 or more variables involved in making a precise prediction. In summary, fixing different positions or different reaches of a river causes these fixed or stabilized reaches to act as geologic controls. The river attempts to adjust between these fixed points to some new alignment consistent with them.

Audience--By adjusting do you mean there will be more instability in the areas between the fixed points?

Answer (Simons)--Yes. Usually the channel adjustment is brought about by deposition in new areas; the development of alternate bars in different positions and so forth. These changes are accompanied by a change in the thalweg position and with this the flow begins to erode different and new parts of the bank, cut new bends, deposit new bars until it ultimately arrived at some new average equilibrium between these fixed points.

Answer (Simons)--That's true. If we still have water in reservoirs it is possible that the consequence of having a reservoirs full making reservoirs releases coupled with heavy precipitation, snow melt and so forth that a larger than normal flood may occur. This larger flow will cause additional instability problems. Generally downstream of a reservoir degradation occurs because of the clear water release. This causes a steep unstable bank that may be undercutting and sloffing. Putting a larger amount of water in such channels can cause very serious erosion problems. This extra sediment load rarely gets carried on through the system. When the water and sediment reaches a flatter segment of the river the materials drop out causing new and possibly severe problems in that vicinity.

Winkley--We've got a problem like that in some of the big alluvial valleys of the Mississippi, where we built reservoir controls and then improved the channel below. They cleared some of the vegetation out and tried to make a more efficient water conveyance channel. Many places they straightened the river with cutoffs. They designed it for a certain flow that will take a normal reservoir release, with some safety measures. But, in the last 20 years these channels have filled in and deteriorated to the point that now they won't take that normal reservoir release and they need to be cleaned out. Now we face the problem that we can't even contain a normal flood in these channels, but the environmentalists won't let us dredge them and spoil anywhere. I guess we wait until there is a really big flood and everybody gets stirred up and then people will act. But, the problem is there. Solving the flood control helped create a new set of control problems. (We should have had the environmentalists a long time ago and it may have stayed where it is.) But, in the meantime the land that was worth $5.00 an acre is now worth about $1,000 an acre and where there were 2 or 3 people per square mile there are several hundred and lots of industry, so I don't know what you're going to stop.

Simons--I guess it depends on your intent and purpose. On the Mississippi the most ideal land to own would be that on the concave side of the bend.

REMOTE SENSING--SKINNER. I will give you a description of a new technique for identifying certain phenomenon about rivers. It's a technique that I have been using for about 10 years. It amounts to using certain equipment from an aircraft to record river behavior. One of the most common forms is aerial photography. I am going to show you some examples of color infrared aerial photography and a couple other systems that we think have definite advantages and applications for looking at rivers as a total system. Whatever you do at one particular location on a stream certainly affects both upstream and downstream factors. So you do need to begin to look at a river as a total system and there's really no better way than to actually overfly the selected stretches of a river.

The systems that we use are flown in a light aircraft, specially modified to accept these systems. That is, you have to have camera ports in the bottom of the aircraft. There are a variety of small aircraft that you can put these things into. The particular one that we fly is an Aero Commander, a twin engine airplane, which has sufficient room to fly two systems at the same time.

Three basic systems are very useful for looking at rivers; multiband photography, photogrammetry and line scanners. A line scanner, in this case, is a thermal infrared line scanner. Photogrammetry system involves primarily analytical photogrammetry, where we're trying to determine very precisely the location of single points on the ground. For example, one needs information about slope of river, width of channel, radius of curvature of bends, and how much material has been eroded from bands. Multiband photography provides a method for qualitative interpretation.

Multiband photography provides a means of recording a picture of a scene using several discrete bands of the spectrum. The multiband camera that we use obtains four pictures of the same scene through four different lenses. Each of these lenses is filtered to accept four discrete portions of the spectrum; the blue, green, red, and photographic infrared. One can look at those pictures individually, and generally they appear a little bit different depending upon which portion of the spectrum you selected to record that picture in. In addition you can combine those four in any combination that you might want to enhance what you are after. As an example, you might want to create color infrared photography. The vegetation that is green you might want to call red. (Color infrared film produces essentially the same thing.) This has considerable use for rivers. Not only does it help you find the green vegetation, but it allows you to trace sediment patterns in streams, detect sediment sources; and detect banks that are rapidly eroding. Color infrared photography is probably one of the most useful single sensors that we have found for looking at river systems.

Let's look now at photogrammetry. Generally a precision mapping camera is required. The lens on this camera weighs almost 40 pounds, and is the most costly portion of the camera. The transparencies from a precision mapping camera can be placed in a Kelsh Plotter to make a map. You can draw contours, delineate the floodplain, trace the stream pattern, and put in the cultural features.

We are also interested in using analytical photogrammetry where we can determine the precise location of an individual point. This is a Wild, STK-1 precision stereocomparator. Photographs are placed in these two positions, and the operator can place the floating dot on the position of the ground he is interested in. Subsequently by pushing a foot button the position information will be digitized and reproduce on an IBM card. The IBM card is placed in a computer, along with the appropriate software and the printout gives you the spatial position of the point. For example, you can fly over a river from a height of about 1500 feet and determine elevation differences of well marked points with this equipment on the order of 0.2 feet.

The photography taken with a precision mapping camera produces a 9" x 9" format of high resolution and minimum distortion. Some examples of prints from such a camera are available on the table for you to observe.

Sediment is one of the big things that we are interested in. Color infrared photography enhances sediment concentration differences and vegetation growth along the banks can be mapped.

Minus-blue film can be used to enhance drainage patterns and detect areas where the soil has been disturbed, either by animals or man.

Question--This also stands out in timber country?

Answer--If you can see down through the timber you can see the enhanced pattern. Now let's look at the line scanners. In this case, a three-sided mirror, rotates to provide a scan in a direction transverse to the direction of flight. The radiant energy comes up off the ground, strikes the mirror and is focused onto a detector which converts that energy into a voltage which can be used to modulate a glow tube to produce a picture. The picture (image) looks very much like a photograph.

Here is an example of a thermal infrared image of the Beaverhead River and Clark Canyon Reservoir near Dillon, Montana. Temperature differences in the water show up as a difference in black or white, or tones of gray.

Question (Audience)--What about the sediment, could you see this?

Answer (Skinner)--That was usually the same temperature as the receiving water so you had to rely on the color infrared photography to discriminate that. That is the value of using two systems at the same time, if one of the sensors doesn't detect it the other sensor may.

Question (Tennant)--On that photograph on the Clarks Fork, did you do that with someone else, like the Bureau?

Answer (Skinner)--The Bureau of Reclamation. John Keys, Billings, Montana, was the man we worked with.

Question (Tennant)--If we were to get a set of prints how much would they cost?

Answer (Skinner)--You can contact Mr. Keys for a price.

Question (Tennant)--Can you make duplicates from originals?

Answer (Skinner)--Yes.

Question (Miller)--Doesn't the Montana Highway Department have a RC-8 camera like yours?

Answer (Skinner)--They have a Wild R.C.-10 which is a newer version than the RC-8.

GENERAL DISCUSSION

Simons--I think we have done a lot of waving of arms in saying that there is an almost unidentifiable number of variables and have maybe sort of left the impression that whatever you do there is high risk. But, I'd speculate that the four of us sitting here would argue that if you get someone knowledgeable about the geology, the materials, river, and the hydrology, that you can use reliable, simple relationships which relate to these types of variables which we have information on and you can come up with some pretty good answers. You can't guarantee that it is going to be precise, but they are good enough to give you an extremely good indication of what is going to happen. It can let you see the alternatives of doing this or doing that so that you can assess the damage. We know the basic forces, we know how the water interacts with the alluvium, and you can look at the alternatives and some knowledgeable people can say alright, if you do this, this will probably happen. Then I think you can see who benefits from each case. I don't know how you decide which way you do it, maybe you issue ball bats and put them in a room and lock the door, and maybe you take it to the courts, but it's not an easy problem.

Question (F & G)-- How much information and time do you fellows want to have before you could make decisions as to whether any one of our many riprap projects is going to be a really detrimental project or one that wasn't going to hurt something?

Simons--I think if one could quickly take a look and see what kind of flow data are available through state and USGS type agencies who collect flow data, if there were some soil surveys along the banks and sampling done of the bed materials, maybe that would all be available. If that wasn't, one would want to go out and maybe get a pretty good handle on what the materials are, not only in the channel, but adjacent to it. You would need to get some information on the geometry of the stream, its profile and basically with this kind of information, the characteristics of the bed materials, the type of flow it's subjected to, then you could carry it out. You could go out and look at one of these problems and give someone a pretty good estimate on it in a matter of a few days time if the data are available.

If you had to go in and get some of the data or if there was no hydrologic information at all and you had to sort of synthesize your hydrological data, based upon watershed characteristics, etc., it would be a little more of an effort; but, it surely isn't a one-year study. I'm sure Mr. Winkley could site many instances where decisions of a pretty sizeable magnitude have to be made in a hurry. If you've got knowledgeable people, can get these various talents together and have the information at hand, you can spell out the alternative with reasonable precision. Now what is right, I guess depends upon due process because definitely what is right for one group isn't necessarily right for another group and I guess what we are all striving to do is say alright, what is, in general, best for everybody. (Not that things get decided that way all the time.)

Question--You said yesterday that you weren't against all riprap. What riprap do you think is justifiable on a river?

Simons--Well let me hit just a few cases. First of all in just going out and randomly correcting the bad spots in the river using riprap isn't the right way. For example, if you go out and look at this river system, first of all an overview, and determine the geologic outcroppings, maybe where channels have filled, anything that is more resistant to erosion, you've got certain fixed points on your river and these fixed points control the river. If the gradients hold tight, why then these sort of lock it in. As long as you do something consistent with these controls, you might go and use riprap. I think what the Corps of Engineers does, is an excellent current example of utilization of riprap if you've got to nail something down in proper alignment. They don't just go out and do something on the spur of the moment, they'll have their work plan laid out four years ahead.

Winkley--Presently we are working eight years ahead because we found out that you just don't go in and indicriminately install riprap. I'd like to work a little bit further than that, but that's as far as the people who have the dollars say go. We are working on 300 miles of the Mississippi River and we are trying to develop a plan in that eight years so that we are utilizing the structures that are there, the work that has been done, the knowledge we know in trying to develop what we want in the river by successive years work, knowing we've got so many dollars to spend each year.

Simons--Let the river adjust to the alignment you want and you've got to have dollars and some method of nailing it there. But, you try to get it into some form that is consistant with these geologic control points. I think if you do a little bit of it here and there with this sort of an approach, you can nail it down, you can have a suitable alignment that is reasonably good for perhaps fisheries and wildlife, maybe not as good as in the natural state, maybe better, I don't know; but just to go out and riprap a river indiscriminately without looking at these other conditions, no.

What are some of the other situations where it's less questionable, take bridges for example. I don't think any of us would argue that if you are going to put a bridge across a river, or any type of a structure that constricts the flow, we've got a potential to scour and you've got to do something to control it.

Certainly we build all kinds of water distribution systems. Our canals for the most part have been built essentially on the contours flat gradient, and we know that on the outside of the bends, they tend to scour and you are limited to right-of-way. So it seems perfectly legitimate where you build a canal, you need to nail it down into alignment and you control the flow between limits and the sediment between limits, that you might use something to help nail it down so it didn't wander outside of the right-of-way. If you let it have the freedom to move like a river does and move maybe several hundreds or several thousands of feet, you've got immediate problems.

Certainly, in cases where you run powerlines across rivers, we've not found a better means of stabilizing the bases of these towers that support the higher transmission lines than riprap. In Canada, for example, if the powerlines came down, you might shut off an aluminum industry. Riprap prevents such a failure which might take you a million and a half bucks to crank back up.

Take the transmountain diversion problem, I pointed out a couple of situations that fell in the category in Colorado. The politicians and the economists were willing to do something that changed the flow to some major degree, and think now about this for the moment. Anytime we take an existing channel and put more water in it, the channel is too steep, and its going to start to degrade and tear down the banks and take on a totally new geometry. Well if you are going to make that kind of a move, then I think in advance you've got to go in and decide what gradient is suitable. Often rock will do the job and you flatten the gradient. You can try to preserve some of the naturalness, also.

Certainly downstream of dams, wherever we are going to put storage reservoirs, or wherever we have them, and these trap the sediment and you essentially, as an old friend once said: "They release hungry water," you tend to pick up more of the sediment there and the channel starts to change. Maybe under those circumstances you need to put in controls; look at the new system and rock might be one way--some type of riprap. You may have some bad channel which you want to improve for example in the relationship shown yesterday, it can be very critical in many instances whether the channel is meandering or whether it is braiding. And generally speaking, a channel that braids very much is not good for anybody. That may be an over-generalization of the case, but it has a lot of bad characteristics. In many instances, from my viewpoint, is the possibility of going in and studying to see where this thing is poised and maybe by putting in some minor controls which would be analogous to what have been given by old mother nature's controls, you might flatten that gradient enough to where you shift it from one case to another and you might take something that is useless from the view-point of recreation and make it extremely useful. You could also use it to help initiate the correct riffle-pool sequence.

You can tie this in with the vegetation patterns. You could look at the type of thing that you are really striving for. Look at the business of flood control. Where these people, independent of you or I, often do something that lowers the stage in the main stem. This essentially steepends the gradient of every tributary into the main stem. And if you don't do something about it, and you initiate these head cuts up these tributaries, you can literally release millions of tons of all sorts of materials which come down, dump into the main stem and changes its gradient. You may go from a very desirable system to an extremely poor system. Well maybe you don't want to use rocks in that case, maybe something out of concrete, it would depend upon the case.

I can see that through surveys on the ground, remote sensing, you might identify some of these key producers of sediment and you might use this as a technique for identifying where you might go in and try and control to some degree that sediment source, for example.

These are just some of the things that cross my mind regarding the use of riprap, but if you want something more specific about how I feel about it, we have just completed a study about a year and a half ago for the Department of Transportation and the Wyoming Highway Commission on what you can or cannot accomplish with riprap in terms of stability. We actually worked with velocities on the order of 15 feet per second, and rock up to 18 inches in diameter. We've had some field test cases and again we're not saying its good, but we're saying if you are going to do it, this is the kind of information you basically need, this is the approach you need to take in order to make the riprap stay in one spot.

Peterson--What is the Corps' annual cost on maintenance on riprap?

Winkley--Well, let's talk about bank revetment or bank protection, because we use several types. On the main stem of the Mississippi we are replacing the entire system theoretically, every 30 years. Its not permanent.

Audience--One of the problems that we have had with our stream riprap comes under the Corps' emergency flood-central arrangement. You talk about 4 years and 8 years of planning; we talk about it the middle of April and by the first of May they've got bulldozers and draglines in there. The type of engineering that is concerned there is somebody calculated how many yards of fill they need and how many miles they got to haul it.

Winkley--That's called "instant problem."

Audience--And then the next year over and above that they've got another problem. It's a continuing problem. The counties use this Corps assistance because its available. They try to get new roads, new bridges, new dikes, new levees, and everything. Its just a constant source of recreating an unstable situation.

Winkley--Well, in light of that and the question that was asked previously about what information you needed, let me make one comment. In addition to what Dr. Simons said, you might go back and dig out whatever geologic information is available. It is important to know where your river is going to change characteristics and where your control points are. You might dig out any aerial surveys of the entire drainage basin. Because you really have to look at the entire basin, you can't just look at one small reach of the river as you pointed out there and do something to it. The effect of that, in time, is going to be felt somehow through the entire system. Now you may not notice that effect going all the way through the entire system because something else happens that nullifies it, but you can be assured that when you do something to the river, something is going to happen to the entire system.

Simons--You know I might just mention one thing, I've got to give a paper this coming Wednesday in Houston, Texas on Rivers and Research Needs in Rivers. But, I think one of the most serious problems we've got is just our method of teaching or not teaching people. For example, if you look at the engineering curriculum which produces Bachelors of Science Degree people who go out for consulting firms, for federal agencies, and for state agencies. These people with a bachelors degree that come out of 99.9 percent of our schools have fluid mechanics as its applied to rigid boundary systems, they may have had a smattering of geology, but probably no introduction at all to geomorphology. They may have had just a wee bit of hydrology. They may have heard a little bit about hydraulic structures. I think you can say the same thing in terms of really teaching a knowledgeable amount of information to our young people in other areas such as forestry and watershed management, in geology itself, and so on. I think we are turning a lot of people loose to work on these problems that don't really have the background. What I surely think that we are going to have to do is somehow supplement their education. Maybe disseminate a little more information because often these people who go out, and as you say, in a few hours decide in terms of cut and fill of alignment, what they are going to do with no other treatment, really don't have the background knowledge, the training to realize what the consequences of their actions really are. And until we can develop some better method of disseminating information and working as a group on these problems, we're going to continue to get some pretty miserable blunders.

Bianchi--That is the problem, just like you say, not looking at the entire system. This is our problem. Every agency that is working on our rivers looks at the immediate problem, whether its the Corps or anybody else. This is what we've been talking about for a long time. Let's look at the whole plan--the whole floodplain and try to develop a plan. Whether its riprap, a Band-Aid here and there, or whatever they're going to do. But, you can't get anybody else to look at it. They go out in one day and make a decision and the next day the bulldozer is in there and they're hauling rock in.

Simons--Well, I think the process is slowing down, for example, I showed some photographs yesterday of part of the Colorado, upstream from Glenwood Springs. Three years ago we were going ahead gung ho and we were doing a little work with a consulting firm out of Idaho that had the problem of how they would encroach on the river to get width for right-of-way in order to go to four-lane divided, and that is absolutely shut off. I don't know what they will ever do. Maybe they never will, but from where I sit I can see there is a lot more interchange of information and there is a lot more sitting around the table to exchange information. Of course, some pounding on the table and some bloodletting, but we are starting to communicate, I think a little better than we have previously.

Winkley--In addition to that, (and now I'm not trying to defend the Corps), but they have put in an environmental section in the last couple of years. In Vicksburg we have a potamology section which is more or less looking at the overall effect of things. No project gets past the initial planning stage until we take a look at it now and say you've got to consider these things, or you must look at this, you've got to do that, or you have to collect this data before it goes even into the complete planning stage. So, at least there is improvement coming, but its going to take time.

Boland--What about these emergency projects that happen in like 5 days?

Winkley--Well, they are still there and when somebody is up to here in water, he gets attention, whether its right or wrong.

Simons--Especially if he had some political friends.

Bishop--Frequently though, for instance, these projects will have been brought to the Corps some months in advance and then when the Corps doesn't get to it, the waters are apt to spill over.

Winkley--Well, I can tell you how that happens. That's called basket placing. The guy that got it looks at it and says I have to do something about that and he puts it in his "something to do basket" and by the time he gets it out one day and he has a cup of coffee and thinking about things and he says, "Now I've got to do something about this." So he takes it over to another division or somewhere that needs to make some decisions, and by the time it gets down to the poor peon that came out to look at it, its been six months getting to him and he's got two weeks to come up with a plan. Now that happens to be the bureau-acracy way of doing it and if you can change that I'll vote for you.

Simons--I don't think that is limited to just the Corps. This also happens in Universities.

Question (Gaffney)--I'd like to ask whether any of this information we have been talking about comes out in a simple form or phamphlet that we could use when we are talking to an individual involved in one of these river projects. You guys are all talking about pretty extensive knowledge of a river system, and I don't know of a case where we have ever been butting heads out on the bank of a river on one of these problems where this kind of information is available. The common answer we get when we are talking to a landowner for example about whether or not he should riprap a particular bend and we say maybe this will effect upstream or downstream, or maybe this is a result of what your neighbor has done. He says I don't care what my neighbor did, I want to stabilize this point. Maybe we're not good enough salesmen, I don't really know where you would go to from that point unless you've got something that you can put your finger on to try to convince that fellow that even though he feels he is helping himself temporarily, he may hurt somebody else or another spot on his land. Is there anything available that we could use in simplified form that might help us over this part of it?

Simons--Not, from my point of view, that necessarily covers everything. There's lots of excellent reports that maybe cover a piece there and a piece here, but in terms of someone having taken current knowledge, knitted it together in a way that would be useful to a broad spectrum of interests, you are at the mercy of various people that you can talk to. Now I know that we as a group have talked about this. There's probably been tens of millions of dollars of work done by various state and federal agencies, by universities, by consulting firms that relate to these problems. I've got a room a fourth as big as this with the walls completely covered with book cases and has nothing in it but just stuff on these topics; overlapped 99 times in some cases with 99 different answers. And, what we really need to do to help accomplish what we are talking about is if somehow a group of people, some guy who had the time and effort to pull the pieces together, could do what you are talking about, I think we are to where something useful could come out.

The schools have been relied on to a large degree to get out stuff into print. But, take this stuff, there is very limited use for it. There is no money in writing it. Its only honor and glory and maybe more criticism than either of those two. You've had a very limited number of people that are interested in this.

Take hydraulic structures, for example. There really haven't been any hydraulic structures books written since those written in 1916 and 1917. And why not, it's not because there isn't a need, it's not that there hasn't been advancements, but it takes a lot of effort to get this thing into print and past the reviewers. When you finally crank it out and you figure you've got a limited sale, maybe 2 or 3 thousand copies, and you divided the 2 or 3 thousand copies into the cost of doing it, and it comes out $75.00 a volume, you essentially shrug. Well, I teach, or try to teach, I should say, in the fall quarter of each year a course called "Erosion and Sedimentation" which is sort of introductory to this. Winter quarter we have another course which is a follow-up on conveyance structures, stabilization, and appurtenances and how this all fits together, coupling the water and the sediment mostly in distribution systems. Then spring quarter we have a follow-up course on river mechanics and potamology, where we try to knit this all together. What do we use to teach from? Bits and pieces from about 99 different sources and we Zerox this. In erosion-sedimentation, there is no suitable text. I Zerox $16.00 worth of pieces from all of these different reports and that is our text. I don't know how Dr. Schumm teaches geomorphology. There are a few books in that subject area. I think they are a little better off than we are in this other category, but what's your situation?

Answer (Schumm)--There is a standard text with a geological approach to rivers. I've discontinued using this and I now use the same technique as Dr. Simons. I copy various pertinent papers and hand these out. I don't feel that there is a textbook of the type that you are interested in, that gives specific answers to specific problems. Geomorphologists are usually interested in the long-term academic approach, and they aren't generally involved in solving problems. Therefore when you look at their reports, you get a nice description of what the river did perhaps over a million years. If you took the bits and pieces which are important to you they could be of real value. I'll admit again, no one has done this.

Simons--Well Dr. Schumm and I, really recognize the tremendous need here so we are leaning on some of the agencies to give us a little money, enough to give us support to develop something to start from. We have a request in for about $25,000 to start to take a look at it. I think we've got to figure out a way of consolidating it, and we've got to figure out a better way of disseminating it.

Now one other thing I've done a couple of summers with geology, we put on short courses, with money coming from the National Science Foundation, where we largely brought geomorphologists, geologists, and engineers together. We are currently thinking about doing the same thing, but bring in some of the biological components in order to broaden the base further.

Winkley--One thing I might add to that, in response to your question is that if you do something to the river, you are going to get a response, sometimes very immediate, sometimes very slowly, depending upon characteristics of the stream. But, you will get a response to the stream and this in time will nullify itself in that particular area and maybe work its way on through the system or maybe only be seen over a very short reach of it, but you're going to get something happening. You can rest assured of that.

Bishop--Could Dr. Schumm put that formula up on the board with depth and relationship?

Schumm--The reference is Leopold and Maddock U.S.G.S. professional paper 252, "Hydraulic Geometry of Stream Channel." This material is also in the book that I just referred to, "Fluvial Processes in Geomorphology." In addition, I think the River Mechanics volumes summarize most of this. "River Mechanics" edited by Dr. Sherwin Shen, $20.00 or $22.00 for the two volume set, purchased through Water Resources publication, Fort Collins.

Simons--We have invited something like 100-120 people interested in rivers from all over the world regardless of background. We've tried to get the most knowledgeable people together, and we've worked 8 to 10 hours a day for about 2 weeks. The material that has been presented by these people does occur in these two volumes on river mechanics.

Schumm--I would just add to this, I have two chapters in the River Mechanics volume, essentially the geologic approach. If any of you are interested in that, drop me a post card at CSU. I'd be happy to send you photocopies of my chapters.

Winkley--I'll add something to that for Dr. Schumm. He has some relationships in there where he has taken the geomorphic change of rivers over many, many changes in cycles of weather. He showed us two slides of it yesterday. I took those two relationships and looked at current changes in rivers due to reservoir action, diversion of waters, changes in straightening channels, channel stabilization, and some of the work that was done by the Corps and the local interests and the Soil Conservation Service on a particular valley drainage basin. The relationships work and they pretty well hold together on short range changes, due to the effects of man's activities. Those four particular relationships are in that particular chapter he's talking about. If you change one particular factor, it will tell you how the other one will probably start shifting.

Audience--I'd like to set up another situation. If you had a natural cutoff that occurred by virtue of a flood or something, would you advocate blocking this off or keep the water bank in its natural position or let it go naturally through the cutoff?

Simons--That's a good one. Mr. Winkley, do you want to tell them about the bend that was about to make the cutoff and they did make it anyway and then they closed it? I think that's a good example.

Winkley--Let me sketch something here on the board. I'll show you what can happen. You can't just make a cut and dried rule. This example concerns the little river called the Tallahatchee River in Mississippi. A heavy sediment-laden stream comes down from the hills which is a stream that many years ago local interest groups straightened out. Also, there is a pretty good size tributary that has a reservoir upstream with several small tributaries. emptying into it. The tributaries are very heavy sediment-laden, also. The Tallahatchee is quite a large river flowing maybe at 10,000 cfs and maybe as high as 60 to 70,000 cfs with present control before it went to 150,000 to 200,000 cfs. It was decided that they were going to make a cutoff through a narrow neck of the land. They made a cut through and let it develop. Within ten months they found out the problem they had created and then shut it off again. Now, in this time period the river completely filled with sediments. It was starting to fill the lower reach of the river and to maintain it again they dredged over 1,000,000 cubic yards of material and shut off all of the sewer outfalls and all of the water intakes. Ten months between opening and closing and the filling of sediments action probably occurred within 4 or 5 months.

But, this is a case where this would have been a natural cutoff. In fact, it would have naturally cutoff within probably a decade or less, because it was a very narrow neck of land and there was active eroding along it. So you can shut one off, but you better look and see what is going to happen somewhere else.

Simons--That is to say, it would happen naturally, and you see the problem is people. If the city wasn't there and these other special interest groups didn't have to be served, why, you wouldn't have to worry about it. Old mother nature would do it anyway and it would grade and this for a while would go back this way and that.

Winkley--For any cutoff, natural or man-made, you're going to get a response to the stream. It'll scour upstream and it'll pile up downstream until it adjusts the slope again to something it likes. As Dr. Skinner was showing here this morning, on these islands and bars showing up downstream in these cutoffs, that's just aggradation, its extra amounts of material piling up there. As soon as that river goes through some phase of adjustment maybe a year, maybe ten years, maybe a hundred years, it will gradually adjust back to something that is compatible with the flow.

Schumm--I think the difference in terms of your question is that you are probably talking about something like the Beaverhead River near Dillon, Montana. In the example of the Tallahatchee you have a crucial problem because a city of probably 30,000 people are involved. It seems to me your sitution is a little bit different.

Simons--Yes, maybe you can afford to let it go. We aren't saying you shouldn't do it, all you can do is look at the consequences and see if you can live with them.

Audience--We know the problems are going to occur, apparently with this cutoff. Should you block it off so it can't go through the cutoff and aggravate these problems and force it back into the bend, or just let it go naturally?

Winkley--Well, if you look at the overall slope of the entire system, the river adjusts its slopes through making cutoffs that adjust the meandering tendencies of it, and over long reaches it keeps some compatible lengths. There is a slope adjustment that lets all of the various factors stay within some sort of equilibrium. So if you block cutoffs, it could be in a particular point that you would gradually decrease slopes to where you couldn't carry sediment. So in one case it might be good and in the next case bad. There is no standard way of saying yes or no.

Bianchi--Actually by the time a stream does cutoff, unless its something that's done during like flood stage or something very drastic, by the time it gets down to where that neck of land will cut through probably that stream is basically adjusted for that cutoff.

Simons--Do you mean ready for it?

Bianchi--Yes.

Simons--No, definitely not, because you see, I was looking at one not long ago in Wyoming where there is a nice big loop, 2 to 3 miles long and there is a little narrow neck of land here, here is the river on one side, here is the river on the other side. There is 20 feet of difference in elevation between here and here and they are 20 feet apart and when that goes and you throw that extra 20 feet of fall in there, that river is going to headcut for miles upstream, unload tremendous quantities of sediment downstream which is going to cause bar and bank deterioration. It just really goes all to pieces because you can't put that kind of a steepness in there without getting some very tremendous, dramatic responses in the system. I think river systems are still adjusting those out after 30, 40, or 50 years trying to get the concentration of slopes spread out to where they could live within terms of velocities, sediment transport, and bank stability. Now, only mother nature does it and we have lived with it. Of course when you get people on here, and you got people downstream why then we all come under pressure to do something about it. No, the stream is sure not ready for it, it can really all go to pieces on you when that happens.

Winkley--Normally your natural cutoffs are spaced far enough apart in distance and in time the river has a chance to adjust to each one over some short period of time. But, again on the Mississippi, what they did down there in a matter of ten years or less, they cut out a third of the river in length and it still hasn't completely adjusted to it. It will never completely adjust to it until it gets some sort of a slope factor clear back up into the Ohio and upper Mississippi and down to the Gulf.

Simons--Of course you've got these things going on naturally, I mean, where does old mother nature stop and where does man take over? For example, I researched a bunch of the historic records of the Rio Grande that were available through the International Water Boundary Commission, and there was an old ditch rider that used to ride something like 140 miles of the Rio Grande before there was really any man-made effects that amounted to anything upstream or downstream. He rode that river for a period of 40 years by buggy, finally by model T, and he carefully documented that naturally, (man not at all), but naturally that 140 miles of river would shorten in length by as much as 40 miles naturally within increments of one big flood to another. In other words, he documented a shortening and increasing in length on the order of 40 miles in that distance several times in a 40 year period. Now, that is an extremely unstable type river, sand bed type, and it was subjected to raising flows, no control upstream. But you get this thing going one way or the other and this is part of the natural process. It's faster in the highly erodable stuff, such as sand bed materials than in the rocks and cobbles, but the change is going on.

Kenneth Fahnestock, who is a geomorpholist that worked with us for years, did some work on glacial streams in Mt. Ranier National Park. He set up a series of cameras on a ridge and took a frame every few seconds through all of the daylight hours over a period of major runoff to see how the coarse rock piles up in the stream. You can see it all in a few minutes and then it will break over and it will pile up and it will break over. It is tremendously instructive regarding the magnitude of these natural forces.

[redacted]

Liter Spence, - Along with these cutting off meanders in a situation where we've got; I can think of a mountain stream where about 50 percent of it has been changed similar to what you have with the railroad along side the highway up here over the last 70 years or more, and I was wondering if you have occasion, through highway construction to have channel - put a stream channel back into an old meander where it was cut off when the highway was put there. Now, of course, the river in that area has reached whatever equilibrium it has reached through all of its process since it was straightened out. We know we are going to be getting that additional length for actual fishing water, and perhaps, you know including that additional habitat, compared to what was in there in a straight channel, but what are we going to do now in doing that, in general, are we going to foul things up above and below or are we going to have to put this thing back into its natural condition or would we have to do it in more areas in order to be successful in recreating the stream that was natural?

Simons - Well I think that if you looked at it historically and maybe the other gentleman can answer it more correctly than I, but we know that the natural length changes. We've got natural cutoffs occurring, new ones forming. We've got a sort of certain average length over some X miles that on the average we have and if as a result of building the highway system or whatever, we have gone and made several cutoffs and shortened this. We've probably steepened the gradient to where at least initially they had to go in and riprap the banks in this section to hold it, to keep the banks from being attacked. Instead of having nice riffle and pool sequence its probably more like channel, whitewater, rapids, not perhaps as good for fishing habitat. So if something else hasn't happened that requires that you have the steeper system to move sediment through,

I would see no disadvantages unless it is just economic cost to go back and put it basically in the system as it was. I don't think you would dare make it much longer by introducing new ones. You can get into the same problem, then, of storage and aggradation and attack of the banks. If the highway people and everybody can get together, unless it shifted way away in time from these and I doubt in this type of material shifts are not that fast, I think there might be some advantages in going back and dropping it in the old channel if you can afford to do so.

Winkley--It might depend upon the length of time it has been in this new channel and what adjustments have occurred in adjacent reaches of the river. If other river sections adjusted to a change within your particular reach you are talking about, its very feasible by going to the longer channel you may flatten the gradient out to the point that you would have a surcharge of sediments. This might develop into a braided type of stream.

Boland--I think this was developed either in the last 20 years if the highway did it or the last 60 if the railroad did it. I'm not sure which one straightened it, but in the area above what they didn't straighten, the banks are eroding very badly on one side of the stream that had not been protected at all. The stream is wide and shallow and it's not moving very fast and it's agrading.

Question (Liter Spence)--The river has gone down in this particular area, below the level of the old cutoff meander.

Simons--You've had some degradation in the channel where you built the chute.

Boland--Right. On the old channel route it's quite a lot higher.

Simons--So there would have to be some adjustments made to bring it back together. There would be some disruption where you got these discontinuities for a period of time.

Winkley--You know you can bet on one thing. In a natural channel, no interference from man, changes will always occur with different storm patterns, different runoff, bringing in different materials maybe; but the channel is going to adjust continually to the amount of water flowing down it, and the shape of the hydrograph: flash floods against slow-rising floods. It will adjust to the type of sediments imposed on it, not only locally but those brought into it. It will adjust to whatever slope conditions are imposed upon it, whether they are natural changes or what. But, in time any channel will find some sort of equilibrium, that time may be something we can't live within a normal human life. On the other hand it may be very short. The river will very often show you similar reaches; that it has a configuration, a type of geometry, the type pools and riffles, the type of everything you want. It's just more or less getting a feel of things, as to how you might start thinking about building the particular area you are talking about.

Simons--Many of us think about a river as something much more static than it is, and when we do try to nail it down in one position, especially on the piecemeal basis, we can't hold it to time ad infinitum and if we put in just pieces and don't totally control it, ultimately you're going to loose it. It's like Mr. Winkley says, replacement costs through maintenance. Of course, it's more than just moving away from it, maybe a replacement in materials every 30 years, but we've got to live with this change. For example, take some extreme ones. The Brahmaputra River in Pakistan, India just simply got up out of its present channel that it had run in for centuries and moved 200 miles. It just left the whole valley and moved and nobody did anything with it.

Bianchi--A couple of years ago the Corps proposed a snag removal program on the West Gallatin, a small river, smaller than the Big Hole, and they were justifying this action of removing all of the trees out of the channel on flood control. Engineeringly speaking or hydrologically speaking, what is the advantage of doing this originally for flood control? Obviously it is poor fish habitat, but, what is the advantage of removing snags for flood control?

Winkley--You'd take the roughness element out of the river so you would have less drag coefficient and have higher velocities.

Bianchi--Or are we going to have more? O.K. so we have higher velocities, then are we going to get more bank erosion because of it?

Winkley--You could very well have more bank erosion.

Simons--Of course, there is another very interesting part to that. We've taken a pretty careful look at some of the work done up in the Pacific Northwest where there are logging operations, and where a lot of the stuff may break loose, get away, maybe limbs, etc., before they've gotten them taken care of or maybe as a consequence of the way they handled it in the past, would move down and pile up on these snags. And then that's just like almost instantaneously putting a new bar in which deflects the currents. With these occurring in there, where these snags are piling up, why it can have some pretty dramatic effects on channel and bank stability in particular. In other words, it can deflect the current, divide the flow and you can undergo some pretty severe situations. Certainly there is some good arguments in certain areas to remove the snags, but better still to remove the stuff that hangs up on them.

Because if you have a situation where that stuff accumulates on there, it can cause some pretty serious problems, bank erosion, sediment problems on downstream and deposition in the flat area.

Boland--You are saying that as far as the snags themselves are concerned you should be very selective as to what you remove and what you might want to leave there to actually improve the situation?

Simons--Well, if you didn't have anything hanging up on them at all and the only consequence was improving or not improving the roughness and if you didn't have these other things and it improved through scoured holes, place for fish to hide in among the roots, this sort of thing, it might be very beneficial and maybe the improvement by snaging it out wouldn't be that great. Here again I think you would just have to see through a computation how much the change would be. I'd seriously doubt that taking a few snags out of the river would have much effect on stage. What's your reaction Bob?

Winkley--I wouldn't think so.

Bianchi--Of course, they were talking about 200 snags per mile, something like that. They were removing them, they found the new ones in there, removed them, so its an annual thing. Something they had to do every year.

Winkley--It is feasible that a lot of snags in one area could act like a weir and could raise your bed up and therefore to get the capacity the channel would probably erode banks and broaden out. By removing the snags you could very well develop a narrower, deeper river without doing anything else than pulling a few snags in some places.

Simons--Look at it another way, if you had several snags in a particular areas so that it caused a deepening of the flow through backwater effect and you are in essence raising the head and changing the gradient from that point to the next point downstream, then you may start some local instabilities of the bed and banks in that reach. This may ultimately head cut back under the thing and dump it. That may be going to the extreme case, but you've got that response to consider.

Bianchi--In thinking about it on a flood-control basis, where most of the snags are deposited on the side of the river and that's where they hang up, they aren't even out in the main flow usually, they are on the deposition side, on the gravel bars. Most of the time they aren't even in the water and yet they were trying to have a snag and drag program based on flood control.

SPECIFIC CASE STUDIES

INTRODUCED BY DR. BILL MILLER FOR COMMENT

Miller--On the Ruby River and Big Hole River we have examples of some of these things we are talking about. We have channel changes and a jetty structure, where they put rock jetties out into the river and slowed the current down. Also we had some irrigation diversions that we are fighting all of the time. I will go through this and show a couple of slides then I'm going to ask the panel what they would expect to happen in this area or possibilities of things happening.

This picture shows a channel cutoff in the Ruby River which was made last year. It was done with a cat going through.

You can see on the left, part of this oxbow was cutoff. I want to show this picture to get some idea of the meanders and type of stream we had there. Now what can we expect in this area due to this man cutting this channel off and more or less straightening it?

Audience--Would you say the bar is filling out downstream because of sediment?

Winkley--Well the normal thing would be for the sediment to be "belched" out of the stream at the first place it had a chance. It would be just immediately downstream, probably at the first bendway. Normally with a cutoff what happens is a slope adjustment which will degrade upstream and aggrade downstream. This will go through some period of adjustment until it equalizes the slope back to something similar to what it was previous to the cutoff. In that time it will normally erode banks both upstream and downstream.

Winkley--Is that hold just upstream from the cutoff on the right-hand bank? Is that something that has occurred since then or was it there before?

Miller--It has occurred since then.

Winkley--Well, what you would expect is actually what is happening there. The channel upstream would deepen and as it deepends it would probably undercut the bank and there would be some bank sloughing upstream. Downstream there would be a building of the bars and aggradation of the channel. As it did, it would broaden and probably flatten and tear down the banks there.

Winkley--It will probably back upstream and make a point cutoff just up this narrow stretch here unless there is some other control there that can't aggrade.

Miller--What will happen to that stream? Will that thing stay straight?

Winkley--Oh no, it will eat out that left-hand bank and be right back where it was if you give it time. Unless it comes through in the meantime and makes a cutoff and tears out that bar situation then it may pick up a whole new sequence of bars.

Simons--Mr. Winkley, why don't you point out on the picture.

Winkley--This is the direction of flow, your cutoff, they built a dam of some sort here to block off this last channel. Normally, what will happen, the channel upstream will start to scour, to degrade, lower the channel bottom and as it does, it will undercut the banks and you will get massive bank failures. This may be evidence of what happened or it may be secondary whirlpool-type eddy action here that has caused that, I don't know. Normally downstream as this material that is eroded here and out of this channel, gets down to some part of the river it'll again be deposited and form some sort of bar situation and normally widen the river eroding both banks. In time, unless there is some control on the bed, we don't know about, this channel digging down here could actually cause a point bar cutoff through the upstream meander. If that happens then an adjustment begins and more sediment, so it will go through a transition period and will gradually reach a new equilibrium. Normally, if this doesn't cut off here, this one bank will probably have more erosion than this other one. Some time in the future it will adjust the slope to something that is compatible to the flows and sediment supply. It will adjust on its own, but in an adjustment period you could get bank erosion quite a ways downstream and upstream.

Audience--Is that channel shifted to the left in that bend, one just downstream?

Miller--I don't think its shifted, we cut that off. Now the flow is from the top down.

Question--How long after you cut?

Miller--A little over a year.

Question--That is after two peak flow seasons?

Miller--Right.

Question--Is this sediment brought down? Were the bars there before?

Miller--I couldn't tell you.

Winkley--In most cutoffs that we've noticed, that were made in the last several decades, the river often completely straightens itself out for several bendways, and then starts aggrading and in doing it goes into a complete braided condition. Maybe for several thousand feet up and downstream or several hundred feet on either side of the channel.

Then sometime in the future it regain equilibrium and goes back into a meandering stream again.

Question--Was there a request for riprap on either end of that cutoff?

Miller--No, but there probably will be.

Question--Do you have any idea what he had in mind when he did that?

Miller--Yes, he wanted to keep that piece of land. What they do on some of these other areas, they cut the meanders off and go in and clear all the brush off.

Question--Does he own the inside or outside?

Miller--He must own both of them.

Bianchi--Are you sure he wasn't worrying about erosion down on that meander where you don't have water flowing now? What's in there?

Miller--Well, when I flew over there they were clearing the brush off the land, stacking it up and burning it. A lot of times, in those big bends where they are eroding and they're losing land, they straighten them.

Peterson--Getting back to your question, there was a request for riprapping on the downstream end. It wasn't on this particular man's land.

Question--How far?

Miller--It would have to be a guess; I'd say about a half a mile down.

Winkley--In that first photo, didn't we have a dam across there? Yes, it looks like it, and across the next one on downstream. It looks like they've been in there with heavy equipment. I don't know, if this starts a chain reaction, you might get this thing straightened out for several bendways. It just depends on what control will in fact stop it again.

Audience--What will be the next? You said you might get that one point bar coming out from upstream. What would be the explanation that caused that to happen--deepening the channel upstream from the cutoffs?

Winkley--Well a head-cutting type thing working its way upstream that would straighten it out.

Question--Would it follow the channel though?

Winkley--Not necessarily. It'll start eating into a bank and high water will probably finish the job. Normally, what will happen, is when you make a cutoff, the tendency is to immediately flush more sediments through to some part of the river and then it tends towards a braided stream, many channels, and you will start a headcut upstream and a braided stream downstream. With a headcut upstream which advances at a rate that will cut through the next meander loop, then you just compound the problem and it will keep going until something controls it. We have known of several streams that will go through one cutoff and then cause 4 or 5 meander loops to straighten out, all on their own, and there comes a complete braided stream for 4 or 5 meander loops where you only effected one to start with. Then after a period of several years it starts regaining sinuosity again and normally it will go right back to the way it was before, unless you try to control it. Even if you control it, it seems the bars go right back to the same side of the river.

Simons--One point to amplify what Mr. Winkley is saying--when this cutoff is cut through here, it drops the level of the water, really steepens the gradient and can make it steep enough so that you tend to shift toward the braided stream; it simply eats the upstream channel away, straightens out and works toward the braided stream. Once that straightens, the same thing is true further upstream and it keeps extending until that slope that you have accumulated in the cutoff area, the steeper slope, is spread out so it can start to reform the meander again.

Winkley--You're back to that thing Dr. Schumm was talking about yesterday, that threshold between a meandering and braided stream.

Simons--You'd push this over the threshold, possibly.

Winkley--And you go into a braided stream condition.

Simons--Or, often, that's what happens. We haven't seen all of these deteriorate yet, but we've seen many where it does happen.

Winkley--Or, you may be far enough down away from this threshold situation we are talking about to where the hydraulics of the stream will react and it will pick up its own meandering tendencies and all it will start building is a bar where those yellow trees are there on the right side of the channel and start moving back towards its old system again.

Simons--I think that is why it is critical to look at each of these changes like they said yesterday in terms of where you are in this hierarchy of stream forms, in that a slight increase in slope will shift you across the threshold value so that if its braided you got problems. If it won't, you are solidly back in this range of conditions where you get meander, why probably the one cutoff will just tend to reform into another loop there without extending its effect very far upstream and downstream.

Peterson--Mr. Winkley, there is something on this particular stream, the Ruby River. There is a dam upstream, an irrigation dam.

Winkley--What has it done to the flow? Has it changed it very much?

SCS man--They built the dam in 1938 and almost all the years from 1938 to 1967, the problem was filling it. Very few flood peaks past over. It was a case of not having enough water. Then in 1967 we began a period of very heavy snow pack, heavy runoff, and they continued to manage the reservoir in the same fashion they had in the past 30 years, and this means generally getting the reservoir full before the flood peak hits. In which case they can pass the entire flood peak down. Now the last 4 or 5 year they have panicked and opened the gates further and increased the peak through the reservoir. I think what we have seen in this 5 years of very unnatural peak flows compared to the previous 30 to 40 years.

Winkley--Well, that could start a meandering pattern. If it stabilized for 30 or 40 years or whatever period you are talking about with fairly uniform flows, low flows, and you increase them suddenly, the river is going to try and pick up some different geometry then it had before and it'll start meandering in places.

Audience--We've run into a lot of problems on the Ruby because of this 4 or 5 years of consistent high flows going down through there.

Miller-- Here is a picture of some jetties that we have downstream close to Twin Bridges, Montana. We have riprap and jetties on the outside of that bend. What is your impression of using such things as jetties or rocks extending out into the river to slow down the flow?

Simons--Again, you could say, probably several things about it. Certainly I don't think putting these jetties in is going to significantly reduce the velocity. They look to be spaced too far apart to me, if you want to protect the bank you essentially got to build them close enough so that you cause the major current to be held away from the bank. The use of them then can be effective in protecting the outside bank, if that is the procedure that you wish to use. In terms of what flood stage does, looking at these as individual roughness elements, you'd be hard pressed through computations or through measurements to show that it would significantly increase the stage, maybe a few tenths of a foot. But, you can use that as a means of keeping the main current from attacking the bank, but they've got to be properly spaced.

Audience--What about the angle in relation to the river? Should they be pointed straight up, angled down, or up?

Simons--Well, maybe Mr. Winkley better answer that. I think in something this small, from my viewpoint, just something essentially straight out or maybe straight out but dropping off a little as you move out into the stream so that you sort of tend to move at low flows, the flow changes, back away or the main current really isn't in the same position in the channel all of the time. It varies with rising and falling stages through the system.

Winkley--Let me reemphasize something that Dr. Simons brought out. This structure, being non-erodable, sitting out here will cause a secondary action and will cause scouring or eddying to form downstream of it. Quite often that eddying will undermine the structure itself; it could be big enough even to go back and deteriorate the bank by undercutting the base of it. That is the reason that anything like this on the outside of the bend, if its just going to be a hard point sitting out there, ought to be shaped so that as your stage fluctuates, your scour point fluctuates and you aren't always scouring the same point. This is more or less level or comes out on a fairly high crown and suddenly drops off. That scouring action takes place in almost the same position all of the time. So you are creating problems instead of solving them. The other point, as far as your velocities are concerned, is that it will move them on out toward midstream and your stream will probably in time adjust providing it doesn't tear your bank out in the meantime. We've found that the angle into the stream is very important, and they've done quite a bit of experimenting at Waterways Experimentation Station in Vicksburg, Mississippi, to try to figure out how you should angle a dike. There are all kinds of theories, perpendicular to the flow, upstream, downstream, and varying degrees of upstream and downstream, and L-heads. On the outside of a bank often times an L-head is best. You bring your structure up far enough and give a flat surface so that you have something for the stream to align itself to, and not just a point that agitates the action out there. As far as upstream or downstream, it depends upon the alignment into the structure. Either way can cause scouring at one place or another, either at the bank or at the outboard end depending upon the flow conditions into it. There is no set rule. It would depend upon the stream, whether you have a straight section or whether you have a crossing or a long radius or short radius bend; there again, its the geometry of the stream and the flow; there is no set answer to it.

Audience--Is there any rule of thumb in the spacing of the jetties like that?

Simons--Well often times you can take top bank widths and get by with about that spacing.

Winkley--Unless you would have an extremely wide channel. If you have a well-confined single channel, meandering stream, then stay within about low bank width. Low water width and tie into top bank is a pretty good rule of thumb. From there I think you are just going to have to play with it on a stream and know lots of other things on it. Nobody's got a good regulation. The Corps of Engineers have been putting these things in for years and they never have come out with a criteria that stuck from one stream to another.

Simons--We do have a report that will be out within a few months, I'd better say, it ought to be out in a few weeks, but like everything else probably won't be. But we have been looking at this type of a structure as well as the L-heads, and we've been seeing what spacing and what shapes will work best to protect the banks. This has been done largely from the modeling viewpoint, but I think that coupled with some observations in the field, it will give you a pretty good index. And well, as I say, other than getting that out, I don't know of any other studies that have really been made.

Winkley--We've just started one in the Corps.

Simons--You are doing one too?

Winkley--On the coalbed and the sandbed model. Both where we are trying different alignment in the river. One we've got a fairly straight section of river with a divided channel and we are trying to control one channel to the other, plus the banks and trying various types structures and alignment to do it. In the other one, we are taking a normal sinuous bendway, in fact three bendways in a row, and we are trying structures at various points, varying the distance between them, the crown elevation, the slope of the crown to the dike, whether its sloped upstream, or downstream. Now part of this has been completed and was published in ASCE Journal in about 1967 or 1968. I'll go on record as saying that I don't agree with it because they took one reach of river and tried everything with one alignment into the structures and made all of their assumptions and conclusions on that. Whereas, in the real river, when you look at it and try the same thing, you get all the variations in the world because the water flows into it at various stages is different than it was in this particular reach they modeled. You are still back to the point that you've got to consider the flow of the stream and the alignment of the water into the structure, mainly in high water where the major damage can be done.

Simons--Now these can be anything from successful to just odd ball hard points on the banks that create extra turbulence and eddies that can cause you more problems than they do you good.

Winkley--Right down to complete disaster.

Bianchi--I've seen on the West Gallatin a riprap job where it was blanket riprap and on the end it was filled with jetties. Apparently what happened when I came back after high water, it must have flowed around the jetties and took off across the guy's hayfield. It probably took out 5 or 6 acres, went right across the fellow's hayfield he was trying to protect. And obviously that little jetty on the end must have caused an eroding action and it went right around the end of the riprap and right across the field.

Winkley--A lot of dikes have been built on the Mississippi River, a lot of them the very same type as this, a lot of rock, groin, dike, jetty, whatever you want to call it, out into the river and we've tried all means of bank stabilization adjacent to it. If the jetty is not aligned properly with the river and is not shaped properly to flow conditions, you can't put anything in there that will stay.

There will be massive scouring and bank failure. Well, in the Mississippi we have some failures that bring out 3, 4, and 5 million cubic yards in one big hunk, and it takes out, well in proportion, it would take out maybe 2 or 3 of these all at once.

Whipperman--I think what happened on some of our projects here is that they built the jetties in first and they don't work to stop the erosion, the riprapping comes later.

Simons--Well, I think again my original observation, based upon what experience I have had, that if you were simply going to use those jetties without the other protection, and the spacing looks too big to me, I don't really see any advantage in using both. I think you could do it either way. I think you could design it to get by with just the (bank) riprap or I think you could design it to get by with the spurs. I personally don't think I would ever use both.

Winkley--I'll show you something on the board that might help clear some of this up. We have a bank to protect and are building a structure that controls some sort of a flow pattern. The water coming around that structure, that you block out here has to move over and come around the dike which increase velocities, you get dead water back behind the dike and you start a whirlpooling action, which scours it out. O.K. if we raise the water little bit and put it just over the top of that jetty structure you now have two actions. This block of water coming in has to go one of two ways, either up and over or around the end. You still have partial blocking where the water has to go around. Well, you get two actions, you get whirling around the end and you get the roll over the top. Now the combination of both of those can cause a third action.

Now most of these, we tie into the top bank somewhere. This interface between the bank and the dike that causes the second eddy action and scours out the bank.

Let's start out and plot time against stage and construct a stage duration curve. Well suppose you took this curve and just flattened this scale out. The scouring that happens, tears your banks out, usually is this eddie being too close to the bank and that eddy action around the end of it, or this interface between the water and the dike occurring at some predominant stage that continually eats the bed out. You can't put anything in the river like this jetty that won't cause some scour action. It's impossible. But to minimize it, if you design a dike maybe a little bit like the stage duration curve you might miminize the scour problem.

Audience--Is it also possible you might scour the whole length and it will all pop open?

Winkley--It is possible, but we haven't seen it happen.

Simons--Well, actually, you see, the scour would not be as great unless you did just happen to get very unusual conditions and you had one sustained flow that didn't fluctuate at all, like control from a dam, and you held it, and then you wouldn't gain anything. But certainly where these flows fluctuate, if you design your structure as Mr. Winkley says, you can move that very active part of the flow back and forth, then you won't get as deep a scour as you would otherwise.

Winkley--You better have a pretty good idea and a fairly long period of record for the stage duration curve. How long, what's your hydrograph going to look like? How long is it going to be at a certain point for any length of time? And don't do it for one year, if you can, do it for several years and then average it all together because runoffs aren't constant, as you all know. All you can do is minimize the problem, you will never completely eliminate it.

Well, some of the dikes I showed you yesterday are 4,000 feet long, and that's a big chunk of rock to stick out in the river. Those dikes will cost in the neighborhood of 2 and 3 hundred thousand dollars a piece. We are building them on sand and that sand will have a D-50 of probably 0.4 millimeters. We're putting rock with probably a D-50 of 6 inches on top of it and its staying pretty well.

Part of the secret of building these dikes is putting enough mass of stone in so that when some of the dike sloughs off it will also armor plate the scour point and stop the scour action. But, there again its a matter if you got a problem you can only correct it by playing with it. You can't go out and build something in the river that is foolproof. Well, maybe you could build a concrete structure if you could drain your river, but if you've got running water you've always got the problem. If we've got a dike that's sitting out in the river, we often times get scour holes below them that do go down 80 feet. We have to prepare against that and try to hold things where they are.

Simons--Another important thing that I would like to emphasize is that when we go out into a small stream and put in these rock structures, in general, they are pretty small volume-wise, and it takes almost 100 percent of the rock volume to armor the scour holes that develop. So, if you don't take that need into account you're totally wiped out. If you will look at the magnitude of the scour hole that you put in and if you will put in a quantity of rock so that after you've armored it you've got a dike left, your chances of having some success are much better. We've often seen instances where people have gone into rivers and maybe put 40 or 50 of these structures in and come back after one flow season and they are gone and they are considered to be a total disaster. That's not really true, the disaster was the methods that they used to design them. If they would have had enough volume in those to armor the scour hole that develops and still leaves a dike, they would have still had them today.

Question (C. Bishop)--Can you kick the current against the opposite side and cause erosion there?

Answer (Winkley)--If you put them out far enough in the stream you would.

Well normally you are going to look at the stream and see what is a compatible width to that stream and it would be rather foolish to try to squeeze that stream in more than it would do naturally. Now for example, you may have a wide river section you want to control. If you build a dike out all in one construction season and then right after you finish it you have a lot of high water come by in the adjacent channel; the structure isn't prepared to handle that surge of high water because there's not enough cross section area. Then you are going to get an extreme amount of scouring and maybe even failure of your structure, or maybe complete flanking of it.

Simons--Yet to achieve stability, I think from our standpoint, there wouldn't be any necessity to build those out so far it would deflect the current the other way. You could surely build them far enough to completely change the alignment of the flow, however, in a small system. This is something you would have to look at and see what you wanted to achieve.

Bishop--I know a number of them in the Billings area. We've got indications that that is occurring fairly frequently and as a result they've almost quit jetties and gone to armor plating.

Winkley--Well its probably in the design of it.

Bishop--They concluded that rockwise it takes just about as much rock one way or the other.

Simons--Not a lot of difference.

Winkley--Well, if you are going to put a jetty in and you're going to put it in to close off an area the river is trying to develop, and you're fighting the river, then its a lost cause. You still have to know the pattern that river wants to maintain and you have to work with it, not against it if you are going to maintain some sort of success. What we are talking about is sinuosity and the fact that you get alternating bars. If you go to the opposite side from where a bar has been building and try to close off that side of the river all you are doing is asking the river to do all it can to tear your structure out. It's not just naturally going to change and go the other way.

Miller--In the Big Hole and many of the other rivers we get gravel dikes being pushed up from the river gravel sometimes on an annual basis. I would like to get your ideas on whether loosening the plating on the bottom of the river by pushing up gravel dikes on the river banks is harmful? The case I am interested in is a gravel dike pushed up on the bnk on the outside of a bendway.

Winkley--First point, each time there is a high flow, because the high flows cut across the point bars, the inside bend bank will normally start eroding away and so you should get a wider, flatter river and you get more loss of land along the inside. Second point. By moving the gravel out of the bed of the stream and building this dike, if there was an armor plating effect from that gravel on the bottom, it's been disrupted and there will probably be some degradation happen there instead of rearmoring itself. This will depend on how much armor plating material of a particular size is present in the stream.

Simons--In any event, whatever you took off would make more of the fine material accessible for transport downstream.

Winkley--You'd increase the amount of sediment you moved through the system by peeling that coarse stuff off. You'll also probably open up the channel on the inside of your bendway and cause it to develop. It may develop to the point that you will abandon the one your protecting in the first place.

Simons--If you skim that armor plate off as Mr. Winkley said, you can just simply develop a double channel situation there.

Winkley--And the next point of attack is going to be the banks downstream. So this armor plate will have to be extended farther and farther downstream. You just really keep chasing the problem.

Bianchi--What kind of land are they protecting with the gravel dikes and riprap?

Miller--Well, the farmer and rancher are worried about other side channels, capturing the river. When the river moves they are going to lose land because some land will go out of production.

Simons--Well, one sure has to look at all the possible situations before he comes up with answers because there are other ramifications that must be taken into effect. Certainly, increasing flow is one point that was mentioned. Increasing the cross section of the stream by this type of action, simply block the cross section of the stream and see how much you have enlarged it, why that's pretty microscopic. If you start trying to improve a channel of that size by pushing gravel around, that takes a lot of money.

Miller -- This is a picture of the Big Hole River where we had some problems on the Giems ranch in the Pennington Bridges area. The river breached a dike going across an old side channel. Well, the year before the rancher put in a lot of riprap and armored the corner right above this old dike. Last year the river breached this dike and went back into its old 1940's channel. Now the Corps wants to reclose this side channel and put the river back to where it was two years ago.

Simons--Well, one of the biggest problems here, and I'll refer this to Mr. Winkley if I'm wrong, but the alignment that they are trying to develop and hold is wrong. They're doing it an awfully hard way. That's a very poor alignment to try to hold.

Peterson--At one time, in 1940, that side channel, it's going down now, was the only main channel.

Simons--This river is uncontrolled, in other words, no reservoirs upstream. Well, just what you see of the evidence, there is a lot of variation and to really decide that you can hold that in any one alignment is mighty tough to do. I think whatever you do is just putting out local brush fires. And I think you are going to lose your maintenance effort at a much faster rate than the Corps loses its 3 percent per year.

Winkley--It looks like they've got a stream that borders on being a braided stream, anyhow.

Miller--It is, right down below here it starts braiding, as a matter of fact at the Pennington Bridge they had to build two bridges there because the stream was braided.

Peterson--They are replacing a lot of the lost riprap; they lost over $100,000 worth of riprap in this Big Hole River area this year. They are replacing it with riprapping and 2 to 3 to 4 foot dike on top of the bank. It appears to me that in a situation like this you are just adding to the problem when you put a dike in on top of that.

Simons--You mean by a dike on top, a dike on the overbank set back a little?

Peterson--No, it's right on the river bank, right on the bank itself.

Winkley--Well in some instances that can be good because it will help build the bar on the other side, and get you a well-defined channel, providing you are in a good bendway type situation.

Peterson--What happens when it's at flood stage and that extra two feet of free board is on top? What happens to the other side?

Winkley--Oh it will equalize itself out, probably during flood stage if its a sinuous channel, the main current is probably over the point bar, anyway.

Simons--One thing to remember, we've shown a certain sinuosity on all of these channels and the sinuosity that a channel adopts is related, maybe, to some dominant discharge. At low stage there is a tendency to build a much tighter sinuosity, a shorter distance between bars. At high stage, there is a tendency to build these bars at a much greater spacing, and over the average you got something that works reasonably well. At flood flow there is a strong tendency for the main flow to move in on the point bar. There's a straightening of the thalweg as the stage rises.

But, if you documented where the main current was, you'll always find with rising stage there is a tremendous tendency for the main thalweg to straighten. This is, I think where the Corps loses control on a lot of these point bars. The flow straightens and impinges on the point bars and will actually cut across them, particularly if they've allowed gravel dredging on the bars so that they've lost the armor. Then, in a short period of time you've got a double channel with an island in the middle. This is, in my estimation, highly susceptible to quick change. You've got a rough problem to really put this in an alignment and hold it. Changes upstream can effect what you do here downstream and this whole thing is different after every flood.

Bianchi--What I can't understand on this Big Hole River Corps project is why they're worried about maintaining that river clear in there where it is right now. Why don't they come out and cut a new bed before it goes into those adjacent fields? It's a real old area there. It's probably even higher than where the water flowed during low flow. We talked about that to the Corps, why don't they come back out next to the fields and maintain the river in the 1940 channel rather than in the channel where they are now pushing it?

Simons--Really, you are saying that the channel bed where they are trying to hold it is relatively higher than some of the adjacent area.

Miller--Just the opposite of what you said, the cropped area is a lot higher.

Bianchi--We're going to spend a lot of time and money just to save a little strip of land in there that probably is not even a foot higher or a foot and a half higher than what the low flow of the river is. They can do it by building a temporary dike in there and riprapping it. Sounds ridiculous.

Winkley--Well, you are looking at a short piece of river here and its awfully hard to tell where the thing should be. If you take that river over long reaches and start looking at what sort of pattern it would likely maintain then you could decide a little bit better where you should hold the bank. If you did hold it where they are trying to, you've got a 100 feet or so of buffer zone in there, at least you've got some protection from it.

Simons--This is basically what I would have said and, again, I'd emphasize also that you don't see enough of it, not having been up there, we may be sticking our necks out. But if I was the rancher that owned the land adjacent to the old side channel I'd be happy to see them try and hold the river back because if you let it come over to here then you've got your bank right against the land that he is using--deep pools, harder to hold maybe than holding it in two stages. But, unless one sees the whole thing why it would be hard to make a decision.

Miller--Something else we are getting a lot of, especially in the Big Hole River are irrigation diversions packed up out of river gravel.

The rancher-farmer tries to get as much water as he can in his irrigation ditch in usually August or September when these streams are low. He has to get right out in the middle of the river with his cat. In the Big Hole its about one diversion every half mile or one every mile, some of them clear across the river and some of them go half way.

Simons--And they are just pushed up out of the material in the bed?

Miller--Yes, with a cat. What effect does this have say on the bed load material, sediment, stream mechanics, and such?

Winkley--Well it's not going to bother too much during that low stage and he has probably only disrupted the bed for a short space away from the dam he built. First high water will wash it out. It'll probably attack the banks on each side before it gets the dike washed out completely. The materials in it will probably end up almost back where he got it from and in some space of time, depending on whats there, it will probably go ahead and build some sort of armor across there. I'd guess the net result would be a gradual widening of the river at that point and ever year he'll build up a wider and wider dam.

Simons--I think whatever they throw up, I know as an old farm boy I've done that myself, and I know how quickly you lose control. Even though it's effect is only temporary, it's effect may be enough that the material is soft on either side to open the river up and then maybe something happens upstream that gives you a better opportunity or a worse opportunity depending on what you want to see happen. It opens the opportunity for exchange one way or another. It is a poor system in that you really don't know what flows are going to be through there from year to year, from runout to runout. You might aggravate, make it look more like a braided section.

Skinner--This is a very similar analogy to a beaver pond. We've seen this happen on meadows, where a beaver builds a pond across there it will bust out upstream and start a whole new channel. There is a big possibility for that here. It depends on the top bank situation. If you get a little flow through there it could bust out and start a new channel.

Winkley--I have noticed from observance of some similar stream early this summer, they continually built bank protection out of the bed material around towns and around bridges. We noticed that where the stream hadn't been disturbed, it had a normal width and seemingly fairly well behaved with cottonwoods on the banks--30 to 40 inches in diameter that had been there for a long time, both banks. But where they had messed with the stream trying to disturb it or trying to build up dikes, bank protection from the bed material, the stream was often up to ten times as wide as it was normally. It looked like the channel could run anywhere and where they put their revetment or the dikes was just a hit and miss proposition and where they got material from was where it happened to be handy and next high flow came down and got a little bit more bank material and the whole thing just kept going wider. Something similar to that could happen here, but these are fairly steep slope streams, they are streams that look like they probably fell 30, 40 or 50 feet per mile.

Simons--By peeling the arms off and building these wing dams you do increase to some extent the amount of sediment moving through the system. You continually lay out more fines that you can more readily get at over a wider range of flow conditions and, of course, if you computed it, it may be relatively small and may not be significant, but it would sure be larger.

Gaffney--On a lot of these riprap jobs which are fairly undesirable from a fisheries standpoint, we ask them to fence to allow the vegetation to come back and hopefully get some fish cover developing at some time in the future. Do you have any thoughts on how much of a buffer zone you need and what the possibilities are for woody vegetation to come in and allow for bank protection if not fish cover, maybe both?

Simons--Let me make sure we understand. You've got the riprap set back with a buffer zone between the riprap and the water or the reverse?

Gaffney--No, the riprap is right on the stream. In some cases we ask for a fence back away some distance from the stream bank and riprap.

Simons--To keep it from being grazed in order to give it a chance to develop?

Gaffney--Yes, grazing, dozing or spraying or whatever, to allow vegetation to come up into it. These are usually fairly narrow, one to two rod buffer zones. Probably more often one rod.

Winkley--What is the normal type growth on your bank: Willow? Cottonwood? We have found that even where we have put asphalt and concrete on banks that through normal soil movements and within one or two decades, sometimes less than that, we've got well-developed willow growth and the protection is also still there. You might even think about a combination. You know willows will grow in almost anything if you can keep a little moisture to them and keep them out of the water enough time of the year.

Gaffney--A number of these we've looked at this year, were primarily hayfields mowed up to within two or three feet of the existing bank. Of course, most of the places they requested riprap now are the weak points where the river breaks through. Maybe there was two feet of willow there last year, but the river broke out and the request is for rock in there now. I was wondering if it is really effective to fence those buffer zones and is this going to leave enough revegetation to have any significant effect on bank protection in the future.

Winley--Wherever you remove vegetation you enhance the possibilities of bank caving. Natural protection helps; it doesn't eliminate it, but it helps.

Bianchi--A program of bank stability would be the next thing, is that right?

Winkley--Well, if you keep buffer zone between the bare ground and the river, yes you enhance the possibilities of it keeping the river there, you won't eliminate it. But, you will at least assure the success of the river staying where it was better. The more growth you can get in there, particularly on the outside of the bendway.

Simons--I might mention a little experience I have had along that line. This material forming the banks and bars that you're talking about revegetating is largely gravels and sands. As you go from a relatively high stage to a low stage, and you do this annually, you cover a lot of the banks. Really this material is so free draining since there are so few fines in it, that it has been my experience that it is very tough to get a good growth developed in that type of material. The soil conditions may not be the critical factor, they may not be very good but the soil is so free-draining you can't keep moisture in there when the river drops long enough to really grow vegetation. I know when we looked at several streams on which we had aerial photos, we saw some channels that had tremendous growth on both sides. We saw some channels that had literally no growth. We saw some channels that had patches here and there that seemed to be developing. So I got a soil auger and on these cases where we had parts of the bank that was essentially bare or had very weak vegetation, and parts of the bank where the vegetation looked like it was really taking hold and went in and did some drilling. I found that in every instance where the vegetation was really taking hold we were in an old area, a pocket that had had silts and clays fill in it; in other words, something capable of holding the moisture and capillary forces to bring it up. In these other areas even though the rainfall is much higher than it is in our area, it drains so fast, was so free-draining that it was very difficult to get much of a helpful vegetative barrier by fencing. So I think the changes in water level and the type of soils, and the degree of free drainage would have a very significant impact on how successful you were with the vegetation.

Gaffney--I'm sure there is a certain amount of variation in clay soils and you know we are talking of several hundred miles of stream. Some of these areas that I'm thinking of didn't get mowed in the past year because of the flood conditions; the water was on it too long so the rancher decided not to mow it. You see pretty extensive growth of willow coming out in just that one year, maybe 50 or 60 feet away from the stream so this would indicate that in a lot of areas there is a potential for this kind of growth if it was given protection.

Simons--Well, I'd say that's very encouraging and I just wanted to point out that I'd seen situations much better than here where you may get none at all or where you might get it patchy, or if you essentially get into a situation where there is more fine silts and clays to fill the space between these other pores why you can develop quite easily very good vegetative covers, continuous bands right along it, like down in your flat floodplain areas.

Boland--Well, aren't we on pretty firm ground when we say that the purpose of the riprap is to stabilize the bank, and vegetation will also stabilize the bank. So that if we riprap we could also fence and protect the vegetation that may grow where we are really doing a better job than just plain riprapping.

Simons--Yes, you're adequately getting the effect or benefits of both, yes, you can gain a little more if you can get them to let you use that ground.

Boland--Well, I think, we as a department can say we can do a better bank protecting job with that brush because of the fisheries habitat that come along with it, and this is probably better for us to sell.

Winkley--You'll enhance the chances of your success if you can keep that zone in there, there is no doubt about that.

Boland--That's what we are interested in. I think with the 3 percent maintenance you have on projects that you really put a lot of money and a lot of work and engineering into a lot of our projects.

Simons--Well, just let me make one remark regarding the dumped rock over the bank. I am assuming you grade these banks to some sort of gradient before you dump it over. Otherwise it falls in there angularly and it doesn't take much force of the water to move it, and if you don't put it on very thick why it may not hold very well.

Audience--Well, this is what the Army Engineers on the west coast call weighted toe. This is the way they are placing it. They've gotten into considerable problems with transportation industry out there and migratory fisheries. From the fisheries point of view, it is very detrimental to see.

Simons--On the other hand you see if you place the material in there on the point of incipient failure, in other words, fail just due to its own weight, roll down like a tallus slope why any velocity at all will move it and if you put on a thin layer it fails, if you put on a thick layer it automatically develops the flat slope anyway and you've lost it so I guess you decided what you want.

Clint--How serious a problem are you likely to create in downstream of areas where you remove substantial areas of woody vegetation that's quite heavy on a fairly wide floodplain along some of these high gradient streams. The thing I'm getting at, is in a number of the areas, for instance in the Red Lodge and Rock Creek area, in planning for summer homes and they are going in with a bulldozer and removing substantial amounts, and when I say substantial amounts I mean several miles, of very heavy woody cover along the stream. It appears to me they may be opening themselves up to substantial flood problems downstream as a result of the holding back effect that the vegetation on those banks will afford.

Simons--Certainly with the vegetation and getting overbank flow why you've got much greater roughness and you get more channel storage which dampens the peak flows downstream a little bit. I don't know how we cope with that particular problem because you get into the real estate activities here and the dollar is, I guess, the magic wand. We heard one of the fellows from Colorado University, Dr. Gilbert White, who all of you know has worked on floodplain management, probably one of the foremost people in the world on that particular problem. He was telling about observing a guy building an apartment house within the limits that the river could attack down there near Boulder and he walked out to him and said, "You know you are building in the floodplain?" And the guy siad, "yes." And Gilbert said, "Aren't you afraid that you are going to suffer some damages as a consequence of high water flows in the future?" And they guy said, "No, I don't have the slightest worry." Gilbert said, "How do you come to that conclusion?" and the guy said, "Well, I'll have it sold in six months."

Clint--We have a curious situation on Yellowtail after they first closed the dam. They wound up with a hundred year flood the first year they closed it and they caused problems upstream and downstream both.

Simons--Well, Mr. Winkley has a little story he tells about flood frequencies that I have always liked. He was pointing out how totally naive we were about what flood frequency means. And most people when you say you are designing for a hundred-year flood, I think most people automatically assume that it isn't going to be seen for at least a hundred years. And, that leads to some tremendously great disappointments for some of these people that apply and count on that philosophy. And, this particular instance that I heard about down in Vicksburg, they had built some dikes that were supposed to protect some property against essentially the ten-year flood. I guess the doctor has called up once or twice and said, look I've been flooded and what's the protection and they explained again that it was designed for a ten-year flood frequency and he made it pretty clear that he'd seen that thing overtop about three times in the last three years and they better get their thinking straightened out, they better find out what a ten-year flood is.

Skinner--Are there any other questions or comments? I want to express the appreciation on the part of the panel for the excellent questions and the discussion that you people provided. Thank you.

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