J. C. Knox

River Response to Deforestation, 1832-1971
Platte River, Grant County Wisconsin

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B.A. Thesis
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Man's impact on his environment is currently a popular subject of discourse; it is a topic of genuine importance in a world of increasing population and increasing utilization of natural resources. This thesis is concerned with man's ability to modify the hydrologic environment of drainage basins. Specific focus is given to man-induced adjustments in hydraulic variables that are regulated by a balance between surface runoff and sediment yield. Land use changes associated with European settlement have greatly altered rates of runoff and sediment yield and have subsequently produced considerable changes in cross-sectional and planimetric morphologies of Southwestern Wisconsin streams and rivers.

I. Origin and Nature of the Problem

Runoff and Sediment Yield

Langbein and Schumm (1958) in studying different climatic regions, demonstrated the relationship that vegetation, sediment and runoff have to precepitation. With increasing precipitation, runoff and the amount of natural vegetation both increase (Figures 1a, 1c). Sediment yield, however, increases as precipitation increases up to twelve or fifteen inches, and then falls off (Figure 1b). The decline in sediment yield with precipitation averages greater than grassland values reflects the increasing amount of vegetation that is present to inhibit erosion in higher precipitation regimes.

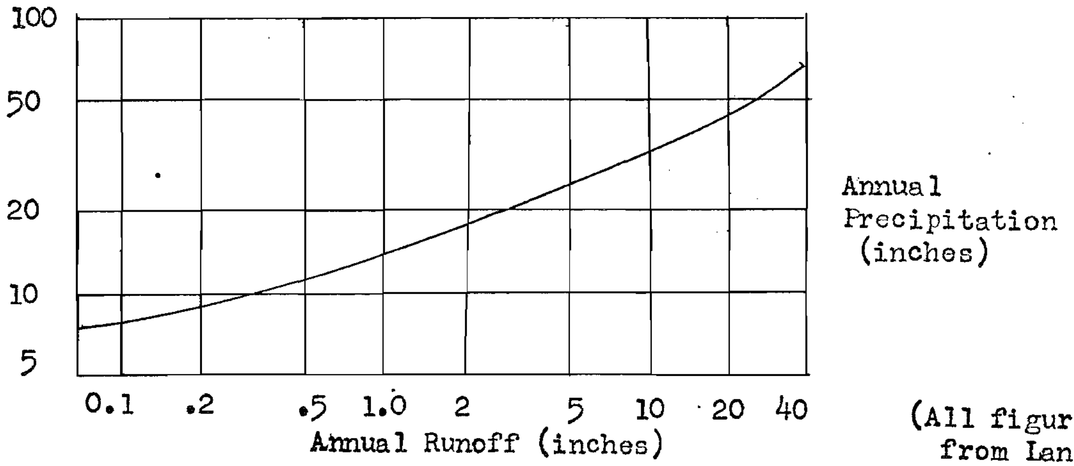


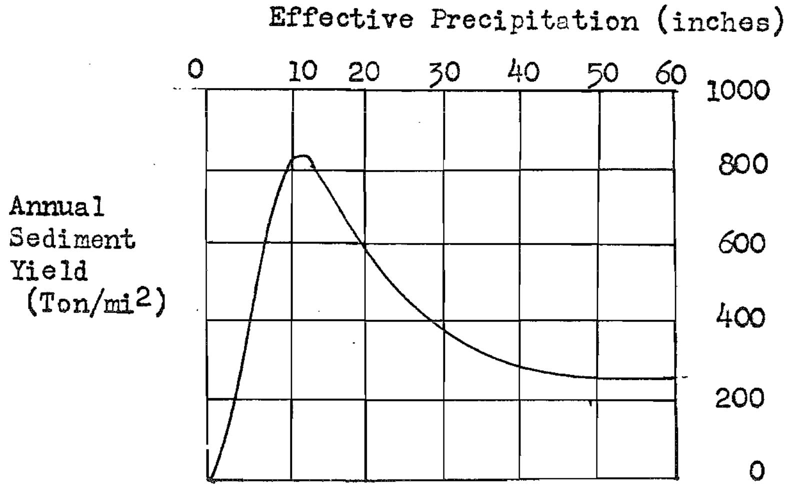
Figure 1a

Relation between precipitation and annual runoff.

(All figures from Langbein and Schumm, 1958)

Figure 1b

Relation between precipitation and sediment yield. (Stream Data)



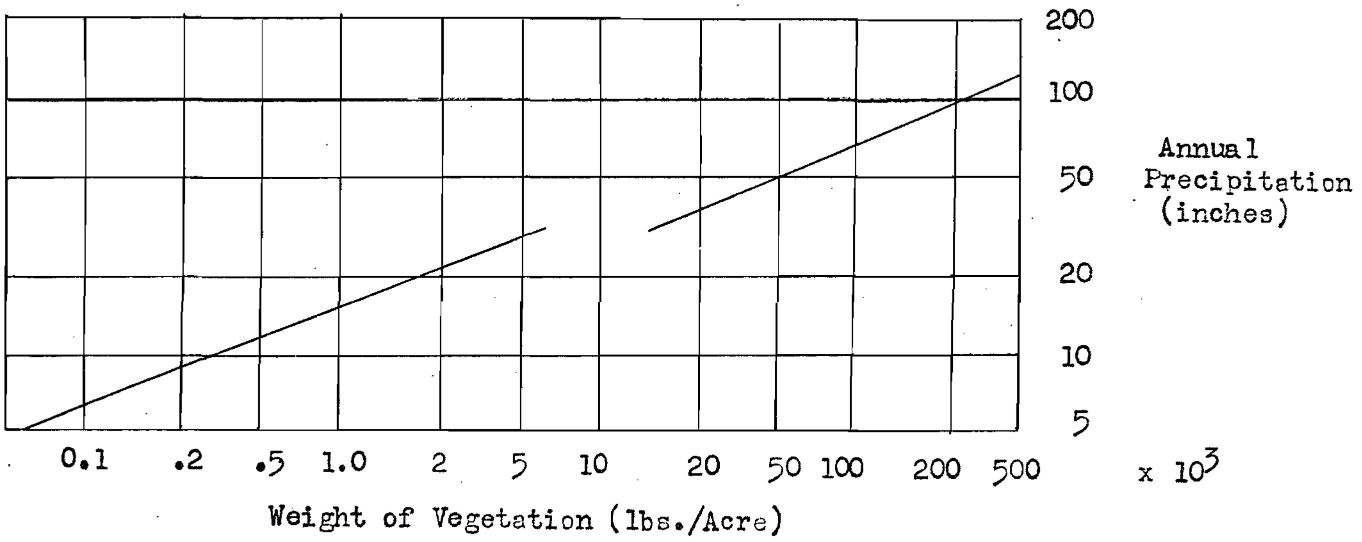


Figure 1c

Relation between precipitation and weight of vegetation

Sediment yield and runoff are therefore broadly defined by the effective precipitation of a region. Although biases and exceptions are introduced by differences in land use, soil type, geology and physiography of a region, the general runoff and sediment yield characteristics of a region are climatically controlled, with vegetation being a key factor in controlling sediment yield.

Langbein and Schumm also discussed the possible effects of climatic change on the runoff and sediment yield of an area, and the consequent impact it will have on the hydraulic variables of streamflow. It is clear that a shift in land use will cause similar changes in the runoff and sediment characteristics of a region and thus induce instability in the hydraulic variables defining streamflow. Man's mechanism, similar to that of climate, is alteration of vegetative cover.

The Hydrologic System

Leopold, Wolman and Miller (1964, p.268), recognize eight interrelated variables that are important to the downstream changes in river slope and channel form, including: width, depth, velocity, slope, sediment load, size of debris, hydraulic roughness, and discharge. A ninth variable is apparent if slope is divided into physiographic and hydraulic components.

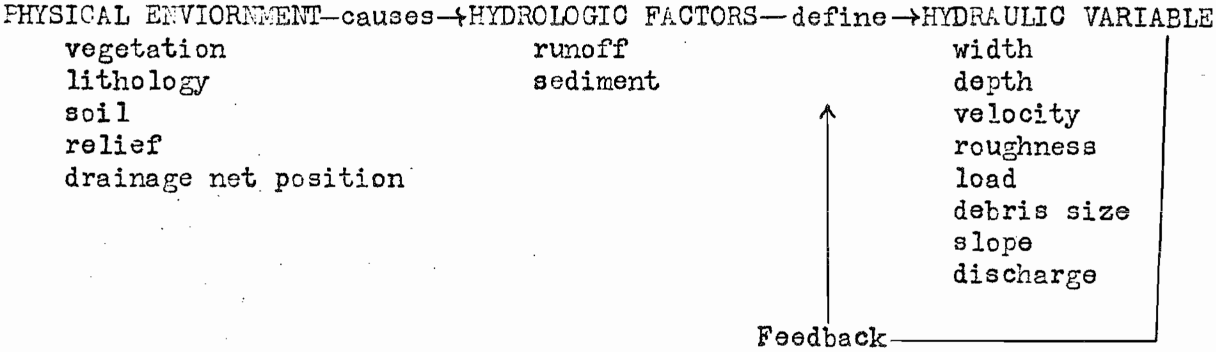
The nine variables may be thought of as dependent, semi-dependent or independent in nature. Generally, channel width, depth, roughness and flow velocity are considered dependent variables, consequent upon one or more of the other hydraulic variables. Sediment load, size of debris and discharge are normally considered independent of the other variables.

Adding the ninth variable, river slope, eliminates some confusion. Slope in a drainage basin generally may mean either a physiographic constraint upon the channel or the hydraulic property of water surface slope. In the first usage, physiographic, slope is an independent variable; in the second usage it is a semi-dependent variable.

In viewing man's impact on a drainage basin, certain dependent variables may be selected as indicators of change in the independent ones. That is, in order to measure changes in hydraulically independent phenomena, one must observe the response of the dependent variables; their modifications may then be related to the independent variables through known mathematical properties and thus provide an estimate of the magnitude of change.

The natural drainage basin exists in a quasi-equilibrium (Leopold, Wolman and Miller, 1964, p.266-268); the hydraulic variables of streamflow are dynamically stable and adjusted to the runoff and sediment yield provided by the physiography, climate and vegetation of the basin. Alteration of the vegetation within a basin will cause changes in runoff and sediment yields, thus entailing adjustments by the stream to the imposed disequilibrium. Figure 2 diagrammatically simplifies the system; the feedback arrow signifies that the hydraulic variables may be changed not only as a response to alterations in sediment and runoff but by shifts in one or more of the other variables also.

FIGURE 2



As stated previously, this system is in a quasi-equilibrium. An outside influence such as a shift in man's use of the land (specifically alteration of vegetation and soil) induced by man will be expected to initiate responses throughout the consequent portion of the system.

II. Hydrologic and Hydraulic Considerations

Runoff and Sediment Yield

Since the hydraulic properties of a river at any point in time take their individual characteristics and relationships from the runoff and sediment delivered to the channel, it is useful to preface a detailed discussion of the relevant hydraulic variables with an examination of some of the influences on runoff and sediment yield.

Runoff may be divided into two portions: that which flows overland during times of precipitation and snow melt, and that which infiltrates the water table. In the first case, the overland runoff is a chief factor in the peak discharge of a stream; in the second case, underground seepage is the main contributor to the base flow of a stream.

In assessing the geomorphic significance of runoff, the surface portion is most important. The size and shape of a river channel are thought to be functions of the bankfull discharge (Leopold, Wolman and Miller, 1964, p.241) which has a return frequency between one and two years. Since the bankfull stage is largely composed of surface runoff, it is this component that we shall be most concerned with.

Surface runoff and sediment yield are greatly affected by the type and amount of vegetation in a basin (Langbein and Schumm, 1958). Areas predominately grass covered may be expected to allow greater surface runoff than a forested area (Hibbert, 1969), while an overall reduction in the amount of vegetation in a basin will lead to increases in the proportion of runoff taking the surface form as well as increases in the quantity of sediment eroded (Leopold, Wolman and Miller, 1964,p.47). Obviously, clear cutting of a forest or plowing of prairie land causes tremendous increases in

FIGURE 3

Relative Erodibility

Cover	Relative Erosion
Row crops or fallow	1.0 to 0.60
Small grains, grass hayland crested wheat grass	0.05
Pasture, excellent condition, and forests	0.01 to 0.001

(Musgrave, 1947, in Langbein and Schumm, 1958) runoff and sediment available to a stream (Langbein and Schumm, 1958; Patric and Reinhart, 1971; Hornbeck et al, 1970; Rothacher, 1970; See also Figure 3).

The Hydraulic Geometry of Stream Channels

With this general discussion of the factors influencing surface runoff and sediment yield in the drainage basin in mind, attention is now focused on the effects that differences in runoff and sediment have on the cross section morphology, planimetric form and longitudinal profile of the stream channel.

Cross Section

Leopold and Maddock (1953) defined three major variables important in determining the cross section morphology of a channel: width, depth and velocity. All are known to have power function relations to discharge of the form:

$$w=aQ^{b} \qquad (1)$$
$$d=cQ^{f} \qquad (2)$$
$$v=kQ^{m} \qquad (3)$$

where w is width, d is depth, v is velocity, Q is discharge, and a,b,c,f,k,m are constants. Since (by definition) the product of width times depth times velocity must equal discharge, (Leopold and Maddock, 1953) it can be seen that:

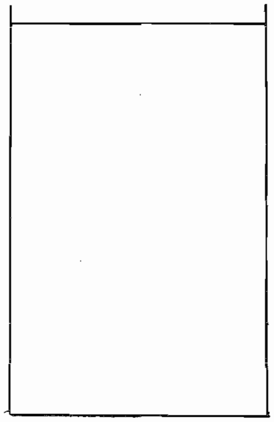
$$\text{if:} \quad wdv=Q \qquad (4)$$
$$\text{then:} \quad b+f+m=1 \qquad (5)$$

These equations mathematically represent the hydraulic geometry of a channel's cross section.

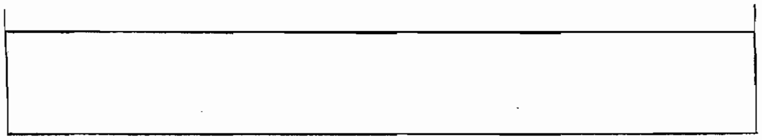
The competency and capacity of a cross section to transport sediment is greatly dependent on the flow velocity of the stream; and since the shape of the cross section, as described by the width to depth ratio, influences the distribution of velocity within the channel, sediment transport is closely linked to the cross section morphology of the stream.

Two types of channels are shown in Figure 4 (After Lane, 1937). Channel A has a low width to depth ratio; maximum flow velocity is high up in the channel (where friction is least) and shear is concentrated on the large area of bank exposure. Channel B has a high width to depth ratio, but it has the same total cross-sectional area. The zone of maximum velocity now must be closer to the bed, and shear is concentrated on the bed.

Particular cross-sectional shapes are associated with certain sediment transport requirements. Cross section A with its maximum velocity high above the bed is representative of a channel carrying large amounts of sediment in the silt-clay size range; most of the sediment is transported in suspension or solution. Cross section B, with a steep velocity gradient near the bed, is representative of channels carrying large amounts of sediment in coarse size ranges as bed load. Channel shapes are of course gradational; the width to depth ratio will become larger as more coarse sediment



Channel A



Channel B

Figure 4

Channel Cross Sections: Areas are equal.

must be moved through the channel; conversely, a smaller width to depth ratio will result for a channel transporting large amounts of silt and clay.

Schumm (1963) has classified channels on the basis of silt-clay content found in the stream banks and bed. He then associated the different channel morphologies with resepective sediment types. His basic three part classification is: 1) Suspended and dissolved load channels; bed load is less than 3 percent of the total sediment; width to depth ratio is less than 10. 2) Mixed load channels; bed load between 3 and 11 percent of the total load; width to depth ratio between 11 and 40. 3) Bed load channels; bed load comprising more than 11 percent of the total load; width to depth ratio greater than 40.

In summary, channel cross section morphology is greatly dependent on the character of sediment transported through it. Large quantities of bed load introduced into the channel require that the maximum flow velocity be distributed close to the bed, and a high width to depth ratio results. But large quantities of suspended or dissolved sediment require a maximum velocity more nearly in the middle of the channel; a smaller width to depth ratio results.

Although sediment character is the prime determinant of cross section shape, the overall size or cross-sectional area is primarily a function of the volume of water carried by the channel (Leopold, Wolman and Miller, 1964,p.201). Simply, the greater the discharge, the larger must be the channel cross section to transport it.

The definitive discharge in forming the channel, that which is the major force in size and shape determination, is thought to be the bankfull discharge, which has a return period between one and two years (Leopold, Wolman and Miller, 1964,p.241). Surface runoff is the main constituent of this discharge.

Longitudinal Profile

It has been shown that slope may be considered as a dependent, semi-dependent or independent variable in different contexts. In the sense that the slope of a stream is governed by the vertical drop and horizontal distance from the drainage divide to the mouth of the stream, it is physiographically determined and therefore hydraulically independent (Leopold and Maddock, 1953).

Slope, however, is also an important hydraulic variable, one that is capable of responding to changes in runoff-sediment relations and changes in other hydraulic variables as well (Leopold and Maddock, 1953,p.52). As a hydraulic variable, channel gradient is a function of: 1)discharge; 2)load; 3)size of debris; 4)flow resistance; 5)velocity; 6)width; 7)depth; 8)physiographic slope

(Leopold, Wolman and Miller, 1964, p.251).

Certain characteristics are known about the hydraulic function of slope. Generally the profile of a stream flattens downstream so that it is concave upward. The flattening is thought to be caused by a decrease in sediment particle size and increasing discharge downstream (Leopold, Wolman and Miller, 1964, p.249).

Recalling the discussion of the cross section morphology of channels, it was noted that energy requirements for sediment transport increase with increasing sediment size. One method of channel adjustment to sediment transport requirements is through variation of the width to depth ratio of the channel. A variation in the slope of the channel, however, may also take place in response to different sediment characteristics. The relationship between sediment and slope is similar to that for the width to depth ratio of a stream; steeper gradients are associated with channels transporting large amounts of bed load material. When debris size decreases rapidly downstream, the longitudinal profile will also flatten rapidly as the channel evolves a more hydraulically efficient form with respect to sediment and discharge. The flattening is caused by the tendency of width and depth to increase downstream faster than velocity; thus gradient must decrease to compensate for the slower increase in velocity (Leopold, Wolman and Miller, 1964, pp. 249-250).

Planimetric Form

An expression of the intricate relationships between stream gradient, sediment and discharge is given by the channel pattern or planimetric form of the stream. Definitions of channel patterns include three major types along a continuum: meandering, braided and straight.

A meandering stream is frequently defined as having a sinuosity of 1.5 or more, where sinuosity is the ratio of channel length to downvalley distance (Leopold, Wolman and Miller, 1964, p. 281). Since all streams show a natural tendency towards some degree of sinuosity, the term meandering implies the additional requirement that the stream display symmetry in the curves (Leopold, Wolman and Miller, 1964, p. 295).

A braided channel is one that is divided into several water courses that separate and rejoin periodically. The building of bars is an important process within the channel; it serves to define the form of the stream and therefore its classification. Generally this separating and rejoining appears to be similar to the energy processes that allow for meandering (Leopold, Wolman and Miller, 1964, p. 292).

A straight channel is frequently defined as having sinuosity of less than 1.5. This cutoff point between meandering and straight is rather arbitrary, especially since the planimetric velocity distribution within a straight channel is analogous to that of a meandering one (Leopold, Wolman and Miller, 1964, p.282).

The significance of these three types of patterns lies in the sediment transport and gradient relationship of the streams. Taking the two extremes for comparison, Schumm (1963; 1968, p.37) has shown that relatively sinuous rivers characteristically transport a high degree of silt-clay sediment as a suspended load. Recalling the relationships between width to depth ratio and sediment size and between gradient and sediment size, a channel carrying large amounts of silt-clay sediment will evolve a meandering channel with a low width to depth ratio and a relatively low gradient. Conversely, a channel transporting a high degree of bed load will be straighter and have a higher width to depth ratio along with greater slope.

III. Variables of the Study

Width and Drainage Area: Power Function Relations

The two major variables in this study are stream width and drainage area. Width is considered as it varies in the downstream direction; this comparison is generally valid only for the same frequency of flow for all cross sections (Leopold, Wolman and Miller, 1964, p.241). As stated previously, width has a power function relationship with discharge of the form:

$$w = aQ^b \qquad (1)$$

Discharge also has a power function relationship with drainage area which displays remarkable regularity across physiographic and climatic zones (for the bankfull frequency):

$$Q=cA^r \qquad (6)$$

(Leopold, Wolman and Miller,1964,p.251)

Since discharge is a common factor in both equations;

$$\ln w=\ln a+b\ln Q \qquad (1a)$$
$$\ln Q=\ln c+r\ln A \qquad (6a)$$

$$\ln w=\ln a+b\ln c+rd\ln a \qquad (7)$$

$$w=ac^bA^{br} \qquad (8)$$

since ac^b is a product of numerical constants, as is br, (8) may be rewritten $w=kA^j$ (9).

In examining (9) it will be noted that the exponent j is the product of the exponents for (1) and (6). If representative values are chosen for b and r,.5 and.6 respectively (Leopold and Maddock, 1953; Knox, 1970), then the resultant exponent j evaluates to .3.

The values .5 and .6 are consistently encountered values for the exponents of the equations relating width to discharge and discharge to drainage area. Their ubiquity results from the generaly tendency towards conservativeness in the drainage basin (Leopold and Maddock, 1953; Leopold, Wolman and Miller, 1964, p.251). Therefore, the value .3 is a generally expected value for the exponent of the relation between width and drainage area.

The usefulness of (9) is that it uses an easily measured spatial quantity, drainage area, in place of a point quantity, discharge, on an ungaged stream. It also allows explanation of varying quantities of discharge at the same frequency of flow for two different times.

Drainage area is a hydraulically independent variable that integrates the components of discharge (slope and vegetation being the primary determinants of runoff if climate is considered constant within the drainage area), and sediment yield. Morphologic (width) changes that indicate variation in discharge and sediment yield at the same frequency of flow from one moment in time to another may then be evaluated by the one constant in the drainage basin--area. Drainage area provides an unchanging quantity to be compared to width at a certain flow frequency both before and after any changes have taken place. Inferences may then be drawn about changes in sediment and discharge.

IV. Nature of the Study Area

The Platte River in Grant County, Wisconsin, above the junction of the Little Platte, is a seventh order basin of 189 square miles (the study area). After its junction with the Little Platte, it joins the Mississippi as an eighth order stream with a drainage area of 339 square miles.

Lithology and Physical Geography

The Platte basin is on the back slope of the Platteville-Galena escarpment, the strata of which dip Southwest at 5 to 6 feet per mile (Soil Survey, 1961, p.4). Since the valley bottoms are commonly 300 feet below the ridge tops, many different outcrop patterns are evident from headwatets to mouth. The geologic column for this area may be viewed in Table 1. Other geologic cross sections (Figures 5,6,7) illustrate the different outcrop and ridge cap associations from mouth to headwaters, besides illustrating the relief components of the different sections. (Figure 5 is in the headwaters, Figure 6 is midway between mouth and divide, and Figure 7 is near the mouth.)

For the seventh order portion of the basin these strata are all of Ordivician age. Their weathering pattern is varied: the Galena dolomite has two units; one that weathers to a multitude of chert fragments is especially notable. Generally, the Platteville-Galena formation if found capping ridgetops. The St. Peter sandstone is generally a coarse, extremely well sorted, massive, friable sandstone; it weathers to a coarse sand. Beneath the St. Peter is an unconformity which causes the contact between it and the Prairie du Chien dolomite to be very irregular. The Prairie du Chien is also irregular in composition and contains much chert.

Geologic Column for Platte River Basin

	Thickness (feet)
Quaternary System	
Pleistocene Loess	4-6
Ordovician System	
Galena Dolomite	
Non-cherty	100-130
Cherty	100-130
Decorah Shale	30-50
Platteville Limestone	45-65
St. Peter Sandstone	35-80
Prairie du Chien Dolomite	205-260

Table 1

(Geologic Quadrangle--Ellenboro)

Both the Prairie du Chien and Platteville-Galena produce large quantities of coarse material, ranging from pebbles to boulders; this coarse material has a great influence on the streams of the area.

Structural features within these strata are responsible for many valley orientations. One may observe on a geologic quadrangle that the alignment of the tributaries correlates closely with the prominent joint patterns, generally Northwest or Northeast (Ellenboro Quadrangle).

Climate

Lancaster, a city just west of the basin (See Plate II), has a climate representative of most of the area (local climatic deviations exist, caused by the steep topography of the basin). Table 2 shows the 1930-1960 U.S. Weather Bureau averages for temerature and precipitation. Note that precipitation values reach a peak in June. The likelihood of receiving one inch of rainfall during a seven day period is twice in five years in June, while it is only once in four years in August. In the winter most of the 3.65 inches of precipitation falls as snow. The yearly precipitation mean is 33.25 inches.

Temperature is cold in winter and warm to hot in summer; the yearly mean is 47.5 degrees Farenheit. October 10 and May 7 mark the average first and last

Table 2

U.S. Weather Bureau Statistics for Lancaster Wisconsin

	Mean Temperature °F	Mean Precipitation inches
Jan.	19.2	1.24
Feb.	2217	1.06
Mar.	32.7	2.15
April	47.4	2.86
May	59.0	3.85
June	68.6	5.07
July	73.5	3.72
Aug.	71.8	3.77
Sept.	63.3	3.60
Oct.	52.5	2.45
Nov.	35.9	2.11
Dec.	24.1	1.35
Ave.	47.5	33.23

32-degree freezes; the growing season is 156 days (U.S. Weather Bureau Statistics).

This area lies on a statistical boundary between mild, dry Pacific air masses entering from the plains to the west, and cooler, wetter polar or Pacific air of a more northerly direction. Both types of air masses show dominance for 50 percent of the year (Bryson, 1966). This type of dominance is thought to be requisite for prairie or oak savanna vegetation (Curtis, 1959, p.300), and is extremely important for diagnosiing climatic changes with respect to geomorphic implications (Knox, 1972).

Vegetation

Since the area to the north of the Platte basin is dominated for more than 50 percent of the year by relatively cooler and wetter air than the area south of the Platte, the study area lies in a mixed-forest/prairie ecotone,transitional from hardwood forest to prairie vegetation.

Table 3 presents the percentages of prairie and forest originally present at the time of settlement for the six townships making up the bulk of the basin's drainage area.

The prairie was maintained by fire at the expense of the forest. Fires caused by lightning or set by Indians frequently burned this part of Wisconsin, the result of

Table 3

Township	Percent Prairie	Percent Forest
Paris	6	94
Harrison	0	100
Ellenboro	0	100
Lima	10	90
Platteville	37	63
Smelser	50	50
Clifton	50	50
Liberty	34	66
Average	22	78

Vegetation of the Platte Basin
in 1839.

(D.D. Owens, 1844)

which was the destruction of trees, except for some oak, and occupation by prairie vegetation (See Curtis, 1959, pp.295-301). After European settlement, the fires were controlled and consequently oak and maple occuppied former prairie areas; since they were no longer inhibited by fire. Evidence of this re-occupation by trees can be found in the dark colored prairie soils under some forests, and the understory of prairie vegetation in others(Soil Survey, 1961, p.5).

Land Use

Today, agriculture is by far the most important activity carried on in the Platte basin. Eighty-nine percent of the general area is in farms, with corn, oats and other small grains for livestock feed being the dominant crops (Soil Survey, 1961, pp.90-91).

North-South and East-West transects along Township and Range lines were measured for the percentage of area depicted as forested on topographic maps. This method indicates that 23 percent of the basin is currently forested.

Settlement

It was during the 1820's that the first permanent settlers came in significant numbers to Grant County as lead miners. In 1827 Joseph Dixon demonstrated the feasibility of growing corn on the rich soil. Although farming was profitable, it was not until danger of the Indians had been eliminated (along with the Indians) by the Black Hawk Wars that the population began to grow and emphasize agriculture over mining (Holford, 1900, pp. 17,27).

The settlers found rich soil on the upland prairies and excellent timber (mostly oak, maple, basswood and some pine) near the rivers, with some oak-openings (grub oak) on the ridges. In 1852 a number of causes led to widespread expansion of farming, and the potential of the fertile prairie soils for agriculture was realized. (Holford, 1900, pp. 56-57)

With the opening of the prairies and the emergence of agriculture as the dominant mode of life, erosion of valuable land became a problem. Today, many of the soils in Grant County are classed as moderately to severely eroded, as one might expect in an intensely utilized region (Soil Survey, 1961).

After 1875 the farm and mining boom subsided a bit, and the population declined from a peak of 39,000. Today, after some minor fluctuations in the intervening years, the population is about 46,000 people, with a relatively stable rate of increase, especially considering the boom years of 1830-1870, when the population increased from less than 5,000 to more than 35,000(U.S. Census, 1970; Holford, 1900; and Lapham, 1846).

The Platte and Its Flood Plain

Lithologic Constraints

The Platte River is subject to some lithologic (and hydraulic) constraints that require explanation before description of any changes of the channel can be adequately described.

The Ellenboro monocline transects the river almost midway between the mouth and headwaters (Platte II). In the two miles of channel above the monocline, the gradient is 8.5 feet per mile, while in the two miles of channel directly below the monocline, the gradient is 10 feet per mile (Plate I). As pointed out earlier, an increase in slope downstream is contrary to expectations. Because of a tendency for increases in discharge and decreases in particle size downstream, slope should decrease. Eventually it does decrease to 5 feet per mile.

Thus, the monocline exerts a strong influence on the stream's gradient by causing an anomalous increase in slope downstream for two miles (Plate I); other hydraulic variables would be expected to show adjustments to this anomaly.

Figure 11 introduces a logarithmic double-mass curve of stream width versus stream length. It is a graph of the cumulation of one quantity against the cumulation of another; the data should plot as a straight line if the two variables are proportional; a break in slope indicates a shift in the constant of proportionality between the two quantities (the slope of the line) (Searcy and Hardison, 1960). Note that the break at point 17 (Plates I and II) indicates that the two mile stretch below it is too narrow, according to the trend established by the other data points. This is the point of transection by the Ellenboro monocline.

At, and below, the monocline, channel slope increases faster than is hydraulically and mathematically expected, so velocity must increase also. Because the increase in velocity is slope controlled and not 'natural'with respect to discharge values, width must decrease to satisfy the continuity equation

$$w \times d \times v = Q \qquad (4).$$

Additional breaks in the double-mass curve (Figure 11) occur at points 1-2 and 6-7 (Plates I and II). The break at 1-2 in the headwater portion of the Platte is probably a function of slope. As the channel distance from the divide increases and slope flattens, the channel's rate of increase in width will fall off. Less coarse debris is being added from slope wash as the flood plain enlarges and tributaries become more important transporters of sediment.

At points 6-7 the Platte enters a narrow gorge of the Prairie du Chien dolomite, caused by the Mineral Point anticline (Plate II). The anticlinal structure causes the Prairie du Chien to crop out long before it would if the slight dip of the cuesta were the sole structural feature of the valley. The abrupt change from St. Peter sandstone to resistant dolomite causes the valley to narrow. A great deal of coarse debris is being contributed by the narrow dolomite gorge, the result of which is the evolution of a channel wider than expected. The relative widening is clearly depicted in Figure 11.

Floodplain Alluviation

The first settlers found the basin to have about 22 percent prairie and 78 percent forest (D.D. Owens, 1844). Today, however, the floodplains are almost clear of trees; the ridges and any tillable slopes are in farms, and only 23 percent of the land is still in timber (See previous sampling method). The river itself is undergoing a metamorphosis.

Upon the floodplain one finds an alluvial layer of recent age that is equivalent to a stratigraphic unit that has been defined as "post-settlement" alluvium (Daniels and Cady, 1966)*. Auguring reveals that it has an almost constant thickness of 3-4 feet. The alluvium overlies a paleosol, the top of which dates as recent (University of Wisconsin Radiocarbon Laboratory Sample No. WIS-454).

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*"Post-settlement" is defined as meaning that alluvium which has accumulated since Euripean settlement of the basin.

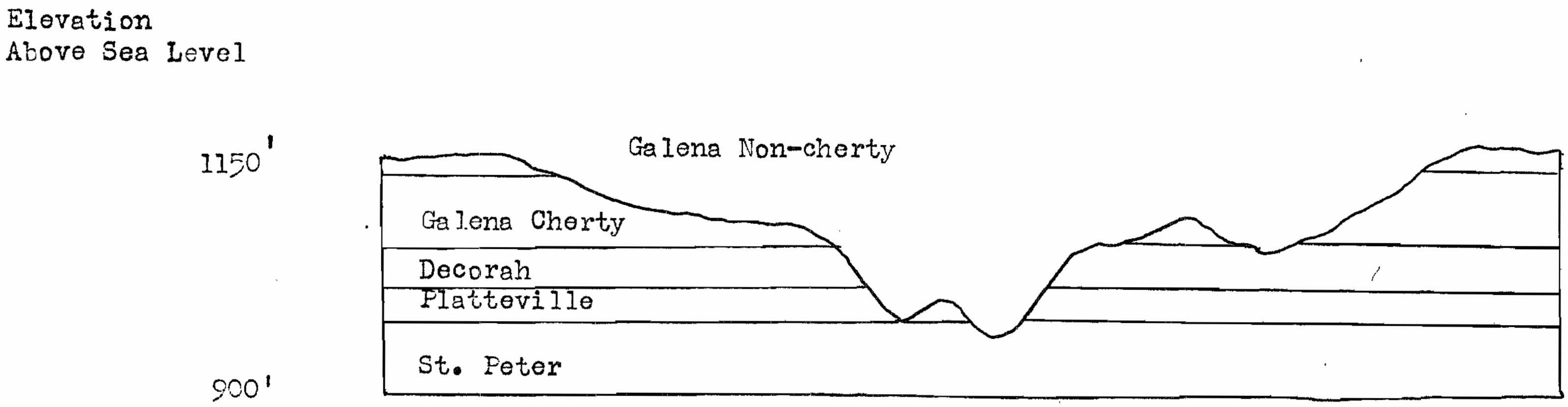
From the well developed paleosol underlying the alluvium it is inferred that the floodplain was relatively stable prior to European occupation. The large amount of fresh alluvium overlying the paleosol indicates relative instability during the last 140 years.

From parallels in other studies in which clearance of vegetation and cultivation have been shown to increase the magnitude and frequency of peak discharges and increase sediment yield (Hornbeck et al, 1970; Rothacher, 1970; Patric and Reinhart, 1971), it is assumed that clearance of the hillslopes and ridgetops for farming has caused an increase in sediment and surface runoff production. Since surface runoff and sediment characteristics have been shown to be critical factors in defining the hydraulic variables of streamflow, one would expect that the channel morphology of the Platte has also changed.

Hydrologic conditions should now be such that the storm hydrograph for the Platte will be higher peaked and flashier than in the early 19th century. Increased magnitude and frequency of flood flows should be the result of clearing of vegetation; instantaneous storm runoff is greatly enhanced (Patric and Reinhart, 1971; Wolman, 1967).

An associated increase in sediment delivered to the channel is indicated by the rapid overbank deposition of the post-settlement alluvium. Rapid overbank deposition is diagnostic of a channel receiving more water and sediment than it can transport (Schumm, 1968, p.40).

The preliminary results of man's activities may be listed in a brief summary: 1) Clearance of vegetation and cultivation of the soil has caused large increases in surface runoff and sediment yield. 2) Peak flows have therefore increased in magnitude and frequency of occurrence. 3) Rapid alluviation of valley bottoms has resulted. 4) The morphology of the river appears to have changed in response to these changes.



Horizontal Scale
1:24,000

Figure 5

Cross section in
headwaters.

(Montfort and Linden Quadrangle)

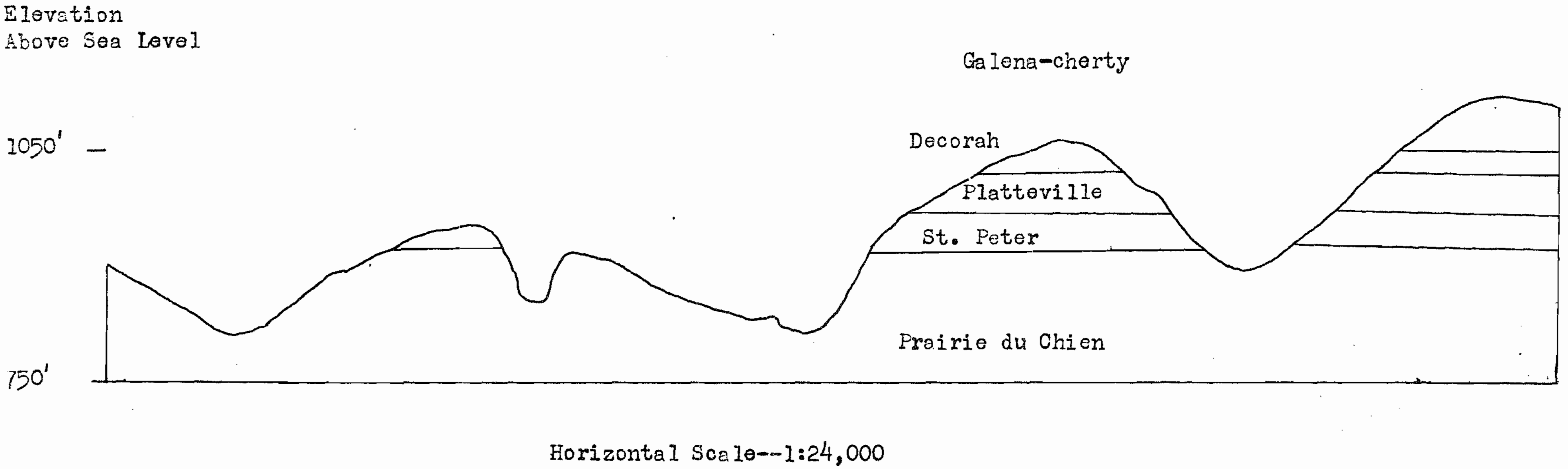
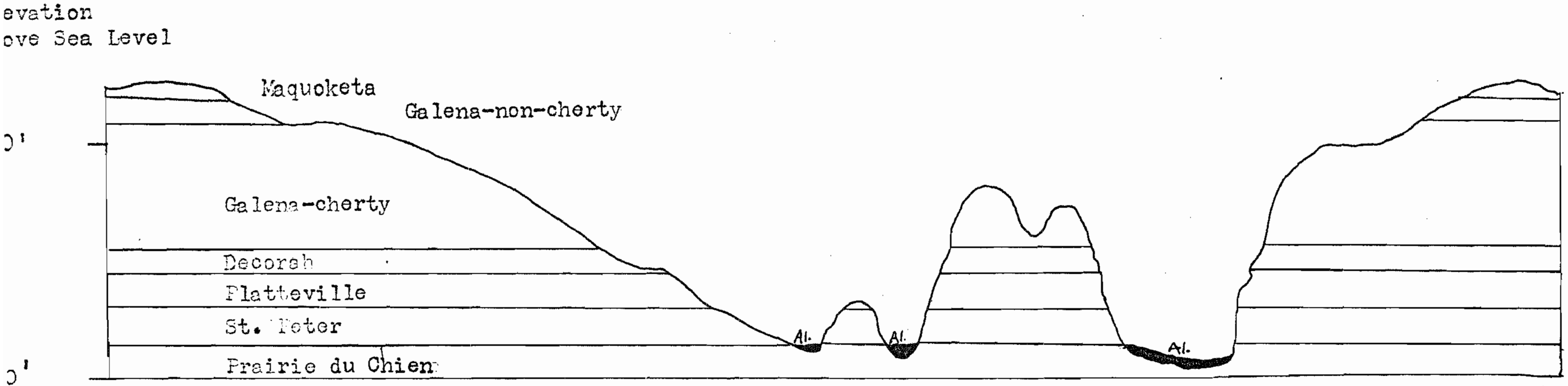


Figure 6

Cross section mid-way from mouth to headwaters.

(Ellenboro Quadrangle)



Horizontal Scale--1:24,000

Figure 7

Cross section near mouth
of Platte River.

(Potosi Quadrangle)

V. Data Collection and Analysis

Stream Widths and Power Function

Surveys and Flow Frequency

The U.S. Land Office Survey of Grant County provides the historical data for this study. European settlement at this time was minimal with a few scattered mining towns and farms constituting the population of the area.

The surveyor frequently crossed streams while establishing section lines and recorded the stream widths. It is apparent that he measured the width perpendicular to the banks, since he noted the direction of crossing as a deviation from the North-South or East-West transect of the section line. That is, he did not measure the width of the stream in the direction of intersection by the the section line.

Twenty-seven sites originally recorded by the surveyor were remeasured in December 1971.

It is assumed that the surveyor originally measured low flow water widths of January 1832. This assumption is made for two reasons: 1) A person not trained in hydrology would be likely to measure water width rather than channel width (assuming they do not coincide) if told to measure a river; 2) The differences between the 1971 and 1832 widths are almost implausible if the 1832 measurements are channel widths. Table 4 shows the various cross section widths for 1832, 1971 water widths and 1971 bankfull channel width. Note the tremendous amount of change which must be accounted for if the 1832 widths are channel widths. Low flow widths (January water widths) have also changed, but not as drastically;

Comparison of Data

Table 4 and Figures 8,9 and 10 indicate mathematically the changes in the Platte's cross section morphology. Above site 6 (Plate II) the river averaged 291 percent wider in 1971 than in 1832 (low flow conditions). Below site 6 it averaged 53 percent narrower for the same frequency of flow.

Consideration of bankfull flows shows a similar direction of river change. The widening upstream approaches the catastrophic, wihile the narrowing downstream is less pronounced in trend (See Table 4).

Figures 8,9, and 10 utilize 36 data points to define the regression line $w=kA^j$. Twenty-seven of these cross sections were measured along the Platte River (See Plate II). The remaining nine cross sections were surveyed in five streams tributary to the Platte's upper reaches. Earlier in the study more data points were included from downstream tributaries. It was found that these channels tended to be wider than headwater tributaries (for any given drainage area), and thus caused the power function between width and drainage area to have a larger exponent (steeper slope).

The downstream tributaries of lower order entering the higher order channel have a higher energy gradient than headwater streams joining the lower order upstream reaches of the Platte. The tributary channels tend to be larger in the downstream reaches than headwater tributaries of the same order because of their higher energy grade (Knox, 1970).

Because of their anomalous channel characteristics, high energy, downstream tributaries were deemed unacceptable in defining the hydraulic geometry of the Platte. Headwater tributaries with slope characteristics comparable to the Platte were utilized to increase the sample size of historic and contemporary measurements.

Indications are that the exponent j, in

$$w=kA^j \qquad (9)$$

has decreased from .65 to .34 (Figures 8 and 9) between 1832 and 1971, thus flattening the slope of the curve. This agrees with the widening of the river in the upstream reaches and the narrowing of the river downstream (i.e. the rate of change in width downstream should be reduced).

Bankfull widths (Figure 10) vary with only the .15 power of drainage area, a value that is again quite different from the expected value of .3 computed above. In other words, the ubiquitous, physiographically stable (with minor variations) values relating width, drainage area and discharge do not hold for the Platte.

Comparison of the exponents for Figures 8 and 10 indicate that if the surveyor were measuring channel width in 1832, the power function exponent would be

Table 4

Stream Widths

Site	1832 Width (feet)	1971 Water Width (feet)	% Change	1971 Bankfull Channel Width (feet)	% Change
1	10	36	260	36	260
2	7	40	471	88	1157
3	10	10	0	40	300
4	15	17	13	52	246
5	17	22	29	36	111
6	20	40	100	101	405
7	40	36	-10	108	170
8	43	35	-18	49	14
9	83	59	-29	79	-5
10	33	25	-24	68	106
11	66	67	1	78	18
12	66	63	-4	89	34
13	40	67	67	100	150
14	50	50	0	102	124
15	50	35	-30	67	34
16	66	59	-10	87	31
17	100	58	-41	69	-30
18	80	59	-25	88	11
19	100	58	-41	140	41
20	83	67	-19	85	2
21	50	40	-20	76	52
22	83	52	-37	57	-31
23a	66	56	-15	68	3
23b	66	45	-31	56	-15
24	53	44	-17	58	9
25	100	39	-60	56	-43
26	113	40	-64	66	-41
27	101				

1832 WIDTHS VS. DRAINAGE AREA

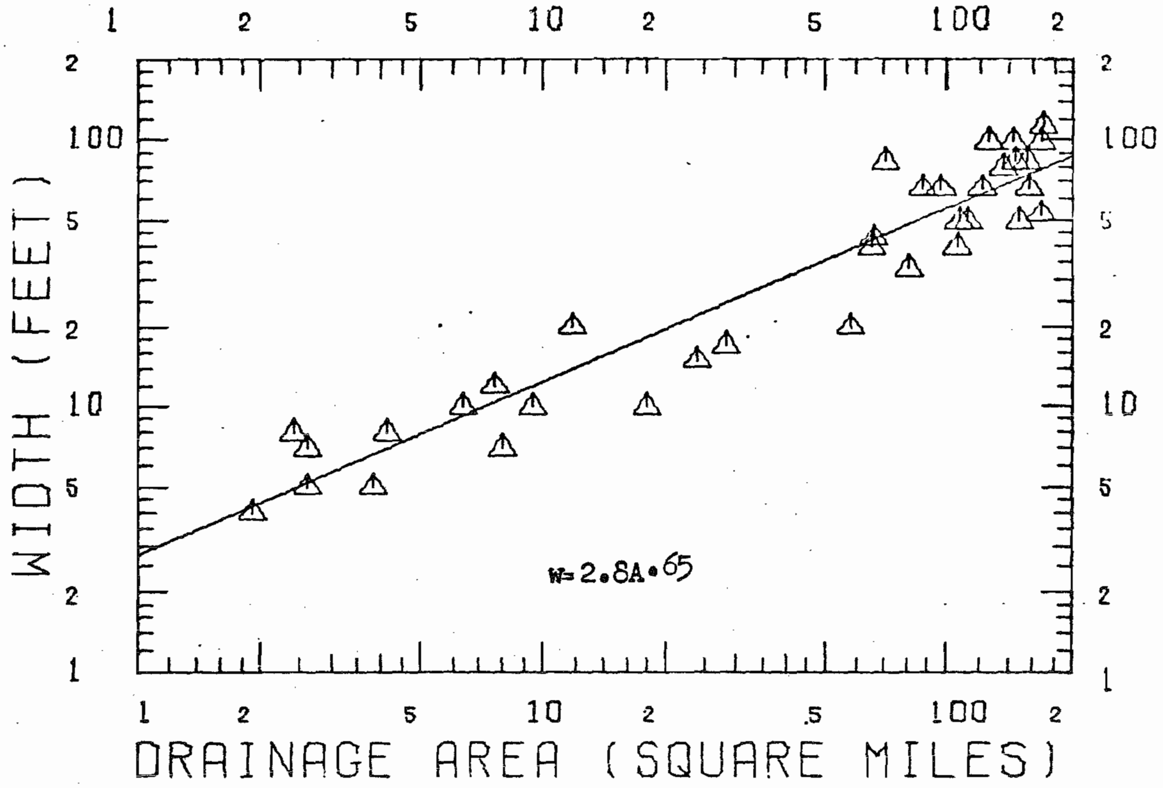


FIGURE 9

1971 LOW FLOW WIDTHS VS. DRAINAGE AREA

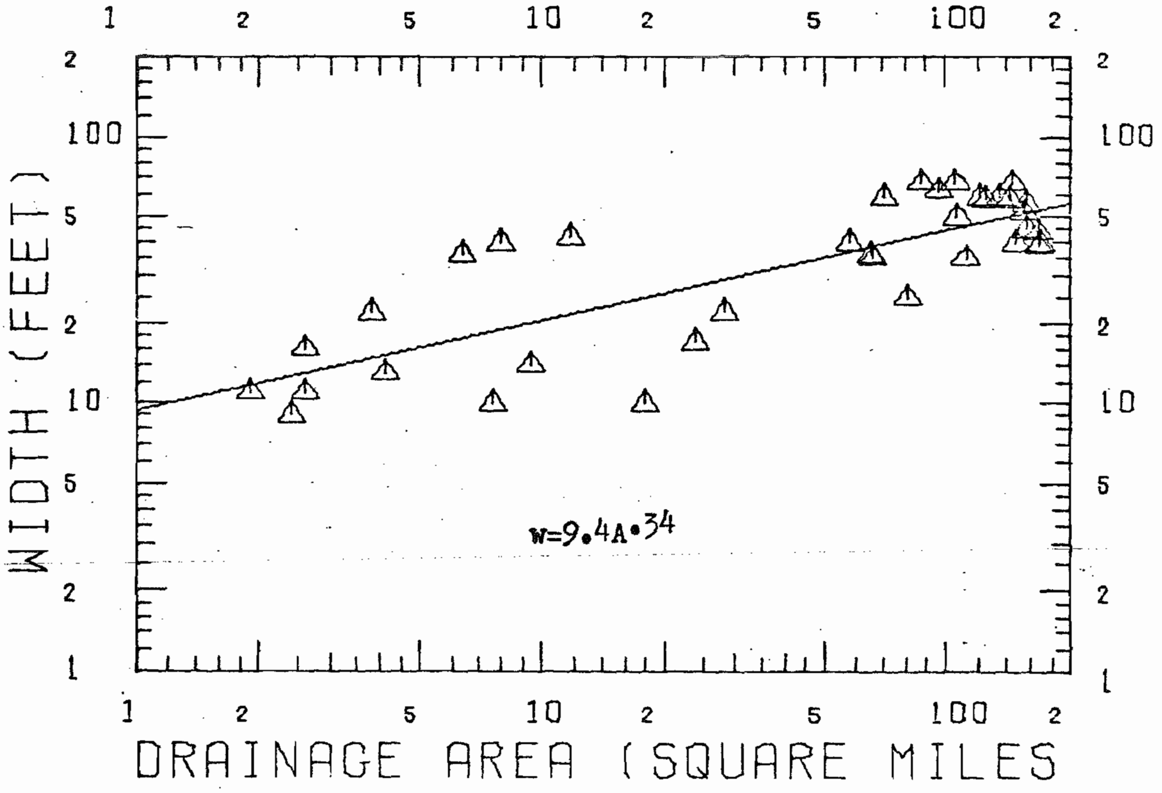


FIGURE 10
1971 CHANNEL WIDTHS VS. DRAINAGE AREA

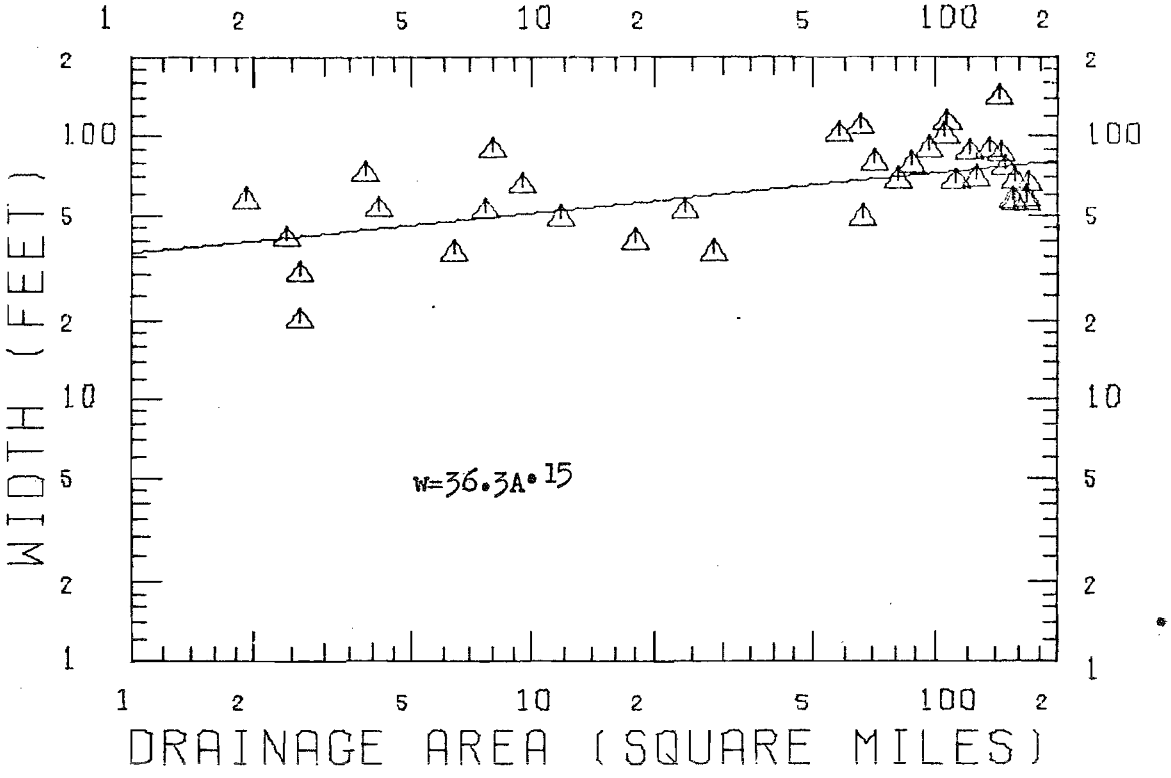
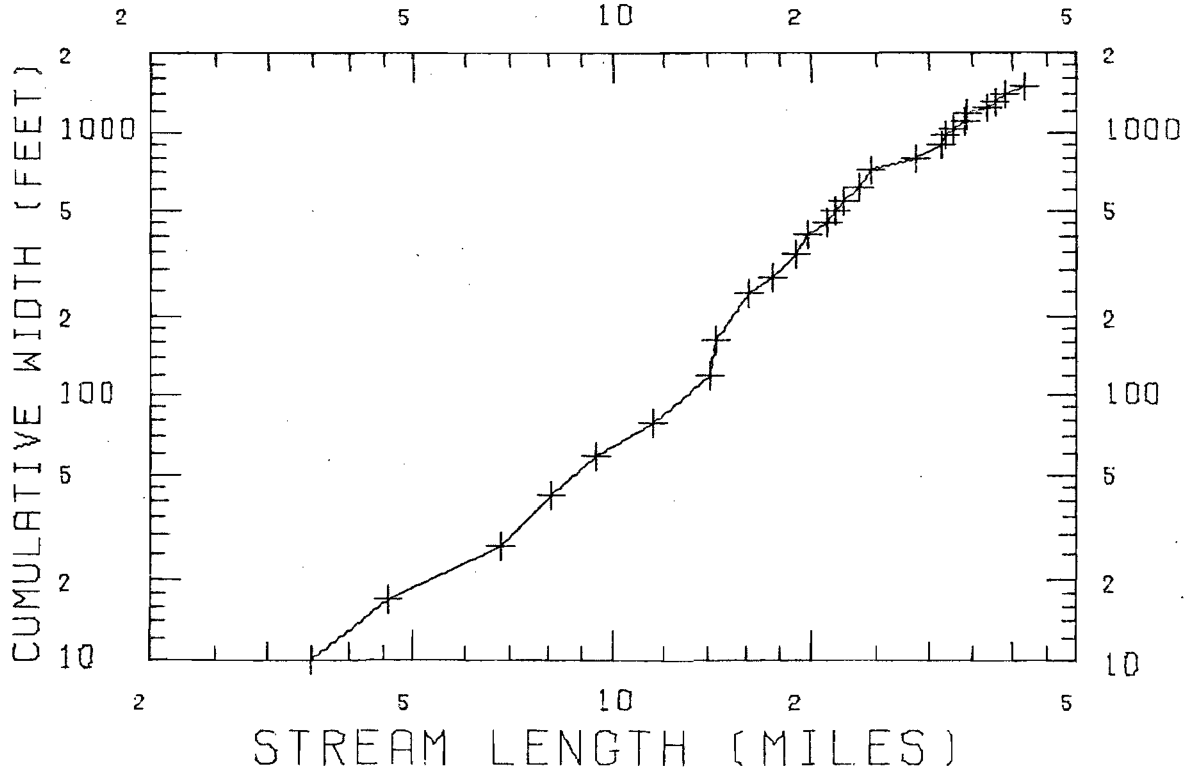


FIGURE 11
1832 DOUBLE MASS



reduced from .65 to .15—an unlikely proposition.

Sinuosity was used as a qualitative check on the changes so far described. By examining field maps drawn by the original surveyor and comparing them with current U.S.G.S. topographic sheets, it was found that channel sinuosity has decreased since 1832. Although the old maps are of questionable validity with respect to overall channel form, comparison was deemed possible where the channel crossed section lines numerous times, since locational points along section lines were accurately controlled by the surveyor. In this manner, a decrease in sinuosity was qualitatively apparent.

Analysis of Data

The implications for both low and bankfull flows and the indications of sinuosity change are essentially the same. In the lower order reaches, the Platte has widened its cross section, while in the higher order reaches it has narrowed its cross section. Sinuosity has decreased. The impetus for these changes has come from large influxes of sediment and surface runoff at channel forming discharge.

In the lower order, u stream reaches of the channel (above site 6, Plate II), increases in surface runoff during flood peaks has allowed for increasing cross-sectional area. The large amount of coarse clastics contributed by the dolomites has also encouraged widening and presumably deepening of the channel to facilitate removal of the increased discharge and coarse sediment.

Increases in the magnitude of channel forming discharge have probably also encourage development of a larger cross section in the higher order, downstream reaches of the Platte (below point 6, Plate II); sediment transport requirements have also changed.

Overall, larger quantities of all sizes of sediment are being introduced into the channel; downstream, however, differential transport of the sediment has eliminated much of the coarse bed load and allowed the suspended load to become the dominant factor in channel morphology. Development of a wider floodplain in the downstream direction has also contributed to the dimunintion of coarse sediment, as colluvial deposits are dropped on the floodplain, rather than being washed directly into the channel. The increase in discharge and relative increase in suspended sediment has allowed the channel to evolve a hydraulically more effecient form by narrowing and deepening its course.

The cross section morphology and size of the Platte has been altered by imposition of different types of sediment transport requiremnts at different locations along the channel, while discharge has increased throughout.

Overall sediment transport requirements, however, have been exceeded throughout the basin. The post-settlement alluvium is evidence of the overloaded condition; it is the prime mechanism by which the channel has evolved a new morphology; its deposition indicates an overloaded channel (Schumm, 1968, p.40).

Sinuosity decreases may be explained as a function of either of two variables. Wave length of meanders has increased either as a result of the increased discharge at channel forming frequency (Dury, 1965) or as a result of the increased amount of sediment being moved through the channel.

Summary

Alteration of runoff and sediment yield characteristics of the Platte basin have led to changes in the hydraulic variables that define the downstream hydraulic geometry of the river. Channel widths have increased in headwater areas and decreased in downstream reaches since 1832. Power function exponent values have consequently been reduced. Qualitative evaluation of sinuosity trends also indicates increases in discharge and total sediment load at channel forming frequency.

VI. Conclusion

General Summary

Langbein and Schumm (1958) have shown vegetation to be a critical variable in controlling runoff and sediment yield. This study has attempted to indicate what sort of changes may take place in the hydraulic variables governing streamflow because of a land use change altering natural vegetation.

A resurvey of the Platte River, first measured in 1832, indicated that headwater tributary reaches have enlarged and widened their cross sections, while downstream the river has narrowed and deepened its cross section as it enlarged. Sinuosity has decreased, presumably thrugh enlargement of meander wavelengths. In the 140 years since the survey, the stream has deposited between three and four feet of fresh alluvium on the floodplain.

The critical balance of runoff and sediment that defines the hydraulic variables has been altered. Reduction of forest cover from 78 percent of the basin to 23 percent has enhanced instantaneous storm runoff and sediment yield. Cultivation has also led to more effective erosion and increses in surface runoff. It is difficult to determine how much of the geomorphic work was done immediately upon clearance of vegetation and how much is still in progress.

Increased magnitude and frequency of overbank flows and of sediment production has altered the hydraulic characteristics or the Platte River. Man, through his land use practices has been the prime cause of these hydrologic and hydraulic alterations; his geomorphic influence has been immense, if not totally quantifiable.

The Equilibrium Condition--Climate

Langbein and Schumm (1958) demonstrated the relationship between runoff, sediment yield and vegetation. Within any region, the sediment yield and discharge of a stream will be in equilibrium with the physical elements of the environment. Vegetation is the key variable in controlling runoff and sediment yield.

Furthermore, Langbein and Schumm indicated the consequences that a climatic shift could have on the runoff and sediment regime. By discouraging or encouraging the growth of vegetation, great impact can be exerted on the hydrologic conditions of a drainage basin.

Since the river channel is in a state of quasi-equilibrium with the discharge and sediment it carries (that is--takes its form from them), one would expect that climatic shifts would have implications for river channels also.

Schumm and Lichty (1963) illustrated the significant role that climatic change can play in altering a channel. The Cimarron River in Kansas was converted from a sinuous, relatively narrow and deep river to a straight, wide and shallow river when several years of drought were followed by major flooding.

Schumm (1968) also enumerated the historical aspect of climatic shift and the consequent impact of runoff/sediment change on stream morphology.

In this study, however, climate was of little importance. Precipitation has fluctuated over long term averages as much as three to five percent, and yearly averages have fluctuated as much as ninety percent in the study area. In addition, the pattern of precipitation throughout the year has changed since the mid 19th century. Little geomorphic significance is inferred from or attributed to these changes for two reasons: 1) The climate of the study area is already humid enough to put it in the area of decreasing sediment with increasing precipitation. Also, the precipitation shifts were too ephemeral to cause major vegetative changes. 2) Man himself altered the drainage basin's characteristics infinitely more than climatic change could have—he is the prime geomorphic agent. The results would have been the same without a climatic shift.

Recent studies (See Wolman, 1967) have indicated the tremendous effects clearance of vegetation may have on the sediment and runoff relationship, and consequently river morphology, in one single year. The main forcing function in hydraulic alterations is man.

PLATE I
LONGITUDINAL PROFILE

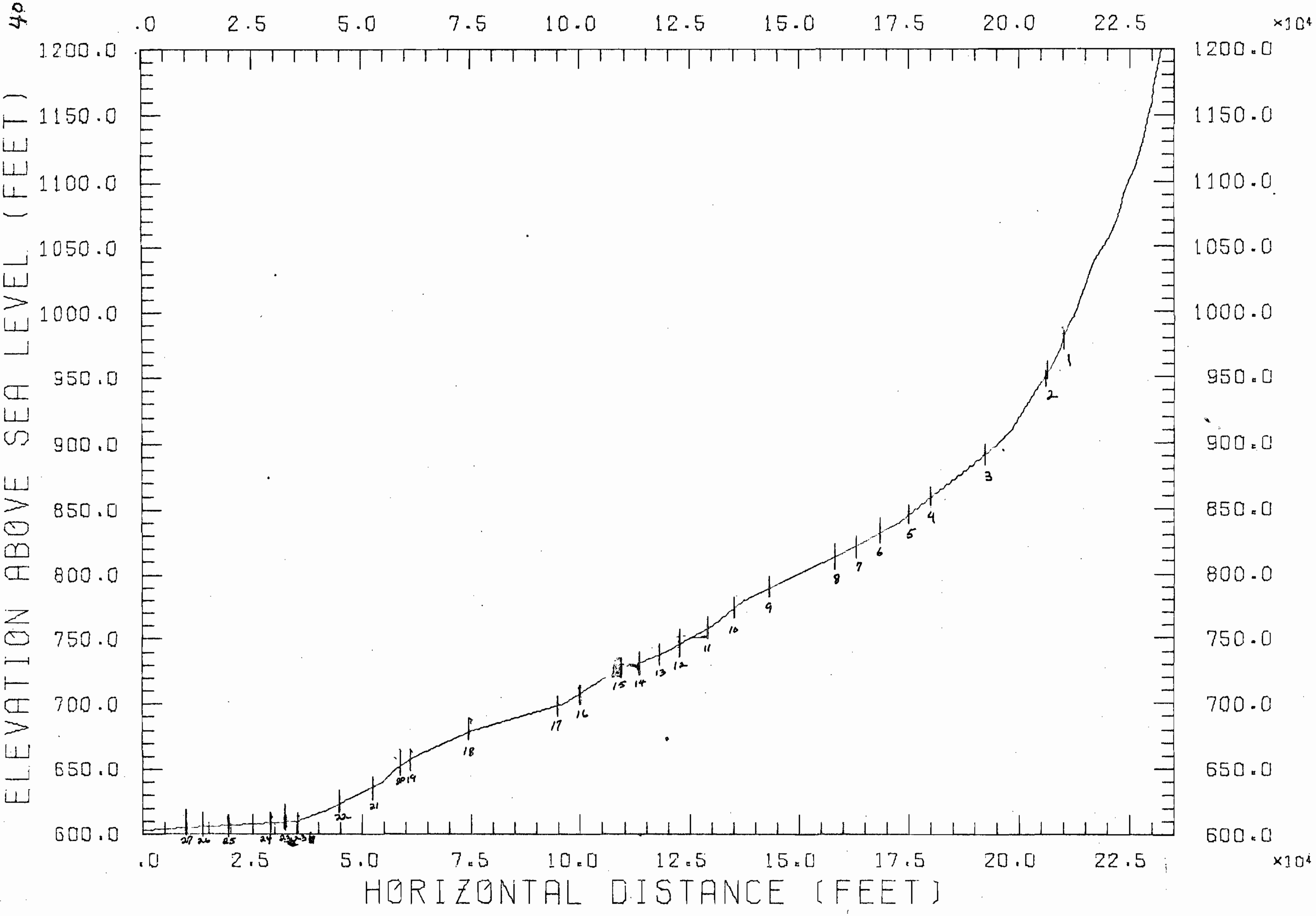
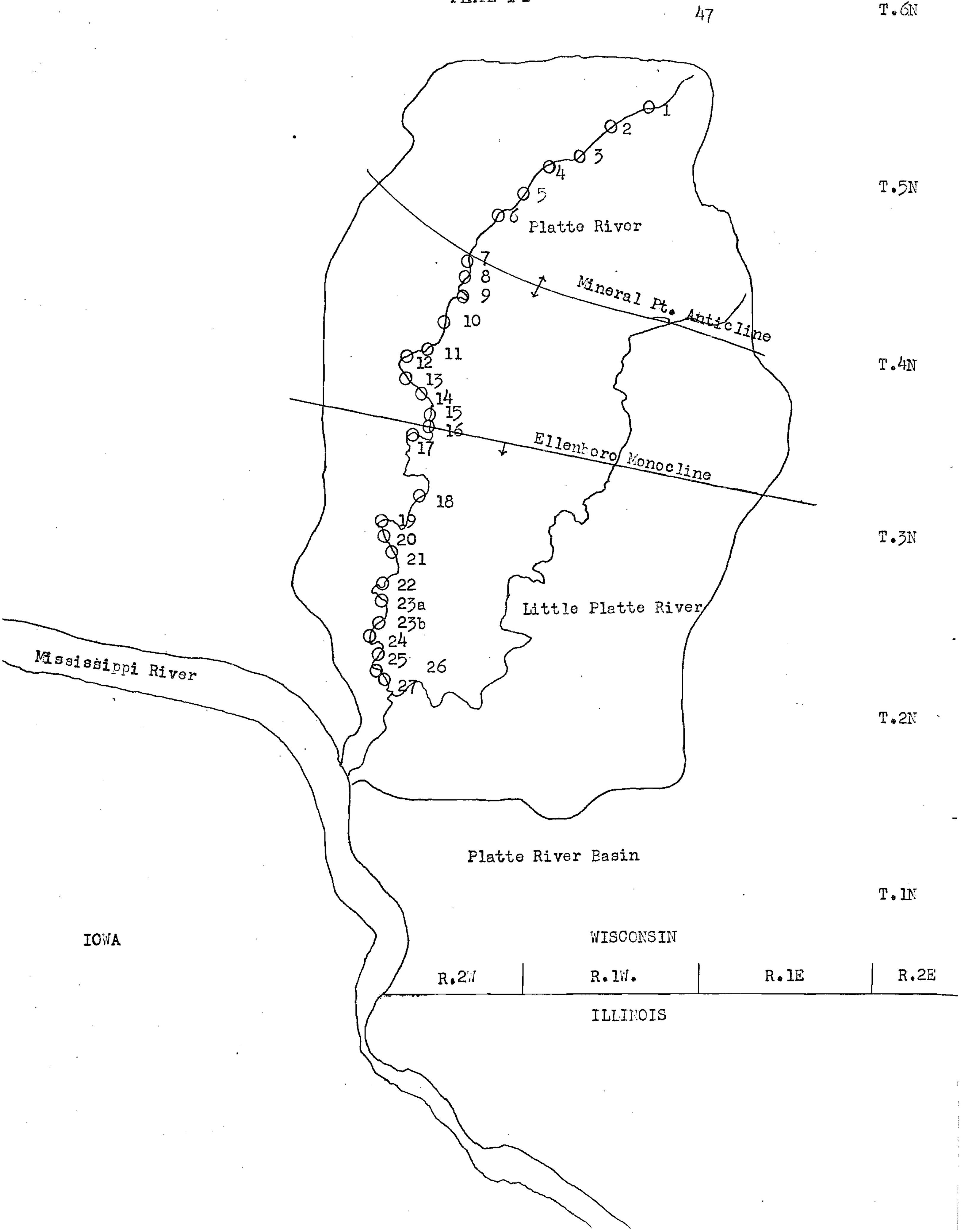


PLATE II


T.6N
T.5N
T.4N
T.3N
T.2N
T.1N
1
2
3
4
5
6
Platte River
7
8
9
Mineral Pt. Anticline
10
11
12
13
14
15
16
17
Ellenboro Monocline
18
19
20
21
22
23a
23b
24
25
26
27
Little Platte River
Mississippi River
Platte River Basin
IOWA
WISCONSIN
R.2W
R.1W.
R.1E
R.2E
ILLINOIS

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