RESPONSE OF TURTLE CREEK

TO SETTLEMENT

1836-1973

Katherine Hirschboeck

B.A. Thesis

May, 1973

Man's impact on the environment has been observed and analyzed to a great extent in recent years. The response of a landscape, vegetal community, or stream to inputs of settlement, cultivation, urbanization, or industrialization is varied and depends for the most part on first, the type of land use input, and second, the type of region being acted upon -- defined essentially by climatic and physiographic parameters. River systems and streams are particularly sensitive to land use changes and in addition, tend to be unique in their response, under a certain combination of climatic and physiographic conditions. For example, under similar precipitation and temperature regimes, a difference in physiography between two drainage basins, such as one flowing on bedrock topography and the other on young glacial drift, will instigate unique channel geometries, flow characteristics, and stream patterns in each basin. Thus it is hypothesized that a change in land use imposed on two basins with varying physiographies will result in two different river responses. This study will investigate the effects of land use changes stemming from man's initial settlement in an uncultivated glacial drift drainage basin and contrast them with the results of a similar impact on a bedrock environment basin.

Origin of the Problem

Existing theory suggests that the impact of man-induced land use modifications on streams can take many forms, but often yields the same results. Deforestation and clear-cut logging will tend to increase both runoff and sediment yield in a basin. Cultivation of a virgin prairie, especially without appropriate conservation practices, will likewise tend to increase both runoff and sediment yield. In addition, drainage activities such as tiling, ditching, and channelization can greatly alter discharge magnitudes and deliver fresh sediment loads to downstream reaches. Discharge and sediment load will be shown to be of prime importance in determining the response of stream dependent variables in a basin and thus are instrumental in originating the problems involved in land use impacts and stream response.

By pooling together several existing theories on channel geometry adjustments, response in the stream channel itself may be viewed in terms of internal and external, and natural and unnatural modifications. The hydraulic geometry of the channel can be internally controlled by natural and artificial adjustments in its width, depth, and velocity. Natural internal modifications occur, for example, in a channel in the downstream direction as it adjusts to increased discharge by increasing the magnitude of its width, depth, and velocity components. Artificial internal modifications are in a different sense brought on by an external input such as the construction of a dam, or the shaping of a drainage ditch,

but they are internal in that they directly alter width,
depth, and velocity in the channel. External modifications,
on the other hand, are inputs which operate indirectly on
the channel geometry by affecting some other variable or
variables which will in turn instigate a response in the
hydraulic geometry. An example of a natural external input
would be fluctuations in precipitation, either in terms of
broad scale climatic change or seasonal and daily variations.
This input influences the discharge and sediment load
variables, which in turn instigate the internal response
in the hydraulic geometry variables. External artificial
inputs refer specifically to man-induced land use changes.
As expressed earlier, these modifications also have a
significant effect on discharge and sediment load and will
subsequently operate on channel geometries.

Hence a model can be envisioned wherein a stream will
respond by natural internal adjustments downstream in its
hydraulic geometry, or by natural external inputs of increased
discharge and sediment load due to climatic variation. In
addition, man may impose unnatural internal adjustments on
a channel geometry such as damming or channelizing, or may
promote artificial external inputs which affect the channel
indirectly through discharge and sediment load.

To separate the effect of the natural from the unnatural
inputs to a drainage basin it is necessary to observe a
stream both before and after settlement. Here a real
inadequecy exists in the ability to assess a stream's

pre-settlement character. A study by Corcoran (1972) and Knox and Corcoran (1972) used records of the original land survey of the southwestern Wisconsin area to reconstruct the pre-settlement conditions of the Platte River. The Platte basin is located in the so-called Driftless Area of Wisconsin and as a result is dominantly controlled by bedrock topography. A basin located on a different type of physiography would perhaps begin with a dissimilar pre-settlement character, as determined by natural internal and external modifications, and in addition might display a varying response to "post-settlement" unnatural internal and external modifications. It is not to be construed here that only unnatural inputs took place after settlement. Instead a combination of natural and artificial adjustments most likely occurred. However, this division is the best attempt that can be made to isolate man's impact.

Corcoran's study analyzed the changes in a bedrock-controlled drainage basin due to settlement, deforestation, and cultivation by man. The origin of the present study was the need for a similar analysis of a basin with a different type of physiography since it is known that streams in unlike physiographic regions will respond to inputs in different ways. The basin chosen for this study was Turtle Creek, a comparably sized watershed in the glaciated, south-eastern portion of Wisconsin. The Platte and the Turtle are located near enough to each other so the climatic dissimilarities will not have a major effect and the thrust of the study

can be placed on differences in physiography.

A general discussion contrasting bedrock and glacial drift (or unconsolidated) basins might be appropriate here. Glacial drift basins tend to have more gentle slopes, lower drainage densities, less joint and bedrock control, and lower magnitudes of surface runoff than basins developed in a bedrock regolith. Locally, vegetation may be different due to drainage and slope conditions. These and other factors combine to produce contrasting flow conditions in each type of basin. A bedrock basin will tend to have a steep hydrograph while a glacial basin will have one which is more broad. The steep slopes of the bedrock basin will concentrate precipitation and meltwater into runoff immediately and flood peaks will be reached quickly. Glacial drift basins, however, have poorer direct surface runoff and absorb more water into their base flow in addition to the effects of gentler slopes which increase the time lag to flood peak. Similarly, recurrence interval curves tend to be steeper in bedrock basins due to a general tendency for more flashy runoff conditions, and more gentle in unconsolidated basins due to higher infiltration and base flow control and, consequently, a more uniform discharge regimen.

The changes resulting from the settlement, deforestation and cultivation of a glaciated drainage basin, such as Turtle Creek, may be examined by empirical observations of alterations in stream channel width from initial settlement in 1836 to

the present, 1973. Analysis of changes in the width parameter may be extended to assimilate changes in the whole channel geometry system. The effects of the above mentioned contrasts in physiography between the Platte, as a bedrock basin, and the glaciated Turtle Creek basin should be revealed in the response of their channel geometries to the changes in time and land use between 1836 and 1973.

Resumé of the Literature

Several studies involving discussion of stream hydraulic variables, longitudinal profiles, man's impact through land use practices, and the Turtle Creek area itself are helpful in examining the present problem. Leopold, Wolman, and Miller (1964, pp. 215-281) and Leopold and Maddock (1953, pp. 1-52), provide an excellent discussion of the dependent and independent variables involved in stream hydraulic characteristics and their variation both at a given cross section and in a downstream direction. By using power functions to mirror the effect of exponential growth in drainage basins, the dependent channel variable characteristics may be related to the independent variable of discharge. Varying exponents in the power functions relate to different magnitudes of change of the dependent variables, and representative values for these exponents have been determined for streams of different regions. For example, the power functions relating width, depth, and velocity, in turn, to discharge are:

$$w = aQ^b$$

$$d = cQ^f$$

$$v = kQ^m$$

Average downstream values determined for b, f, and m are 0.5, 0.4, and 0.1 respectively, such that b + f + m = 1.0. In addition, a + c + k = 1.0 such that:

$$w \times d \times v = aQ^b \times cQ^f \times kQ^m$$

$$= (a + c + k) \, Q^{b + f + m}$$

$$wdv = Q$$

This continuity or flow equation, Q = wdv, can be viewed as the definition for discharge measured in cfs (cubic feet per second):

discharge (Q) = cross sectional area (w x d)

times velocity (v).

Similarly, the power function equation may be applied to many other dependent and independent variables of stream characteristics.

Along with discharge and the three main variables which define a channel cross section -- width, depth, and velocity -- Leopold and Maddock (1953, pp. 50-51) and Leopold, Wolman, and Miller (1964, pp.250-251) discuss four more dependent and independent variables which, when combined in a series of complex relationships, should result in a stream having a unique longitudinal profile for its characteristic variables. In short, the shape of the longitudinal profile has been suggested as the integrator of the following variables:

Q   discharge

G   sediment load

D   sediment size

n   flow resistance or roughness

v   velocity

w   width

d   depth

s   slope

Morisawa (1968, pp.120-133) discusses the longitudinal profile and these variables in the light of an equilibrium or steady state system such that "over a period of time, the discharge and load entering the system are balanced by the discharge and load leaving the system" (Morisawa, 1968, p. 126). This steady state is arrived at and maintained by adjustments and interactions among the above dependent and independent channel characteristics.

Schumm (1968, pp. 37-41) gives an example of such an internal adjustment in a stream system by classifying alluvial river channels according to the type of sediment transported within them and relating it to their shape in terms of the width-to-depth ratio. Bedload channels tend to have width-to-depth ratios greater than 40, mixed load channels, between 10 and 40, and suspended and dissolved load channels, less than 10 (Schumm, 1968, p. 40).

Concavity vs. convexity in the longitudinal profile, the shape of which should reflect such adjustments in the stream channel, has been the subject of much discussion and

controversy. Morisawa (1968, p. 100) suggests that an increase in discharge downstream contributes to excess capacity and competence and thus lowers the stream gradient causing a curve concave-to-the-sky to result. Convexity, on the other hand, tends to occur where deposition and a subsequent increase in stream gradient is brought on by the inability of the water volume to transport the load, due either to loss of water volume or increase in load.

Hack (1957, pp. 73-74) related particle size to the concavity or convexity of the profile. If particle size decreases downstream a concave profile will tend to result, the degree of concavity being determined by the rate of decrease in particle size downstream. Conversely, if particle size increases downstream the profile will tend to be flatter or straight, and, if the rate of increase is large enough, convexity may result.

Leopold, Wolman, and Miller (1964, p. 255) discourage the simplicity of this idea referring to the many interactions that stream parameters, such as sediment size, undergo before the end product of a longitudinal profile may arise. They in turn suggest a combination of increase in discharge and decrease of particle size as the most likely cause of profile concavity but note the effect that other accompanying variables might have (Leopold, Wolman, and Miller, 1964, p.256).

Wolman (1955) in his analysis of the natural channel of Brandywine Creek discusses the controversial subject of

the longitudinal profile's concavity as an indicator of
the equilibrium condition in a river system. He views
the equilibrium state as one maintained by a combination
of adjustments in slope, as reflected in the longitudinal
profile, and in channel cross section, as reflected in the
parameters of hydraulic geometry at a given site (Wolman,
1955, p. 47). He further agrees with earlier statements by
Henri Baulig and J.H. Mackin in emphasizing that a stream
in equilibrium or quasi-equilibrium need not be characterized
by a uniform longitudinal profile which is concave-to-the-
sky (p. 49).

These summaries of studies concerning the variables
involved in channel adjustments, including the steady state
in which they operate, the operational forms of power
functions, and the longitudinal profile shapes, have been
presented as pertinent to the problem of assessing the
response of Turtle Creek to post-1836 external and internal
modifications. Also important are studies already completed
which have analyzed river responses to land use changes.

The effects of deforestation on watersheds have been
discussed by Patric and Reinhart (1971), Hornbeck, Pierce,
and Federer (1970), Rothacher (1970), and Hibbert (1969).
Patric and Reinhart found that deforestation of mountain
watersheds resulted in an increase in total runoff, a more
consistent duration of flow, greater peak flows, and an
increase in turbidity and stream temperature. Hornbeck,
Pierce and Federer's study of forest clearing in New England

produced similar results: annual water yield increased,
especially during the critical low flow periods of late
summer and early fall, and instantaneous flood peaks increased.
Rothacher found that water yields increased in response to
clear cut logging practices and that increased yields were
roughly proportional to the area cleared. Hibbert observed
the conversion of a forested watershed to grass and found
that, in general, runoff increased due to the less demanding
moisture requirement of grass.

Agricultural practices comprise another form of land
use impact on drainage basins. These practices have an
effect of increasing sediment yields in a basin, in addition
to changing runoff conditions. Onstad and Jamieson (1970)
reported on the different hydrologic responses in corn-planted
watersheds to the applying of improved conservation methods
in comparison to those remaining unchanged from such
practices. Runoff was shown to be greater for the unchanged
watersheds. Wischmeier and Smith (1965) employed the
universal soil-loss equation to predict sediment losses
and evaluate land uses, and found it effective for indicating
the relationship between crop management and sediment yield.
Hays, McCall, and Bell (1949) reported extensively on
runoff and soil loss percentages for varying crop types,
cover conditions, and agricultural practices examined at the
LaCrosse Conservation Experiment Station from 1933-43.
Table 1 displays some of their findings. It was concluded
that: "From the standpoint of controlling runoff and soil

loss, protected woodland is the best land use. No runoff

or soil loss has occurred on this watershed since 1936 and

only small amounts from 1932-35."(p. 37). It can be

observed in Table 1 that the second highest runoff and

highest sediment losses occur with an unterraced cultivated

watershed. This information is highly pertinent to the

present study, for the impact of initial settlement and

cultivation on the natural landscape of the Turtle Creek

watershed would in effect be similar to a drastic change

from either a protected or pastured woodland type watershed

to an unterraced cultivated watershed since the early

settlers employed few conservation practices. Thus, man's

impact probably brought on a change from the lowest to

highest extremes of runoff and sediment loss on Table 1.

Channelization probably had the greatest direct effect

on Turtle Creek itself. Ruhe (in Coates, 1971, pp. 9-23)

found that in the alteration of the Willow River to a

drainage ditch in Crawford County, Iowa, filling occurred in

the lowermost reaches while entrenchment and widening

occurred higher upstream. Severe entrenchment and gully

erosion were instigated in the tributaries to the Willow

Drainage Ditch and water table levels were lowered at least

10 feet. Emerson (1971), in a similar study concerning the

Blackwater River in northwestern Johnson County, Missouri,

observed greatly increased flooding in the downstream

unchannelized reaches of the river along with a reduction

in channel size due to sedimentation. The channelized

TABLE 1

Annual Runoff and Soil Loss from
Small Watersheds with Various Cover Conditions
LaCrosse, Wisconsin Agricultural Experiment Station
(1935 - 1941)

Watershed type	Annual runoff as percent of rainfall (%)	Annual soil loss per acre (tons)
Pastured woodland	1.16	.14
Protected woodland	.02 (in 1935 only)	none
Cleared pasture	.35	.05
Unterraced pasture	4.65	none
Strip-cropped	7.34	2.66
Unterraced cultivated	7.49	5.00
Cultivated	10.39	1.20

(after Hays, et al., 1949, p. 36)

portions themselves increased in cross sectional area with
a maximum change of 1173% in 60 years! Upstream tributaries
also increased in cross sectional area. A report on stream
channelization hearings before a U.S. House of Representatives
subcommittee (Reuss, in Committee on Government Operations,
1971, p. 3) lists several additional complaints and effects
of such drainage practices. They tend to inhibit ground
water recharge, pollute downstream reaches, promote bank
collapse, increase instantaneous flood peaks, and decrease
channel roughness.

These, then, are the major studies related to stream
response to land use practices. Several investigations
have been undertaken in the Turtle Creek area itself. Alden
(1904 and 1918) discussed the glacial geology of the Turtle
Creek area, and Bleuer (1970) updated some of his interpre-
tations and included particle-size analyses of the area's
tills. The basin's hydrology and water resources were
specifically dealt with by LeRoux (1963) and Cotter, Hutchinson,
Skinner, and Wentz (1969). In addition, the U.S. Army Corps
of Engineers (1967) have investigated the Rock County
portion of the basin and have produced a flood plain information
report for the area.

Also significant to the present study are the findings
of Knox (1970) in reference to differences between bedrock
and unconsolidated drainage basins. He found that, in
general, channels developed in regolith on basins in bedrock
tend to be wider and shallower than comparable channels

developed in regolith from basins on unconsolidated materials
(p. 107). However, he observed that one particular glacial
drift basin, Dry Run in northwestern Iowa, when influenced
by coarse terrace deposits, produced a wider than expected
cross section (p. 132). He also observed that "the rate
of change in channel width approaches a maximum limit in
streams of basins producing large inputs of bed load
sediment in downstream reaches of the channel" and that
"concavity of the long profile varies inversely with bed
load transport demands" (p. 143). In other words, basins
with large amounts of coarse load will tend to produce a
straight longitudinal profile.

The study of Corcoran (1972) and Knox and Corcoran
(1972) will be the basis for comparison in this study of
Turtle Creek. Corcoran found that the power function
relationship between low flow width and drainage area in
the Platte River basin changed from $w = 2.8A_d^{.65}$ to $w = 9.4A_d^{.34}$
for the years 1832 to 1971. This functional change was
reflected in a general widening of the channel in its
headwaters with a narrowing in its lower reaches. The
cause of this change was hypothesized to be a result of
deforestation and cultivation practices commencing in 1832
on the steep slopes of this bedrock controlled basin and a
concomitant increase in runoff which eroded the tributaries
and headwaters but silted in the lower reaches. Consequently,
a major alteration in the hydraulic geometry of the main
channel occurred as it transformed from a dominantly wide

and shallow, bed or mixed load channel to a narrow and deep suspended load channel. The present study on Turtle Creek will investigate the possibilities and evidence of a similar change on a different type of physiography.

The Dependent Variables

The major dependent variables of the study are width (w), depth (d), velocity (v), slope (s), and roughness (n). Width, depth, and velocity have been previously discussed in reference to power functions and the continuity equation (p.7). However, width was the only variable for which consistent measurements could be made to show the change from 1836 to 1973. Former studies have shown that the downstream exponent for velocity, m, averages about 0.1 indicating only a slight increase with discharge relative to the more responsive width and depth components. If velocity is considered constant, the changes in the depth variable should be inversely proportional to the changes in w in order to comply with $Q = wdv$ and $b + f + m = 1$ for a given discharge regimen. Thus the width variable will be used in its operational form as a surrogate for the entire cross sectional hydraulic geometry at a site. Downstream variation in width will be examined for both 1836 and 1973 to assess the changes that have occurred in the channel geometry during that time period. Corresponding changes in depth will also be estimated.

The power function equation for slope measured along the channel is $s = tQ^z$ where average downstream values for

z range from -0.49 to -1.07. These negative z values
indicate a decrease in channel slope with increasing
discharge or drainage area downstream, as is naturally
expected. This dependent variable can be altered drastically
by the construction of channelized waterways and drainage
ditches which tend to smooth out meanders and lower sinuosity
in the natural stream thus decreasing the stream length for
a given drop in elevation and significantly increasing
the channel's gradient. The operational form for examining
the slope variable will be the shape of Turtle Creek's
longitudinal profile.

Roughness, or resistance to flow, also decreases in a
downstream direction as indicated by the average value of
-0.28 for y in the power function equation: $n = rQ^y$. This
decrease relates to the usual decrease in particle size
downstream, but the exponent value is not large because
other forms of flow resistance, such as bars and channel
bends, tend to gain importance in the lower reaches of a
stream (Leopold, Wolman, and Miller, 1964, p. 247).
Quantitative estimates for n were not attempted in this study
but qualitative and descriptive observations were made.
The direct effect of channelization on the roughness parameter
could prove to be an important factor in Turtle Creek.

In summary, the dependent variables involved in changes
in stream hydraulic geometry are width, depth, velocity,
channel slope, and roughness. Modifications in width and
slope will be examined most closely in this study.

The Independent Variables

The dominant independent variables in determining stream hydraulic geometry are discharge, Q, and sediment load, G. Sediment size, D, can be considered semi-dependent because its value is determined both independently, by the lithology of the basin, and dependently, by its history of transport within the channel (Leopold, Wolman, and Miller, 1964, p.250),

Q has been present in all of the dependent variable power function equations and is highly important in determining the magnitude of change in these stream variables, especially in the magnitude of the w and d variables, which is reflected in the size of their cross sectional areas. However, direct measurements of discharge at a given site are nearly impossible in the field and to successfully examine downstream variation in the dependent variables a substitute variable must be used to reflect the exponential increase of Q as one travels downstream. Drainage area, (A_d), has been shown to be a successful surrogate of discharge by Knox (1970) and was used by Corcoran (1972) in his analysis of the Platte River. Leopold, Wolman, and Miller (1964, p.251) list a power function equation which relates bankfull discharge to drainage area: $Q_{bf} \propto A_d^{.75}$. Although the measurements taken at Turtle Creek were based on low flow and not bankfull conditions, Wolman, in his study of Brandywine Creek, plotted discharge against drainage area for both low and high flows and found the two curves to be

nearly parallel, indicating that the exponential relationship between Q and A_d does not change significantly during low flow conditions (Wolman, 1955, p. 34). Thus in the present study, the independent variable, discharge may be justifiably represented by drainage area.

Sediment load and size as independent variables play a more important role in determining the shape of a channel cross section than the magnitude of its cross sectional area. Sediment in a channel may be classified as suspended load, bedload, or a combination, termed mixed load, and these three types of load in turn regulate three different responses in the channel's shape. According to Schumm (1968, p.40), suspended load channels usually have width-to-depth ratios less than 10 indicating a narrow and deep channel. When excess load conditions are prevalent, most deposition occurs on the banks rather than on the stream bed, and if a deficiency in load is present, most erosion will occur on the stream bed with channel widening relatively insignificant. Mixed load channels have width-to-depth ratios ranging from 10 to 40. Under excess load conditions initial deposition occurs on the banks, followed by deposition on the bed, while under deficiency of load conditions stream bed erosion is followed by channel widening. Bedload channels exhibit width-to-depth ratios greater than 40, deposit most of the excess load on the stream bed, often forming islands, and tend to widen the channel more than erode the bed when a deficiency in load occurs.

An operational form in which to examine the sediment load variable is difficult to obtain because of the lack of sediment yield data and problems involved with collecting it. Qualitative obsrvations were taken at the sites and measured width-to-depth ratios at some locations were used to identify the type of load present according to Schumm's classification and thus indirectly evaluate the sediment size variable.

The two independent variables, discharge (represented by drainage area) and sediment (load and size), will tend to govern, respectively, the size and shape of a channel cross section. Evidence that a change has occurred in the cross section should be visible in a comparison of the plots of width vs. drainage area for 1836 and 1973. In summary, the interaction of independent and dependent variables in a stream system might be viewed in terms of a steady state model (Figure 1). The independent variables of discharge and sediment enter the system and in turn are balanced by the discharge and load leaving the system (Morisawa, 1968, p. 126). Inside, the dependent variables of width, depth, velocity, slope, and roughness adjust themselves in proportionate ways to this input-output balance. In the light of the present study it might be imagined that these internal adjustments vary according to the particular climate and physiography affecting the stream. Morisawa states that such an open system is self-regulating in that "any change in the con- tributing environment results in a compensating change in the system" (Morisawa, 1968, p.125). Hence natural and
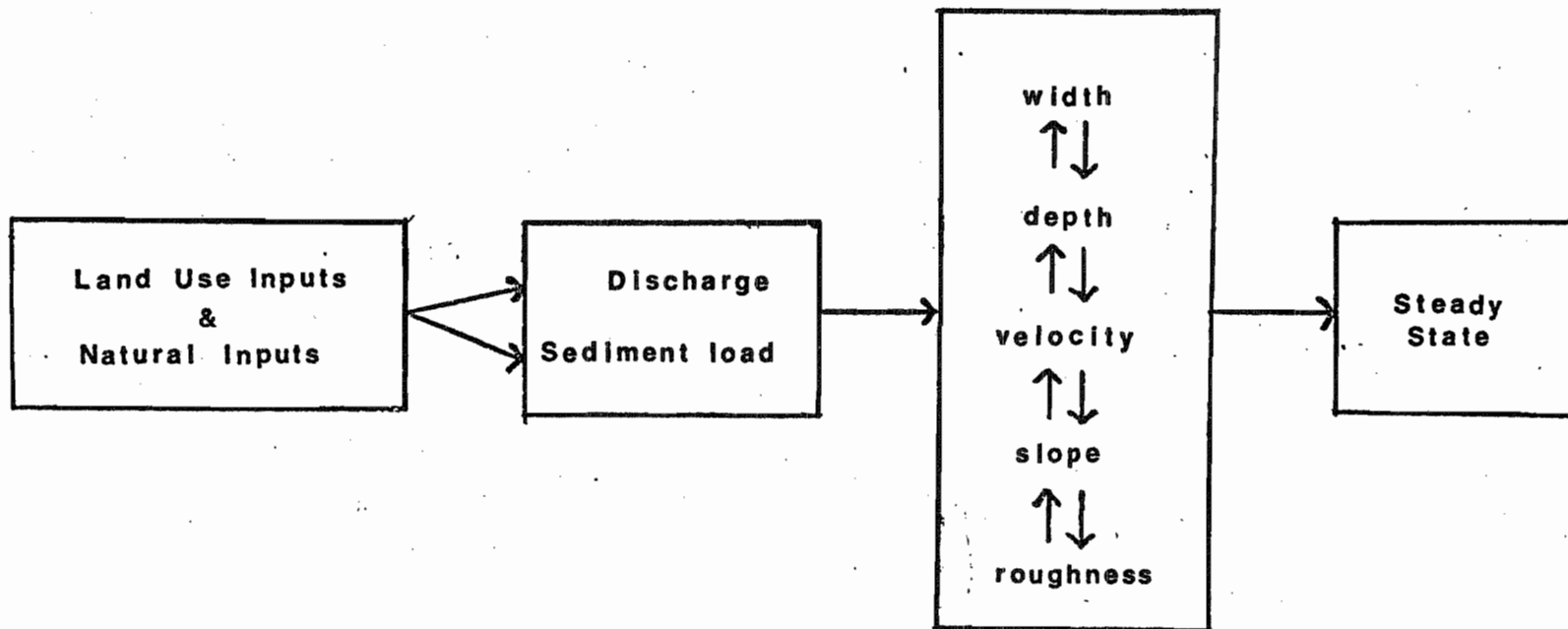
A STEADY STATE SYSTEM

FIGURE 1

artificial external inputs, as discussed earlier (pp. 2-4),
should instigate an adjustment or absorption of the effect
of this change within the system by interaction of the
internal dependent variables. The direction and magnitude
of these adjustments is determined largely by the type of
input and in part by the physiography, vegetation, and
climate of the basin. For example, an increase in the
discharge input might be reflected in an increase in cross
sectional area, and if the stream were situated in an arid
environment, the magnitude of change would be very great.
Likewise, an increase in suspended sediment load introduced
into a shallow and wide bedrock basin would lead to an
.adjustment in cross sectional shape related to decreasing
width and increasing depth. The latter occurred in the
lower Platte River due to a change in the external input
of land use. The response of Turtle Creek's internal
variables to external inputs will be discussed later.

The Study Area: Physiography

The Turtle Creek watershed (Figure 2), located in Rock
and Walworth counties in southeastern Wisconsin, has a
drainage area of roughly 240 square miles. Flowing south-
eastward from Turtle Lake in Walworth County, the stream
travels for a length of about 40 miles before joining the
south-flowing Rock River just below the Wisconsin state
line in South Beloit. Gentle and rolling slopes, end and
ground moraine, and an outwash plain characterize the

The Turtle Creek
Watershed

ROCK CO.

WALWORTH CO.

Rock River

Turtle Lake

Delavan

15

16

17

Spring Brook

5

8

Darien

Delavan Lake

19 Clinton gorge

20

21

18

14

Allens Grove 13

22

3

2

12

23

Shopiere

1

Clinton

24

9

Little Turtle Creek

7

4

Ladd Creek

Beloit

25

10
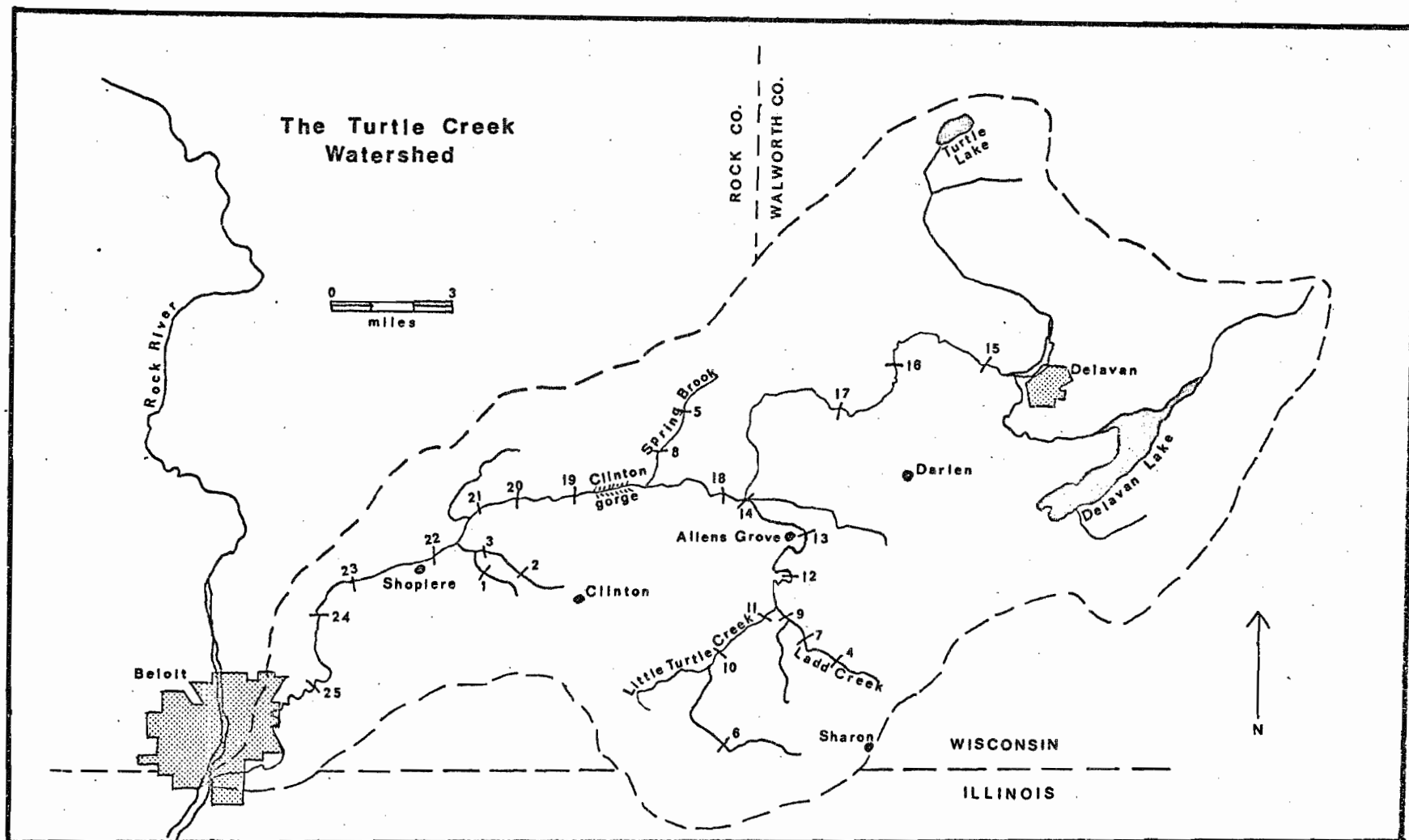
6

Sharon

WISCONSIN

ILLINOIS

N

0 __ 3
miles

FIGURE 2

landscape and allow for the classification of Turtle Creek
as a glacial drift or unconsolidated basin.

The lithology of the basin is notably uncomplicated.
The Platteville-Galena dolomite formation underlies nearly
the entire basin except for a portion near the mouth which
displays St. Peter sandstone at the surface due to down-
cutting in the Rock River valley.

The preglacial topography of the area was dominated
by the ancient Rock and Troy valleys. The preglacial Rock
valley was situated slightly to the east of the present
Rock River valley and was characterized by several short
tributary valleys entering from the east, one of which may
have been the original Turtle Creek (Alden, 1918, p.119).
The ancient Troy valley, like the Rock, extended in a north-
south direction but was situated even further east with
its deepest portions located in the area south of Delavan
and east of Sharon in Walworth County.

Pleistocene glaciation drastically altered this pre-
glacial topography. The surficial glacial geology of the
area is presented in Figure 3 and little evidence remains
of the two former valleys. Although the preglacial Turtle
Creek may have been merely a short tributary valley to the
ancient Rock valley, glaciation must have transformed it by
using it as a major outlet for meltwater drainage from the
Lake Michigan and Green Bay glacier lobes, as its strategic
position in relation to their terminal moraines suggests.
The stream heads behind the Darien terminal moraine and cuts

FIGURE 3

Surficial Glacial Geology

through it below Delavan in a valley much wider than the
size of its present channel might indicate. Higher discharges
and sediment loads from the melting glacier were instrumental
in cutting this large valley and in depositing the outwash
sand and gravel terrace materials displayed in Figure 3.
Further downstream, the channel is constricted by what
can be referred to as the Clinton gorge, characterized by
ledges of Platteville-Galena dolomite outcrops. It is also
within this stream reach that the Argyle till flanks both
sides of the main stream channel. The preglacial topography's
major influence on the basin today lies in the thickness of
valley fill drift which is about 200 to 300 feet in the
upper reaches of the river, thins to less than 100 feet in
the middle reaches, and thickens again to over 300 feet
near the mouth where the ancient Rock valley was located
(Borman).

The character of the various drift deposits has an
important influence on the particle sizes of sediment in
the stream channel. The upper reaches are dominated by end
and ground moraine and hence a wide range of particle sizes
is available as a sediment source for the stream. The middle
and lower reaches traverse both outwash sand and gravel
terraces and a portion of the Argyle till whose sand, silt,
and clay percentages were found to be 62, 28, and 10
respectively (Bleuer, 1970, pp.5-14). Two major tributaries
to the trunk stream, Little Turtle Creek and Ladd Creek,
also flow on this extremely sandy till. The coarseness of

the material available for transport by the stream as sediment load should be reflected in the shape of the channel. Furthermore, the tendency toward an increase in particle size downstream could result in convexity of the long profile as discussed earlier (see pp. 8 and 9).

Soils

Soils in the Turtle Creek watershed range from poorly drained muck and peat in the marshlands of the headwater streams to the relatively well-drained loams in the upland and outwash plain areas of the basin. The original land survey maps and 1893 U.S.G.S. topographic maps of the region show a huge tract of marshland, extending from Turtle Lake to Delavan, which today has been almost completely drained. The abundance of natural marshlands in the headwaters of the tributary streams, Little Turtle Creek and Ladd Creek, has also been reduced. Today only 2.62% of the entire drainage area above Clinton remains in marshland (Conger, 1971, p. 189). The soils of the area must certainly suffer from such moisture modifications. For example, a description of the Houghton muck, found along the "Turtle Lake-to-Delavan" reach warns: "If this soil is drained...subsidence and wind erosion are serious hazards" (Haszel, 1971, p. 27).

Alluvial soils are mapped as occurring along the channel for most of the main stream. but unlike the Platte basin in southwestern Wisconsin, a post-1836 soil unit defining the initiation of clearing and cultivation in the

basin was not readily apparent in the field. Post-1836
land use operations were probably equally effective in both
basins in producing unnatural sediment yields, but Turtle
Creek's post-1836 soil unit may be difficult to detect
because of poor soil profile development or because of little
contrast between the character of the pre- and post-1836
soils. Alternatively, the coarse nature of the available
sediment could have prevented it from being deposited over
the river's banks to any great extent. Perhaps, also,
variations in the types of land use alterations imposed on
the Platte and Turtle basins may be responsible for this
difference in alluvial soil characteristics.

Climate and Discharge

The Beloit weather station reports precipitaion averages
of 33.18 inches per year for the period 1850-1930, and 32.64
inches annually for the years 1935-1964. Mean annual
temperature for the 1935-64 period was 49.3°F (U.S. Dept. of
Commerce, 1965). Although the Platte basin's mean annual
precipitation is only slightly higher than the Turtle's at
33.6 inches (Conger, 1971, p. 188) the discharge regimes of
the two streams are significantly different, as can be seen
in Table 2. The small increase in precipitation of the Platte
does not account for the great disparity between discharge
values and hence the physiographic factor seems to be most
in control here. Flood peaks are greater in the Platte
basin because of its steeper slopes and direct surface runoff,

TABLE 2

Discharge per Square Mile
for Various Return Frequencies

	Q_2	Q_5	Q_{10}	Q_{25}
Platte River	37.3	71.5	102.9	153.9
Turtle Creek	11.6	21.7	29.6	40.4
Little Turtle Creek	19.1	34.2	44.7	57.7

(data from Conger, 1971, p. 178)

whereas Turtle Creek is characterized by a substantial base flow related to moderate to good surface infiltration and storage capacities. Cotter, Hutchinson, Skinner, and Wentz (1969, Sheet 2) have shown in low flow frequency analyses that Turtle Creek experiences a decrease in runoff per square mile in a downstream direction. This may be explained by a change in the stream's ground water flow regimen from an effluent to an influent stream upon entering the region of thick Rock valley fill and the St. Peter sandstone contact just downstream from Shopiere (LeRoux, 1963, p. 8). Instead of receiving inputs from the ground water body, the stream loses its discharge to a lower water table which is recharged in the thick and very permeable glacial drift and the sandstone aquifer. This decrease in water volume downstream is another factor which might lead to convexity in Turtle Creek's long profile (see pp. 8 and 9).

A comparison of recurrence interval curves for the Platte River and Turtle Creek (Figure 4) reflects many of the differences between the two as representatives of watershed environments controlled by bedrock and glacial drift respectively. However, when plotting Turtle Creek's recurrence interval curve with others of the Rock-Fox River Basin, it was found that the curve for Turtle Creek fell high in the grouping according to its drainage area, except for the smaller and more frequently recurring floods. The explanation provided by Cotter, et.al. (1969, Sheet 2)

Recurrence Interval (in years)

Discharge (in thousands of cfs)
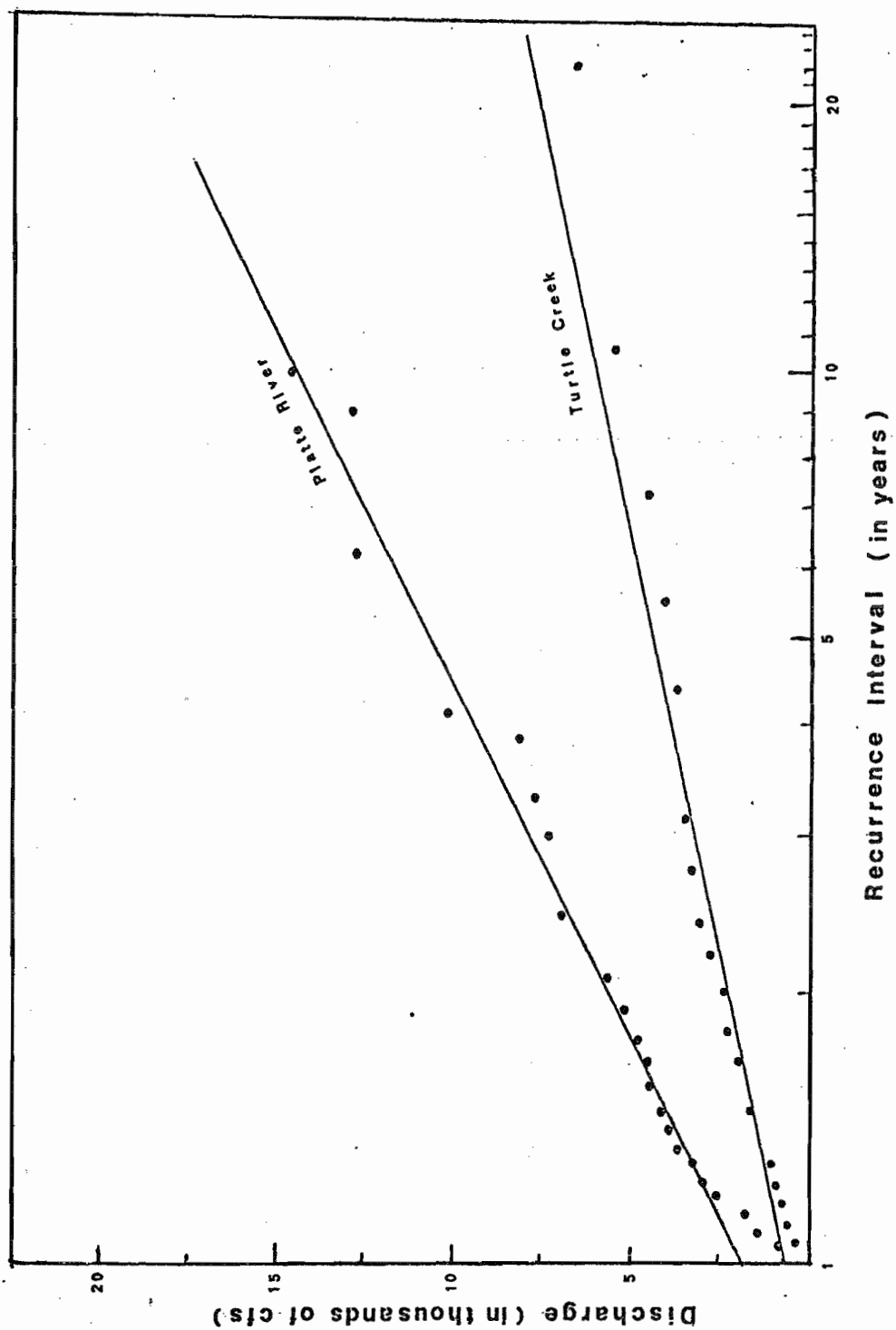
Platte River

Turtle Creek

FIGURE 4

is that "the stream has a steep gradient and few flat,
marshy areas adjacent to it to retard rapid runoff."
Steep stream gradients and lack of marshy areas, which are
usually not associated with glaciated drainage basins, are
characteristic of Turtle Creek's basin partly because of
the impact of wetland drainage and channelization in the
watershed. Despite this, the Platte and Turtle Creek curves
are significantly different and it can be imagined that the
pre-settlement recurrence interval curves for the two basins
were equally divergent.

Flooding in Turtle Creek has been studied by the U.S.
Army Corps of Engineers. They list 44 floods above bankfull
stage at the U.S.G.S. gaging station near Clinton for the
27-year time period of 1938-1965 (U.S. Army Corps of
Engineers, 1967, pp.28-29). Of these, 37 occurred in late
winter or early spring and all of the ten highest floods
on record, except that of September 28, 1945, took place in
January, February, and March. The recent floods of April and
May, 1973, coincide with this spring peak pattern. No
significant obstructions to flood flow have been constructed
in the basin. A small dam is located above Shopiere but
the floodplain is so low on either side of the channel at
the site that, in large floods, it has a negligible effect
(U.S. Army Corps of Engineers, 1967, p. 12).

History of Settlement

The original land survey of the Turtle Creek region
was conducted in the spring and summer of the year 1836
and it was at about this time that the first permanent
settlers began to establish themselves in the area. The
native vegetation type that they found was a savanna:
white, black, and burr oak stands combined with dry-rolling
to wet-bottomland prairie. The rich prairie soils and
conveniently close timber supply instigated rapid settlement
in the townships of the Turtle basin in the years from
1850 to 1880. Population declined somewhat after this
initial surge, yet the 1910 census recorded Walworth County
as having 2,803 farms comprising 94.0% of the land, and
Rock County as supporting 3,787 farms on 95.9% of its
total land area (Whitson, Geib, Conrey, and Gibbs, 1922, p.67).

A fairly large amount of initial deforestation occurred
in conjunction with this modification toward a cultivated
watershed. As early as the 1840's a saw mill at Shopiere
was reported to be cutting 150,000 feet of oak lumber
annually (Guernsy and Willard, 1856, p. 128). However,
several prairie townships were deficient in woodlands from
the beginning, and with the additional factor of more
gentle slopes, the Turtle Creek basin must not have felt
as great an impact as the Platte to the practice of
deforestation. A failure to employ conservation methods
in plowing the prairie lands for crops was perhaps the
greatest source of sediment as the data for unterraced

cultivated watersheds given in Table 1 suggest. It may be recalled, however, that a distinct post-1836 soil unit marking the initiation of cultivation on the basin was not readily defined (see p. 28). The apparent lack of large amounts of overbank deposition is perhaps a function of a smaller sediment yield and of a proportionately large, coarse sediment fraction which rarely appears as an overbank deposit.

Probably an even more important impact of settlement on the basin was the drainage of wetlands by channelization and construction of drainage ditches. On November 1, 1908, a petition was filed by two-thirds of the land owners along Turtle Creek and its marshlands to establish the Turtle Creek Drainage District, and a contract was subsequently signed on June 26, 1911 to begin work on 11 miles of ditching and dredging to drain 3,188 acres at a cost of nearly $38,000 (Beckwith, 1912, p. 211). By 1920, Walworth County as a whole had 8,910 acres in drainage enterprises with 23.3 miles of open ditches and 7.5 miles of tile drains, a good portion of which must have been constructed in the Turtle Creek watershed (Whitson, et.al., 1924, p. 86). The repercussions of such severe alterations in both the discharge regime of the watershed and the actual dimensions of the stream channel should reveal themselves in a significant change or adjustment in one or more of the five dependent variables in the steady state model. Thus, the history of settlement of the Turtle Creek watershed provides many

indications that land use changes which have taken place
could significantly alter inputs of the two independent
variables of discharge and sediment load.

Methods of Data Collection

In the original land surveys of the Wisconsin
territory, stream width measurements were recorded at
those sites where the stream intersected a surveyed section
line. It is assumed that the width reported was probably
low flow or water width, rather than bankfull width (Corcoran,
1972, p. 34). Such measurements for Turtle Creek and
several of its tributaries were collected at 25 sites from
maps drawn from the surveyor's notes (Lyon, 1836). The
1973 low flow widths at these 25 sites were measured in the
field as a basis for comparison of the 1836 and 1973 channel
geometries. These width measurements were plotted on 3-cycle
log paper against corresponding drainage area values,
measured from U.S.G.S. 1:62,500 topographic maps to provide
a linear scatter of data points for relating the two
variables. The least-squares regression lines were computed
for the data and correlation coefficients for these lines
in the 1836 and 1973 plots were 0.946 and 0.964 respectively.
Lines "fitted by eye" did not deviate substantially from
the lines representing the statistically determined
equations.

Longitudinal profiles for Turtle Creek and the tributaries
involved in this study were obtained from measurements of

elevation and stream length taken from 1:24,000 U.S.G.S topographic maps.

Figure 2 locates the 25 sites which provided data for this study. The Turtle Creek trunk stream has been channelized so intensely in the reach above Delavan that measurements taken there would have been totally unrepresentative of the true magnitude and direction of change in the natural channel. Hence this reach was eliminated from the study and tributary headwaters in Little Turtle Creek, Ladd Creek, Spring Brook, and two small streams northwest of Clinton were measured as alternates. These tributaries can be used to simulate the change in the headwaters of the main stream itself because an entire drainage basin will generally act as one system, with the exception of those tributaries closer to the mouth of the trunk stream, (i.e. having a shorter distance to base level), which often show anamolous characteristics. However, Knox (1970, p. 267) found that "for materials very easily modified by erosional processes, an equilibrium phase is generally attained throughout the basin and distance as a base level constraint also loses significance." Hence the unconsolidated nature of the Turtle basin tends to increase the legitimacy of using tributary headwater measurements as a substitute for the main stream's headwaters.

Bankfull width-to-depth ratios were derived for several cross sections along the channel. Data for ratios along the main stream, sites 17 to 19, were taken from

cross sections surveyed by the U.S. Army Corps of Engineers
for their <u>Turtle Creek Flood Plain Information Report</u> (1967).
Since their choice of sites was not determined by position
along a section line, these ratios represent cross sections
only relatively close to the sites examined in this study.
Nevertheless, an idea of the general width and depth charac-
teristics of the large trunk stream can be obtained. The
width-to-depth ratios for sites 2 to 15 in Table 4 were
derived from actual field measurements made during the
present investigation.

Hypothesis

This study observed the response of a river system to
the impact of settlement and subsequent land use modifications
and compared this response to that of a river system
adjusted to a different type of physiography. Given the
fact that streams in different physiographic regions respond
in unique ways to inputs into their systems, the basic
hypothesis of this analysis was that the impact of settlement
and subsequent land use changes should instigate a different
response in a glaciated drainage basin than one situated in
the Driftless Area. To test this hypothesis an attempt
was made to reconstruct the character of Turtle Creek of the
1830's and to compare it with its present nature, keeping
in mind the character of the Platte River during the same
time interval.

Turtle Creek in the 1830's

Figure 5 displays the power function relationship

between low flow width and drainage area for Turtle Creek

in 1836. The equation for the least-squares line is

$w = 1.1A_d^{.99}$, describing almost a one-to-one relationship

between low flow width and drainage area. Stream widths

calculated from this formula for various drainage areas

are listed in the column headed 1836 of Table 3. Turtle

Creek in the 1830's must have been very narrow in its marshy

headwaters but quite wide in its lower trunk stream where

the channel is developed in sand and gravel outwash and

terrace deposits. The gentle slopes of the basin, large

wetland areas, and a high water table most likely minimized

the variability of the discharge regime and reduced the

frequencies of major flooding events. Stable banks and

abundant marshland were probably instumental in keeping

sediment losses minimal and the stream flowing clearly.

Settlement by the white man consisted of major alterations

in land use and consequently an upheaval of the natural

inputs that formerly controlled the pre-settlement river

system. Deforestation released sediment and increased

surface runoff to the downstream reaches of the basin.

Farming, especially with a lack of conservation practices,

greatly increased the sediment load in the stream in addition

to runoff. Channelization was employed to drain the

headwater marshlands, and as a result large sediment loads

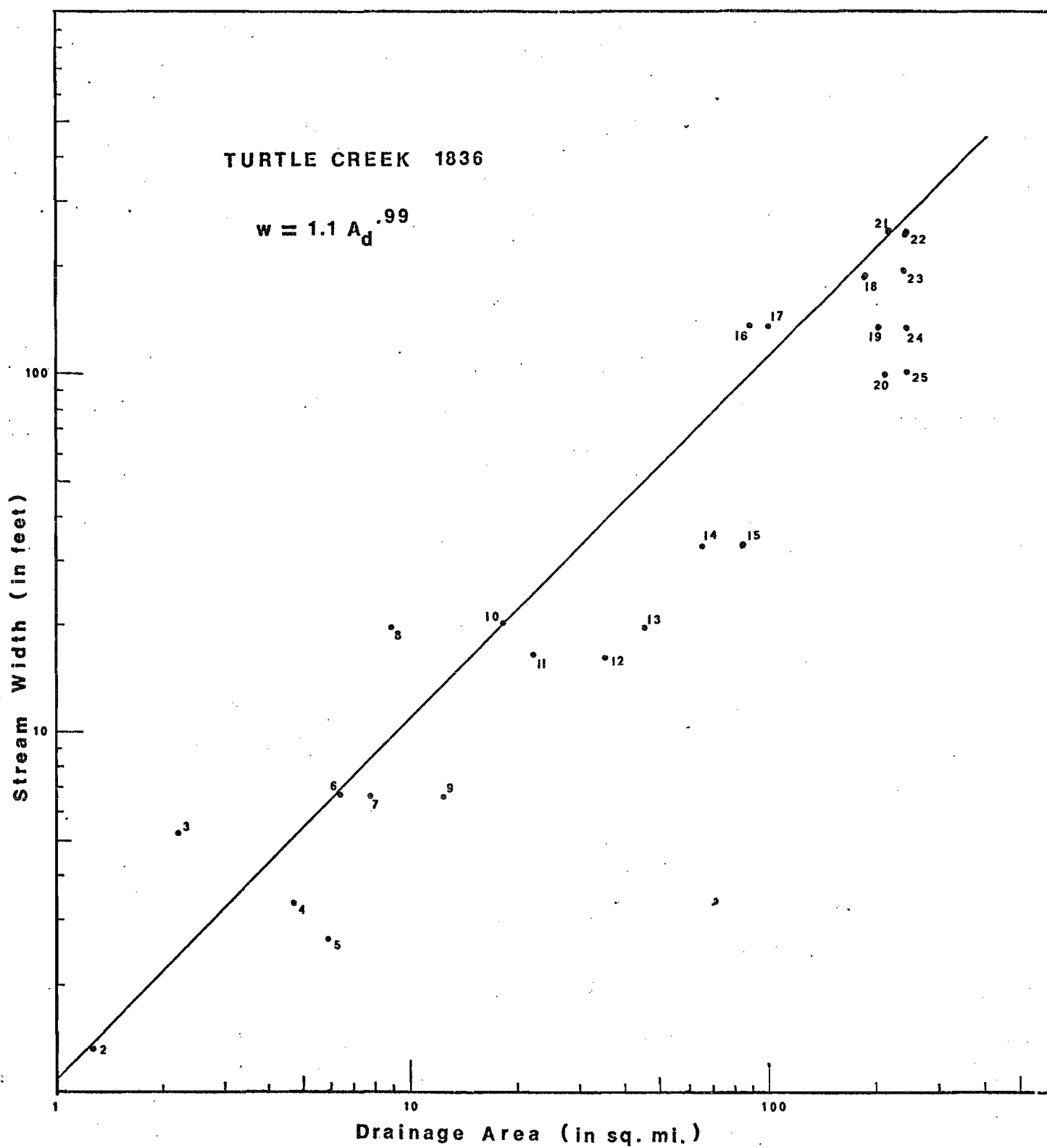were released and bank collapse was prevalent in the upper

FIGURE 5

TABLE 3

Calculated Low Flow Widths
(in feet)

Drainage area (sq. mi.)	TURTLE CREEK		PLATTE RIVER	
	1836	1973	1832	1971
1	1.1	3.0	2.8	9.4
5	5.4	9.1	8.0	16.2
10	10.7	14.7	12.5	20.6
25	26.6	27.7	22.7	28.1
50	52.9	44.6	35.6	35.5
75	79.0	59.0	46.3	40.8
100	105.0	72.0	55.9	45.0
200	208.6	116.1	87.1	56.9

reaches. The stream's channel gradient was steepened and larger discharges were thus delivered downstream, increasing the tendency to flood.

Turtle Creek in the 1970's

The results of these modifications are revealed in the channel of Turtle Creek as it is today. Figure 6 displays the present relationship between low flow width and drainage area in the basin. The least-squares line has an equation of $w = 3.0A_d^{.69}$ revealing that the values of both coefficient and exponent of the power function equation have changed since 1836. By comparing the graphs in Figures 5 and 6, it can be seen that a change in the exponent from .99 to .69 reflects a shift to a more gentle slope for the least-squares line, brought on by channel narrowing for the larger drainage area (or downstream) sites. On the other hand, the increase of the coefficient from 1.1 to 3.0 results in a higher intercept value on the 1973 width axis and consequently reflects a widening trend in the smaller drainage area (or upstream) sites. In short, the decrease of the magnitude of the exponent indicates that in general the lower reaches of the Turtle have narrowed since 1836, while the increase of the magnitude of the coefficient reveals that the tributary sites have widened. Calculated low flow widths for Turtle Creek in Table 3 depict this relative alteration from narrow to wider in the headwaters and wide to narrower in the lower

TURTLE CREEK 1973
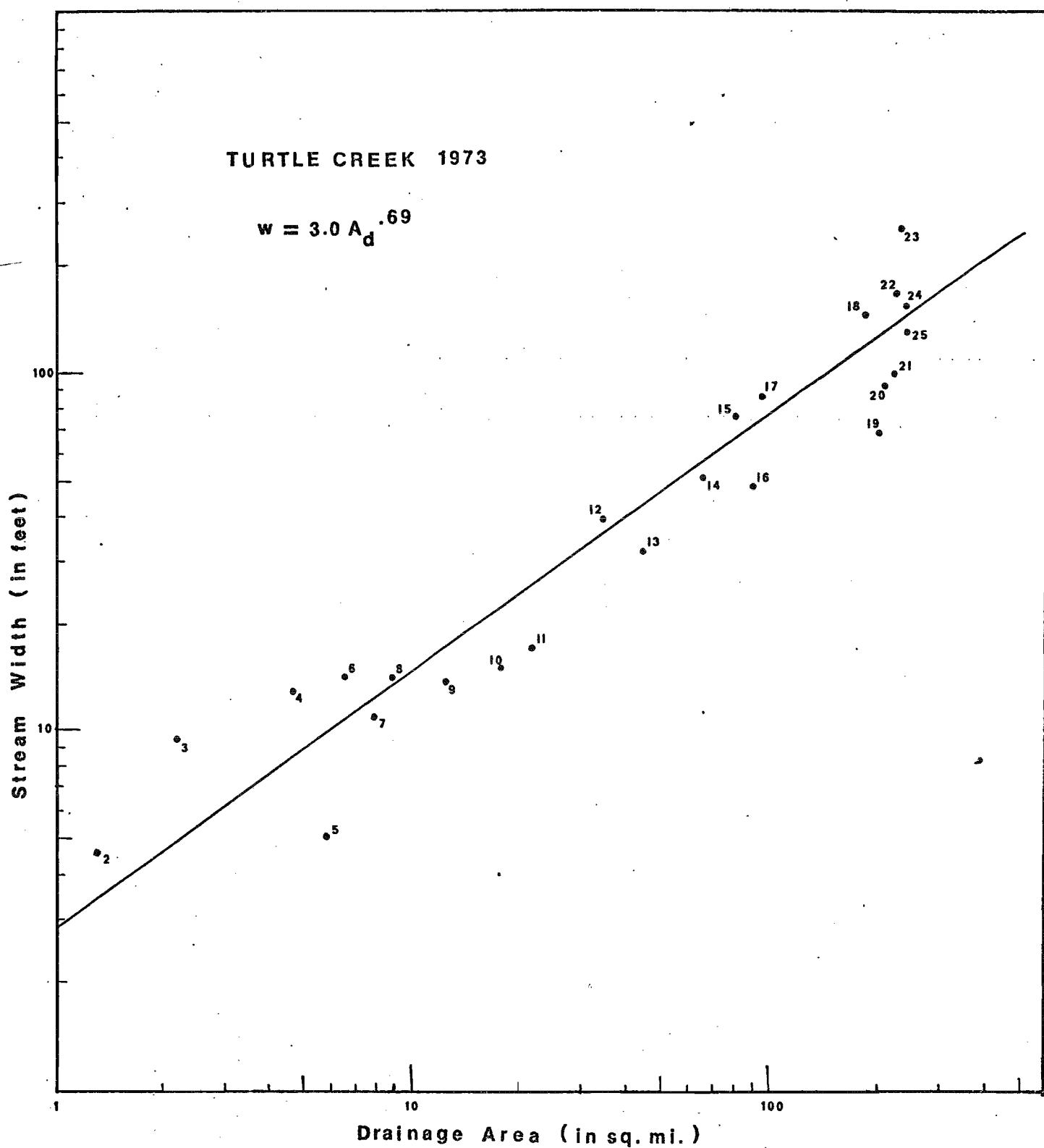
$$w = 3.0 \, A_d^{.69}$$

FIGURE 6

reaches. In addition to this change in channel geometry, the 1836 discharge regime was altered to the present regime of more frequent floods, a shorter lag time before flooding, a lower water table, and less base flow control, while turbidity in the river was increased due to wetland drainage and bank collapse.

An examination of the Turtle Creek basin's longitudinal profiles (Figure 7) is an additional means of observing the stream's 1973 character. In previous literature, a convex long profile was often viewed as an indication that the stream was not in equilibrium. Wolman, however, has maintained that the equilibrium condition cannot be determined solely by the shape of a longitudinal profile and that the profile's reflection of adjustments in slope and channel geometry are more realistic indicators of an equilibrium or steady state in a river (see p. 9). The convexity of Turtle Creek's profile may be logically explained by some of the unique properties which have been emphasized earlier (see pp. 26-30). The unusual downstream increase in particle size and the decrease in discharge per square mile in the Turtle's lowermost reaches are both feasible explanations for at least some of the convexity present. In addition, constraining factors such as the Clinton gorge, the Shopiere dam, and the St. Peter sandstone contact appear as knickpoints, or reaches of sudden steepness of gradient, on the profile and contribute to its convex nature. Later discussion will show that adjustments corresponding to these knickpoints in the
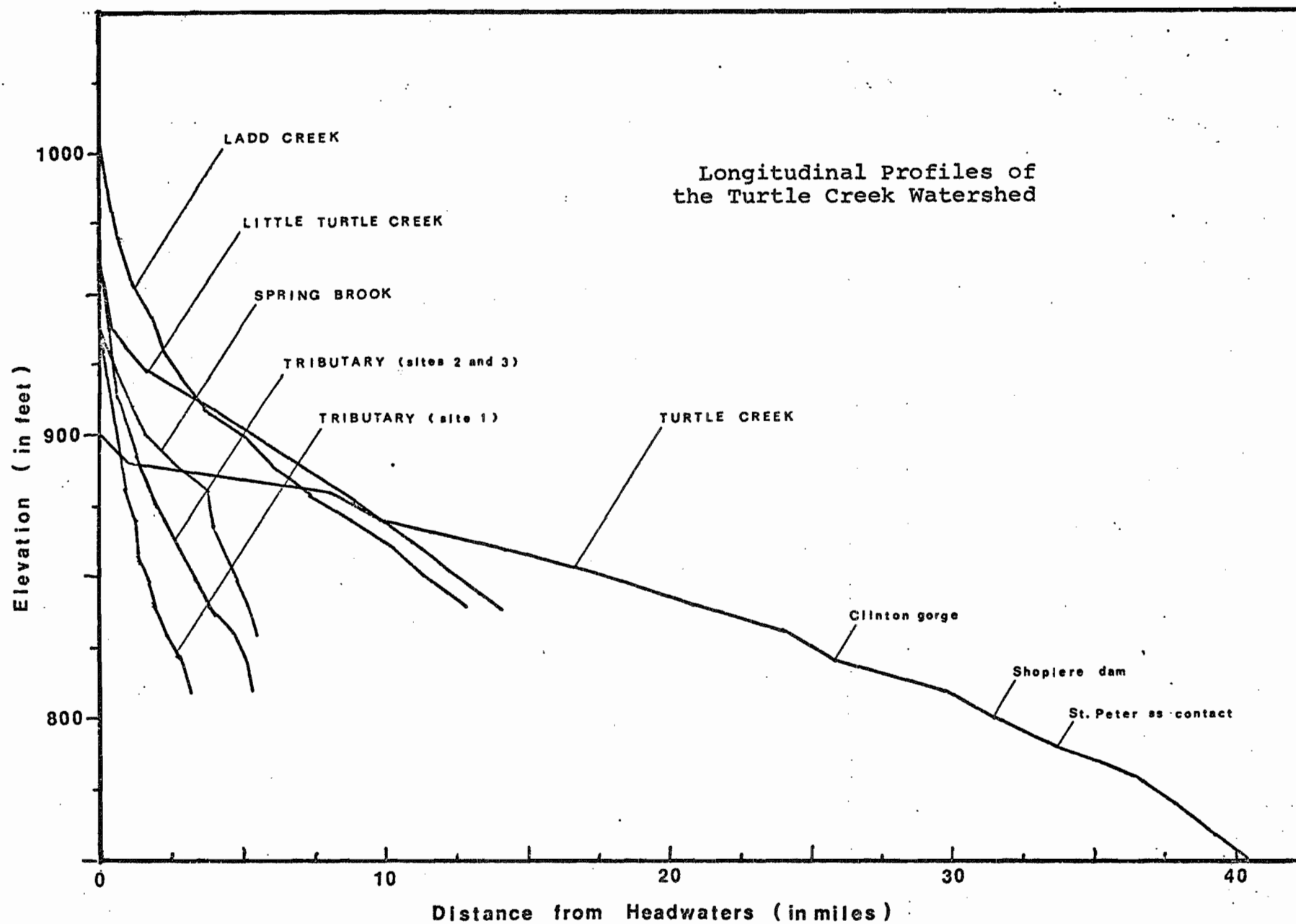
Longitudinal Profiles of
the Turtle Creek Watershed

LADD CREEK

LITTLE TURTLE CREEK

SPRING BROOK

TRIBUTARY (sites 2 and 3)

TRIBUTARY (site 1)

TURTLE CREEK

Clinton gorge

Shoplere dam

St. Peter ss contact

Elevation (in feet)

1000

900

800

Distance from Headwaters (in miles)

0   10   20   30   40

FIGURE 7

longitudinal profile can also be detected in the downstream
trend of channel widths.

The Platte River: 1832 - 1971

The change in Turtle Creek's channel since the 1830's
must now be compared to the findings of Knox and Corcoran
on the Platte River to test the hypothesis that different
physiographies will produce different channel responses to
land use modifications. The equation describing the low
flow width-to-drainage area relationship for the Platte
River of 1832 was found to be $w = 2.8A_d^{.65}$. A comparison
of the 1832 and 1836 columns in Table 3 indicates that the
Platte was also narrow in the headwaters and wide downstream,
but not as narrow and wide as the Turtle was in the 1830's.
Although bedrock environment basins should tend to have
wider and shallower channels than basins developed in
unconsolidated material, Knox's example of the Dry Run
basin (1970, p. 132) in which coarse terrace deposits
produced a wider than expected cross section might be
analogous to the Turtle Creek case.

Land use modifications in the Platte basin consisted
predominantly of deforestation and cultivation since the
steep slopes and lack of marshland made channelization and
wetland drainage only occasionally neccessary. However,
the practices which were employed in the basin increased
discharges and sediment load downstream just as in the
Turtle. The 1971 Platte River equation, regressing low

flow width against drainage area, was found to be $w = 9.4A_d^{.34}$.
A summary of all four equations is best seen in Table 3
which provides comparative estimates of the historical changes
in stream width for both the Platte and the Turtle systems,
calculated from their respective power function equations.
As Corcoran and Knox have shown, a large widening seems to
have taken place in the upstream reaches of the Platte with
a significant narrowing in the lower reaches. The direction
of this change parallels that of the Turtle, however Table 3
also reveals that today the Platte headwaters are wider than
those of the Turtle and its downstream reaches are generally
narrower.

Discussion

The results of this analysis have indicated that both
the Platte River and Turtle Creek have widened in their
headwaters and narrowed in their lower reaches to adjust to
the land use alterations imposed on their basins by man.
It has been hypothesized, however, that basins developed
on different physiographies will respond in different ways
to the unnatural external impact of land use modifications.
The essential point to be realized is that the similar trends
observed in stream width alterations within each basin do not
neccessarily indicate that the entire stream channel cross
sections of the Platte and Turtle responded in the same
way. For example, the magnitude, not the direction, of
the stream width modification in each basin might be the
factor which reflects the contrasting physiographies of

the driftless area vs. the glaciated area most effectively. Alternatively, the divergence due to physiographies might best be seen in the channel shapes, in terms of differing width-to-depth ratios, rather than in the observed width values alone. These possibilities will be examined in the subsequent discussion.

The variable upon which the final conclusions of this study are based is the stream width variable. Before proceeding any further, some clarification of the differences between low flow and bankfull channel widths must be made to avoid confusion with preexisting analyses of aspects of river channel geometry. In most of the literature concerned with this subject the stream width variable is commonly discussed in terms of its bankfull measurement. Thus the average value of the b exponent for the equation $w = aQ^b$ given earlier as 0.5 (see p. 7) refers to the downstream increase of bankfull channel width as discharge increases downstream. Since the land surveyor of the 1830's most likely measured the water width or low flow width of the channels he traversed, the present study has been confined, for the sake of comparability, into using low flow, not bankfull, channel width measurements.

Wolman has examined the value of the b exponent at both low and high flows in his study of Brandywine Creek. When data from the entire Brandywine watershed were plotted, the change in the width variable in the downstream direction was nearly the same at low flow as it was at high flow.

The low flow b value was equal to .57 and the high flow
exponent was equal to .58 (Wolman, 1955, p. 26). Thus the
present discussion of the historical changes in stream
width occurring in the Platte River and Turtle Creek may
continue on the basis of low flow width measurements with
at least some validation that the same trends, although
perhaps not absolute values, of change would be observed
if the entire investigation had proceeded on the basis of the
more common bankfull measurement.

It has been shown that despite significantly divergent
physiographies, the Platte River and Turtle Creek have
experienced a similar trend in historical channel width
adjustments to land use modifications. The hypothesized
divergent response neccessitated by dissimilar physiographies
might perhaps be only observable in the magnitude or
degree of adjustment in each stream's channel. Reason
suggests that the Platte should have suffered a more severe
change in channel geometry than the Turtle due mainly to
the basin's steeper slopes which tend to concentrate water
into the stream channel more quickly and which are also
more susceptible to severe erosion losses than the gentle
and permeable slopes of the Turtle Creek watershed. However
to make an absolute judgment on which of the stream channels
was more severely altered, it would be essential to know how
much land use modification was imposed upon each basin and
also what degree of effect was produced by different types
of modifications (channelization vs. deforestation, etc.).
The data to answer such questions is simply not available.

In addition, a measure of the changes in the power function
equations obtained for each basin in the 1830's and 1970's
would not neccessarily allow a valid comparison of the
degree of width adjustment because the measurements leading
to the equation were taken over slightly different time
intervals and involved a different drainage area for each
basin. Thus the reflection of differing physiographies by
a divergent response in magnitude of channel width adjustment
can only remain as an open possibility for acceptance of the
hypothesis.

The discussion thus far has involved the idea of
channel change mainly in terms of its width variable,
revealing that trends in widening and narrowing are similar
in each basin. However this fact does not indicate that
both channel cross sections neccessarily responded in the
same manner. For example, a decrease in channel width could
be the result of a decrease in w and d, thus reducing the
whole cross sectional area and changing the size of the
channel, or it could be the result of a decrease in w with
a corresponding increase in d thus maintaining the same
cross sectional area or perhaps even increasing in area,
but changing the shape of the channel.

Channel Size Response

The comparison of recurrence interval graphs in
Figure 4 indicates that an increase of discharge should
tend to have more effect in changing the size of a bedrock

environment channel than that of a glaciated watershed.
Steeper slopes, greater surface runoff and more frequent
floods in the Platte basin suggest that increased discharges
due to land use alterations would be concentrated in the
Platte channel more quickly and with greater impact than
in the channel of the Turtle. In addition, the gentle slope
of the Turtle Creek recurrence interval curve in Figure 4
reflects the strong influence of base flow in the stream's
hydrologic regimen. The severe channelization imposed upon
the Turtle watershed has significantly lowered the water
table and reduced the importance of base flow in the channel
forming process.

Thus in the bedrock environment basin, the land use
modifications of deforestation and subsequent farming and
grazing of the steep slopes should have concentrated greater
and more frequent flood peak discharges into the channel,
eventually requiring its enlargement. In the glaciated
Turtle Creek basin, however, deforestation and cultivation
may not have had as great an influence as channelization
because of the permeable nature of the glacial drift deposits.
The infrequent high magnitude floods in the basin no doubt
experienced larger than usual discharges due to straight
channelized waterways designed to facilitate the quick
removal of flood waters to downstream reaches. However,
channelization most likely had nearly an opposite effect
on the daily low to moderate flow of water in the stream
channel. It may be recalled that one of the more severe

effects of channelization is a lowering of the water table
which eventually leads to a significant reduction in base
flow. In accordance with the magnitude and frequency
concept of Wolman and Miller (1960, p. 65), the channel
forming discharges of a stream are not the infrequent, high
magnitude floods which channelization must have increased,
but the frequent, low to moderate flows which must have
been significantly diminished due to the reduction in base
flow. Thus land use practices affecting discharge in the
Turtle may have produced an opposite response to that of the
Platte by causing a downstream reduction in channel size
due to a decreased base flow.

Channel Shape Response

Corcoran's study concluded that a major change in
channel shape took place in the Platte River when responding
to land use modifications, thus indicating control by the
sediment independent variable. The steep slopes, high
surface runoff capabilities, and frequent flooding conditions
of the driftless area basin seemingly had a greater influence,
not in delivering increased discharges downstream to increase
the cross sectional area size, but in delivering large
amounts of suspended sediment to the lower reaches which
prompted the channel to adapt by changing its shape from
wide and shallow to narrow and deep. Although the shape
transformation seems most obvious, the size of the channel
may also have increased to accomodate the increased runoff

while still allowing the channel to decrease in width in
its lower reaches.

It is possible that Turtle Creek may have had a
different response in channel shape. Table 4 shows present-
day bankfull width-to-depth ratios for selected sites along
the stream system. If the Turtle had responded in the
same manner as the Platte by changing its downstream channel
shape to narrow and deep to accomodate the increased discharge
and sediment load, its downstream sites should tend to
have relatively small width-to-depth ratios and a suspended
load type channel. Because the 1830's data represent low
flow widths and provide no information at all on channel
depth, it is impossible to present any estimate of the pre-
settlement channel's width-to-depth characteristics. However,
by applying Schumm's classification of channel type to the
observed present-day ratios it is found that the Turtle's
downstream reaches are dominated by relatively high width-
to-depth ratios and thus would be considered mixed or bed
load -- not suspended load -- type channels. This indication
of a present day wide and shallow channel in the Turtle's
lower reaches is conflicting with the more narrow and deep
suspended load type channel observed in the lower Platte.
Recalling that both streams experienced a narrowing in
their lower reaches, it is likely that the lower Turtle
Creek channel widths became smaller, not by a change in
channel shape as in the Platte, but by an overall reduction
in channel size while still maintaining a relatively wide

TABLE 4

Selected Bankfull Width-to-Depth Ratios
for Turtle Creek

Site #	W/D	Drainage Area (sq. mi.)	Type Channel (after Schumm, 1968)
2	2.76	1.3	suspended load
3	10.76	2.2	mixed load
4	6.66	4.7	suspended load
6	7.52	6.5	suspended load
7	3.91	7.8	suspended load
12	8.69	35.5	suspended load
15	64.65	84.4	bed load
near 17	19.26	95.9	mixed load
near 19	40.27	208.1	mixed load
near 20	45.16	213.4	bed load
near 22	56.79	228.0	bed load
near 23	22.19	233.3	mixed load

and shallow channel geometry. A schematic diagram illustrating this concept is presented in Figure 8.

Previously discussed contrasts in physiography and discharge regimens in the two basins support the feasibility of this conclusion. For example, Figure 8 suggests that the Platte changed its shape not only be filling in the channel sides with the increased suspended sediment load obtained from upstream reaches and deforested slopes, but also by a scouring of the stream bed which increased the channel depth. Therefore the decrease in width was most likely offset by an increase in depth such that, either the same cross sectional area, or even a larger channel size could have developed to accomodate the post-1830's increases in daily discharges and flood peaks. The drastic lowering of the water table and subsequent reduction in base flow due to channelization in the Turtle Creek watershed affected its post-1830's discharge regime by diminishing the effect of the low to moderate channel forming flows, yet exaggerating the effect of the infrequent high flood flows. Thus the lower Turtle, while receiving large inputs of sediment from deforestation and cultivation practices, was unable to transport this increased load out of the basin, except perhaps at times of peak floods. As a result, the entire channel probably shrank in size and a scouring of the bed was not neccessary to accomodate the post-1830's channel forming flow which had been drastically reduced.

PLATTE RIVER

TURTLE
CREEK

—————— 1830's channel
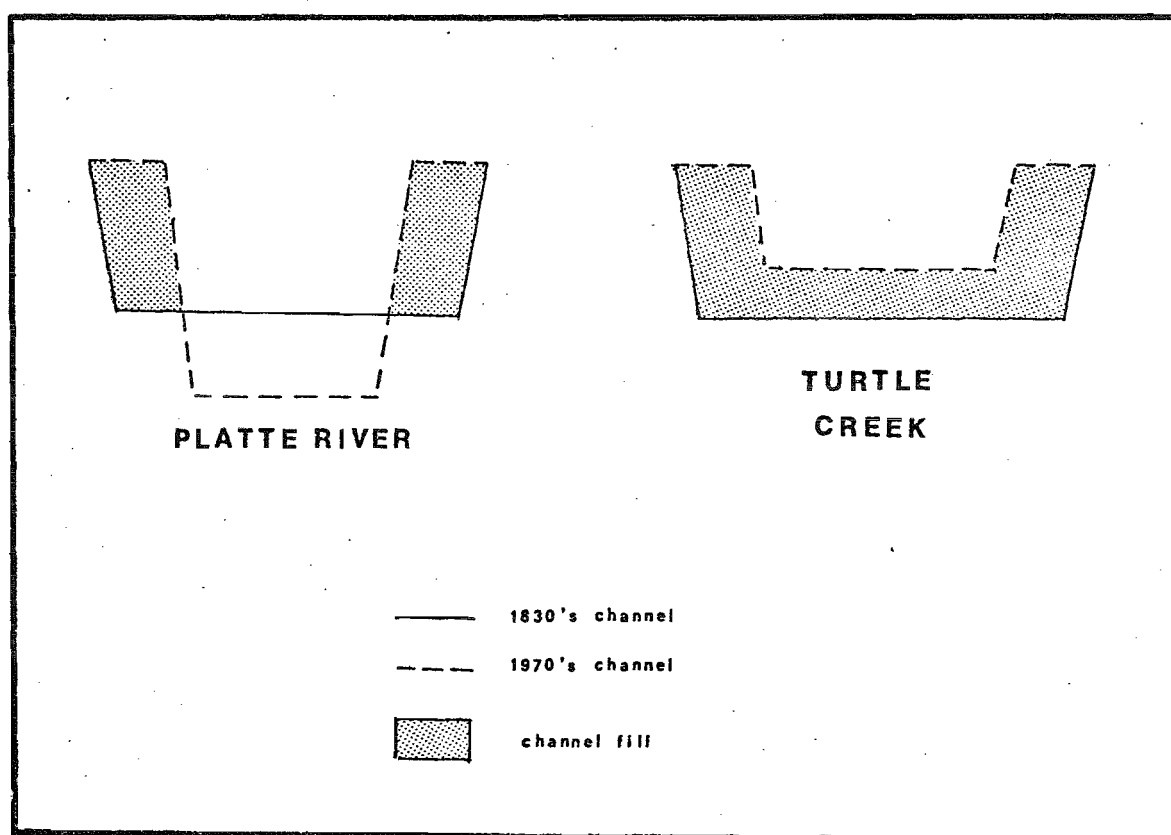
— — — — 1970's channel

[channel fill] channel fill

FIGURE 8

Schematic Diagram
of Historical Channel Change

Another factor which might have contributed to the situation described in Figure 8 would be that of the type of sediment load dominant in each basin. Schumm has stated that an excess in sediment load delivered to a downstream reach of a river will be deposited either on the banks, the stream bed, or on both -- depending on whether the excess load is suspended, bed, or mixed. It is a possibility that due to the thick loess deposits in the Platte basin and the more coarse outwash sand and gravel deposits in the Turtle basin, an excess suspended load would be more readily available in the Platte than in the Turtle. If post-1830's excess sediment in the lower Platte was mainly of the suspended load type, and in the Turtle mainly of the mixed load type, it is conceivable that the Platte would have experienced more of a tendency to have most of the sediment deposited on its banks alone while the Turtle would have had both bed and banks aggraded, thereby reducing the entire channel size, not neccessarily altering its shape. However, detailed sediment data for both streams would have to be obtained before a theory such as this could be validated.

Most of the discussion thus far has centered around providing explanations for the post-1836 narrowing of Turtle Creek's downstream reaches, yet the net widening experienced in the upstream reaches and headwater tributaries may be likewise explained by the same theories. For example, channelization, which has been presented as the cause for the reduction in size of the lower Turtle, was most likely also

the source of tributary widening because it was in the small headwater and tributary basins that most of the wetland drainage took place. This sudden instability imposed on these small basins must have resulted in a widening of the channels due to the diminishment of storage capacity in the basins and an immediate concentration of both low and high runoff discharges into the actual channel. Thus by this process, wetland drainage and channelization must have eventually lowered the water table for the entire watershed, and the repercussions of this reduction in base flow probably became most effective in the main channel and lower reaches of the stream.

The sediment load type theory could also explain some of the tributary and headwater widening because the source of the increased loads downstream was probably partly from upstream scouring of the smaller channels.

A careful examination of Figure 9 indicates that the above conclusions may be quite reasonable. The diagram shows that in 1836 the headwaters and tributaries of Turtle Creek were quite narrow but that the channel began to widen drastically downstream for a drainage area greater than 85 square miles (site 15). The trunk stream continued to increase in width downstream to allow easier transportation of the larger sediment sizes of the outwash and terrace deposits. A narrowing occurred at sites 19 and 20 just below the Clinton gorge because the steep gradient of this
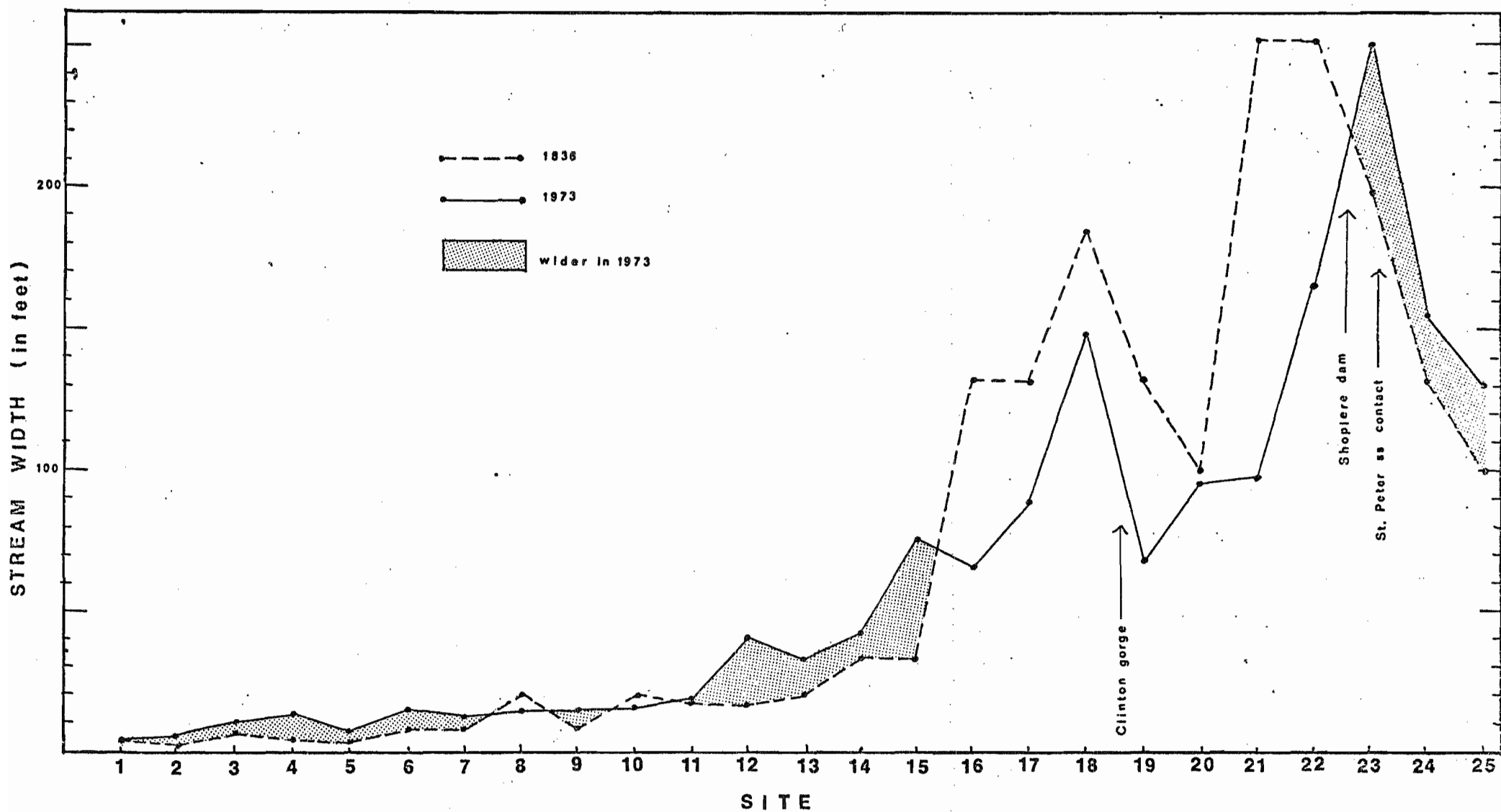
FIGURE 9

Summary of Channel Width Changes

reach no longer neccessitated such a wide and shallow channel
to transport the large sediment load. When the gradient
returned to its gentle character, the stream once more
increased in width to accomodate the mixed and bed load
nature of the channel until a major narrowing of the channel
began again at site 23 and continued to the river's mouth.
The unusual narrowing in the stream's lowermost reaches is
directly related to the effluent-influent transition
mentioned earlier. The contact with the St. Peter sandstone
is located about 1/4 mile downstream from site 23 and this
reach also marks the area in which the fill of the ancient
Rock Valley begins to thicken significantly. Hence the 1836
narrowing below site 23 corresponds with the point at which
the stream began to lose its discharge to a lower ground
water table instead of receiving inputs from the ground
water body.

The downstream trend of the 1973 channel width and its
departure from the 1836 trend may be observed in the shaded
portions between the two curves in Figure 9. At present
the tributary channels for the most part are wider than in
1836 because of locally increased discharges, sediment loss,
and bank collapse instigated by deforestation, cultivation,
and channelization. This widening continues until the trend
is reversed below site 15. The transition at this point seems
to weigh heavily on the fact that site 15 also marks the
transition between tributary and trunk stream sites. However
site 15 itself is located on the trunk stream yet its channel

widened as did the tributaries, while site 16 marks the first occurrence of a narrower channel in 1973. The calculated channel widths derived from the power function equations show in Table 3 that the transition from widening to narrowing theoretically takes place somewhere between a drainage area of 25 to 50 square miles. Figure 9 reveals that the transition actually takes place at a drainage area between about 85 to 90 square miles (sites 15 and 16). It is here that the problems involved in using small tributaries to substitute for the headwaters of the main stream seem to reveal themselves. Based on these measurements, it is impossible to determine whether a certain threshold drainage area holds any significance in pinpointing the exact place at which the stream channel began to narrow in response to land use modifications. Furthermore, such factors as threshold values of sediment load and size, and the local channel gradient may have a more direct control over the transition point than drainage area. Thus a suitable explanation for the position of the transition from a historical widening trend to a narrowing trend cannot readily be offered in this study.

Continuing downstream, in Figure 9, historical narrowing of the channel is evident through site 22. This most likely reflects the reduced base flow and the resulting smaller channel due to channelization's effect of lowering the ground water table. Between sites 22 and 23 another transition takes place wherein the 1973 channel becomes wider than it was in

1836 and remains wider, although compared to upstream reaches
it has narrowed. Here, just as in 1836, the St. Peter
sandstone and the Rock Valley fill have reduced the discharge
due to higher infiltration capabilities, and consequently
the size of the whole channel has been reduced. However the
relative channel width remains larger than that of 1836
because the Shopiere dam may have had an effect in filtering
out sediment and preventing deposition of the excess load
in the downstream channel.

Summary

In summary, the historical changes that took place in
Turtle Creek were instigated by land use modifications
which altered the discharge and sediment regimens of the
river system. It is believed that the post-1836 upstream
widening and downstream narrowing of the channel are closely
linked to the impact of channelization on the basin whereby
immediate concentration of runoff into the tributaries
caused local widening, but the consequent reduction of
wetland storage lowered the ground water table and reduced
overall base flow which in turn resulted in a decrease in
channel size downstream -- detected in this study as a
general narrowing trend.

Conversely, in the Platte River, land use modifications
other than channelization produced the major impact by
increasing discharges and sediment load throughout the basin
thus widening the steep upstream reaches by scouring and

bank collapse, but narrowing the downstream reaches by changing the shape from a generally wide and shallow bed load channel to a narrow and deep suspended load type channel.

The steady state model (Figure 1) presented at the outset of this analysis provides a simple framework in which to summarize these conclusions. The unnatural external input of land use modifications acted upon the independent variables of discharge and sediment load in each basin, affecting the dependent variables within the channel system. Because the physiographies of the basins are different, the altered discharge and sediment regimens generated a different response in each basin. However the dependent variables adjusted themselves within the constraints of their respective physiographies and the steady state or equilibrium condition was achieved.

BIBLIOGRAPHY

Alden, W.C., 1904, The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation: U.S.G.S Prof. Paper 34.

_____., 1918, The Quaternary geology of southeastern Wisconsin: U.S.G.S. Prof. Paper 106.

Beckwith, A.C., 1912, History of Walworth County Wisconsin, Vol. 1: B.F. Bowen and Company, Indianapolis, Ind.

Bleuer, N.K., 1970, Glacial stratigraphy of south-central Wisconsin, in Pleistocene Geology of Southern Wisconsin: U.W. Geol. and Nat. Hist. Survey Inf. Cir, 15, p. J1-J35.

Borman, R.G., compiler, _____, Preliminary map showing thickness of glacial deposits in Wisconsin: U.W. Geol. and Nat. Hist. Survey.

Committee on Government Operations, 1971, Stream Channelization, Part 1, Hearings before a subcommittee of the Committee on Government Operations, House of Representatives, 92nd Congress, 1st session, May 3 and 4: U.S. Government Printing Office, Washington, 388 p.

Conger, D.H., 1971, Estimating Magnitude and Frequency of Floods in Wisconsin: U.S.G.S. Water Resources Div. open file report, Madison, Wisconsin, 200p.

Corcoran, W.T., 1972, River response to deforestation, 1832-1971, Platte River, Grant County Wisconsin: Unpublished Bachelor's thesis, University of Wisconsin, Madison, 47 p.

Cotter, R.D., Hutchinson, R.D., Skinner, E.L., and Wentz, D.A., 1969, Water resources of Wisconsin, Rock-Fox River Basin: U.S.G.S. Hydrologic Investigations Atlas HA-360, sheets 1-4.

Emerson, J.W. 1971, Channelization - a case study: Science, v. 173, pp. 325-326.

Guernsey, O. and Willard, J.F., eds., 1856, History of Rock County, and Transactions of the Rock County Agricultural Society and Mechanics' Institute: Wm. M. Doty and Brothers, Printers, Janesville, Wisconsin.

Hack, J.T., 1957, Studies of longitudinal profiles in Virginia and Maryland: U.S.G.S. Prof. Paper 294-B.

Haszel, O.L., 1971, Soil Survey, Walworth County Wisconsin: U.S.D.A. Soil Conservation Service, 107 p.

Hays, O.E., McCall, A.G., and Bell, F.G., 1949, Investigations in erosion control and the reclamation of eroded land at the Upper Mississippi Valley Conservation Station near LaCrosse, Wis., 1933-43: U.S.D.S. Soil Cons. Service Tech. Bull. No. 973, 87 p.

Hibbert, A.R., 1969, Water yield changes after converting a forested catchment to grass: Water Resources Research, v. 5(3), pp.634-640.

Hornbeck, J.W., Pierce, P.S., and Federer, C.A., 1970, Streamflow changes after forest clearing in New England: Water Resources Research, v. 6(4), pp. 1124-1132.

Knox, J.C., 1970, Stream channel adjustment to physiographic factors in small drainage basins: Iowa and southwestern Wisconsin: Unpublished Doctoral thesis, University of Iowa, 302 p.

_____, and Corcoran, W.T,, 1972, River adjustment to deforestation 1832-1971, Platte River, Grant County, Wisconsin: G.S.A. North-central Division Abstracts with programs, vol. 4, no. 5, p. 331.

Leopold, L.B., and Maddock, T., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S.G.S. Prof. Paper 252.

_____, Wolman, M.G., and Miller, J.P., 1964, Fluvial Processes in Geomorphology: W.H. Freeman and Company, San Francisco, 522 p.

LeRoux, E.F., 1963, Geology and ground-water resources of Rock County, Wisconsin: U.S.G.S. Water Supply Paper 1619-X, 50 p.

Lyon, Orson, 1836, Original land survey notes of southeastern Wisconsin.

Morisawa, M., 1968, Streams: Their Dynamics and Morphology: McGraw Hill Book Co., New York, 175 p.

Onstad, C.A. and Jamieson, D.G., 1970, Modeling the effect of land use modifications on runoff: Water Resources Research, v. 6, pp. 1287-1295.

Patric, J.H. and Reinhart, K.G., 1971, Hydrologic effects of deforesting two mountain watersheds in West Virginia: Water Resources Research, v. 7(5), pp. 1182-1188.

Rothacher, J., 1970, Increases in water yield following clear-cut logging in the Pacific Northwest: Water Resources Research, v. 6(2), pp. 653-658.

Ruhe, R.V., 1971, Stream regimen and man's manipulation, Chapter 1 in: Coates, D.R., ed., Environmental Geomorphology: Publ. in Geomorphology, State Univ. of New York, Binghamton, New York, pp. 9-23.

Schumm, S.A., 1968, River adjustment to altered hydrologic regimen: Murrumbidgee River and paleochannels, Australia: U.S.G.S. Prof. Paper 598.

U.S. Army Corps of Engineers, 1967, Flood Plain Information, Turtle Creek, Rock County, Wisconsin: prepared for State of Wisconsin Dept. of Natural Resources, Div. of Resources Development, 60 p.

U.S. Department of Commerce Weather Bureau, 1965, Climatological Summary for Beloit, Wisconsin 1935-1964.

Whitson, A.R., Geib, W.J., Conrey, G., and Gibbs, W.M., 1922, Soil Survey of Rock County Wisconsin: Wis. Geol. and Nat. Hist. Survey Bull. no. 53B, 80 p.

_____, 1924, Soil Survey of Walworth County Wisconsin, Wis. Geol. and Nat. Hist. Survey Bull. no. 56C, 98 p.

Wischmeier, W.H. and Smith, D.D., 1965, Rainfall-erosion losses from cropland east of the Rocky mountains: Agriculture Handbook No. 282, Agric. Res. Service, U.S. Dept. of Agriculture.

Wolman, M.G., 1955, The natural channel of Brandywine Creek, Pennsylvania: U.S.G.S. Prof. Paper 271, 56 p.

_____, and Miller, J.P., 1960, Magnitude and frequency of forces in geomorphic processes: Jour. of Geol., Vol. 68, No. 1, pp. 54-74.

APPENDIX

Data Collected for this Analysis

Site	Location (township and section lines)	Drainage Area (sq. mi.)	1836 Width (ft.)	1973 Width (ft.)
	line			
1	T1N R13E 1/2	.8	1.9	2.0
2	T1N R13/14E 1/6	1.3	1.3	4.5
3	T1N R13E 1/2	2.2	5.3	9.5
4	T1N R15E 17/20	4.7	3.3	13.0
5	T2N R14E 14/23	5.9	2.6	5.0
6	T1N R14E 35/36	6.5	6.6	14.0
7	T1N R15E 17/18	7.8	6.6	11.0
8	T2N R14E 27/22	8.9	19.8	14.0
9	T1N R15E 18/7	12.2	6.6	14.0
10	T1N R14E 13/14	18.1	19.8	15.0
11	T1N R14E 13/12	21.7	16.5	17.0
12	T1N R15E 6/7	35.5	15.8	40.0
13	T2/1N R15E 31/6	44.9	19.8	32.0
14	T2N R15E 25/36	66.3	33.0	52.0
15	T2N R15E 12/13	84.4	33.0	75.0
16	T2N R15E 10/15	91.4	132.0	48.0
17	T2N R15E 20/17	95.9	132.0	88.0
18	T2N R14E 25/26	189.0	184.0	148.0
19	T2N R14E 29/32	208.1	132.0	68.0
20	T2N R13/14E 31/36	213.4	99.0	95.0
21	T2N R13E 35/36	214.8	251.0	97.0

Site	Location	Drainage Area	1836 Width	1973 Width
22	T1N R13E 2/3	228.0	251.0	165.0
23	T1N R13E 9/8	233.3	198.0	250.0
24	T1N R13E 8/17	237.9	132.0	155.0
25	T1N R13E 19/20	242.8	99.0	130.0

$n = 25$ $n = 25$

$a = 1.27$ $a = 2.58$

$b = 0.88$ $b = 0.69$

$r^2 = 0.51$ $r^2 = 0.53$

$p > .01$ $p > .01$