THE USE OF MEANDER PARAMETERS IN RESTORING HYDROLOGIC BALANCE TO RECLAIMED STREAM BEDS

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The Use of Meander Parameters in Restoring Hydrologic Balance to Reclaimed Stream Beds

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A river or stream is dynamic through time. Change is one of the most common features associated with river and stream channels. In general, this change is very slow, however, and only over long periods of time is it actually noticeable to most individuals. As a result, engineers, ecologists, and others involved with the hydrologic balance of a stream many times treat the stream system as static (i.e. unchanging in shape, slope, or pattern). One only has to observe a favorite fishing stream or pleasure area along a stream to notice that the stream channel itself probably looks slightly different now than it did two or three years previous.

In general, most streams are continually changing position and shape as a consequence of hydraulic forces acting on their beds and banks. This stress is mainly a result of climatic changes from year to year in the amount of water flow variation that occurs in the stream. Over time, the stream system adjusts to this natural variation in flow and develops a pattern which puts the system in a quasi-steady, yet dynamic, situation where only unusual climatic events or human activities may cause rapid changes in the nature of the stream channel morphology (dimensions, shape, or pattern). It should be noted, however, that streams are, in fact, the most actively changing of all geomorphic forms, especially alluvial stream systems. It is the rule rather than the exception that banks will erode, sediments will be deposited, and floodplains, islands, etc., will undergo change with time (Richardson et al. 1975). The problem in all this comes when humans induce change upon the system without taking the necessary steps to restore the quasi-steady situation and thus set in motion a response by the stream system to adjust to this change, which results in the propagated response along great distances from the human-induced action.

In planning and designing stream channel restoration and stream system balance, it is critically important to avoid the geometric stress thresholds of a stream at which dramatic and significant undesirable landscape modifications occur. It is desirable to approximate a range of appropriate stream channel features that will cause the stream system to respond to its natural inclinations (the stream pattern which would exist under normal conditions) as if no human action had occurred. This intervention will result in controlled sediment production and produce a channel similar to the existing stream channel. The end result will be a system where stream habitat should be equivalent to predisturbance and, hopefully, a slight enhancement of habitat and form.

This chapter discusses methods and techniques for restoring a stream channel to its natural inclinations after a human-induced change such as surface mining, road construction, etc. The main emphasis will be on meander parameters and their importance in stream channel stability.

STREAM SYSTEM FACTORS

In spite of the complexity of a stream system, the same basic factors govern the delicate balance of all streams. It is important that stream managers understand and work with these basic natural factors that govern the stream system. These natural factors are (1) geologic, (2) hydrologic, (3) hydraulic, and (4) geometric. Together these factors interact to develop the stream system.

Geologic Factors

Geologic factors influence the nature and amount of sediment production and the development of meanders due to topography and soil conditions. Topography determines overall slope of the area and can be a limiting factor in meander formation as a result of the location of large relief areas (hills) which will automatically change the direction of the stream channel. The abruptness and amount of change will be a characteristic of the soil material. The amount of sediment production will also depend upon the type of soil and general slope of the stream channel.

Hydrologic Factors

Hydrologic factors will influence the variations in flow and runoff and thus the type of meander system developed by the stream. Long-term climatic fluctuations can cause variations in runoff which can cause major changes in a stream's morphology. Along with the soil conditions, the amount and type of vegetation on the landscape will have a great influence on runoff and associated infiltration characteristics. The hydrologic effects of changes in land use can result in major modifications in runoff characteristics and thus the channel morphology. Land use changes could have a dramatic effect on meander characteristics and on morphology in general if not addressed in the reclamation of a disturbed area.

Hydraulic Factors

Hydraulic factors include depth, slope, and velocity of a stream. These factors are the characteristics which directly produce bank cutting, sediment transport, and the like. Hydraulic factors tend to change channel cross-sectional shape, pool and riffle formation, and meander shape.

The hydraulics of flow in streams is complex. Some of the major complications are (a) the large number of interrelated variables (depth, slope, and velocity) in describing the response of natural or imposed changes to the stream system and (b) the continual change of stream patterns and channel geometry with changes in flow and sediment discharge. By changing the slope of a stream, it is possible to change a stream from a fairly stable situation (meandering stream) that has fairly tranquil flow to an unstable situation (braided stream, very dynamic) that has high velocities and carries large quantities of sediment.

Geometric Factors

Geometric factors consist of the channel cross-sectional shape, stream pattern (straight, meandering, or braided) and the pool-riffle pattern that may exist on smaller streams. On many alluvial type streams, significantly different channel dimensions, shapes, and patterns are associated with amount of discharge and sediment load, indicating that changes in these variables can cause significant adjustments to the geometric factors. Perhaps the most exceptional example was the Cimarron River located in southwestern Kansas which was a stream approximately 15 m wide in the late 1800s and into the early 1900s. During the 1930s a series of floods widened the channel to almost 370 m occupying the greater part of the flood plain. By the 1960s, the channel had receded to a width of approximately 150 m (Schumm and Lichty 1965).

The example of the Cimarron River indicates how important it is to understand the many factors involved in the mechanics of a stream system. Artificial changes in a stream, by disturbance of the stream channel through mining or placement of flood control structures, can have far-reaching impacts on the stream system for many kilometers upstream and downstream of the disturbance. It is important to study all the factors whenever artificial disturbance of the stream is to take place and to avoid the critical stream system stress threshold factors which produce dramatic and significant channel modifications.

MEANDERS

Stream patterns can be broadly classified as straight, meandering, braided or some combination of these classifications (Leopold and Wolman 1957). Straight and meandering stream sections are considered reasonably stable. A combination of discharge, slope, and suspended sediment load generally determines the type of stream pattern (Leopold and Wolman 1957, Chitale 1970, Skinner 1971, Schumm

1977). As pointed out by Chitale (1970), straight and meandering refer to direction changes while braiding refers to multiple channels. Thus, streams are more appropriately grouped into single or multiple channels with single channels further divided into straight or meandering. Multiple channels are comprised of braided channels and alluvial fans. Braided channels are generally straight unless constrained to a winding path by valley walls. The categories are not unique, for a stream can possess characteristics of straight, meandering, and braided in different reaches of its course. The division between meandering (nonstraight) and straight is arbitrary

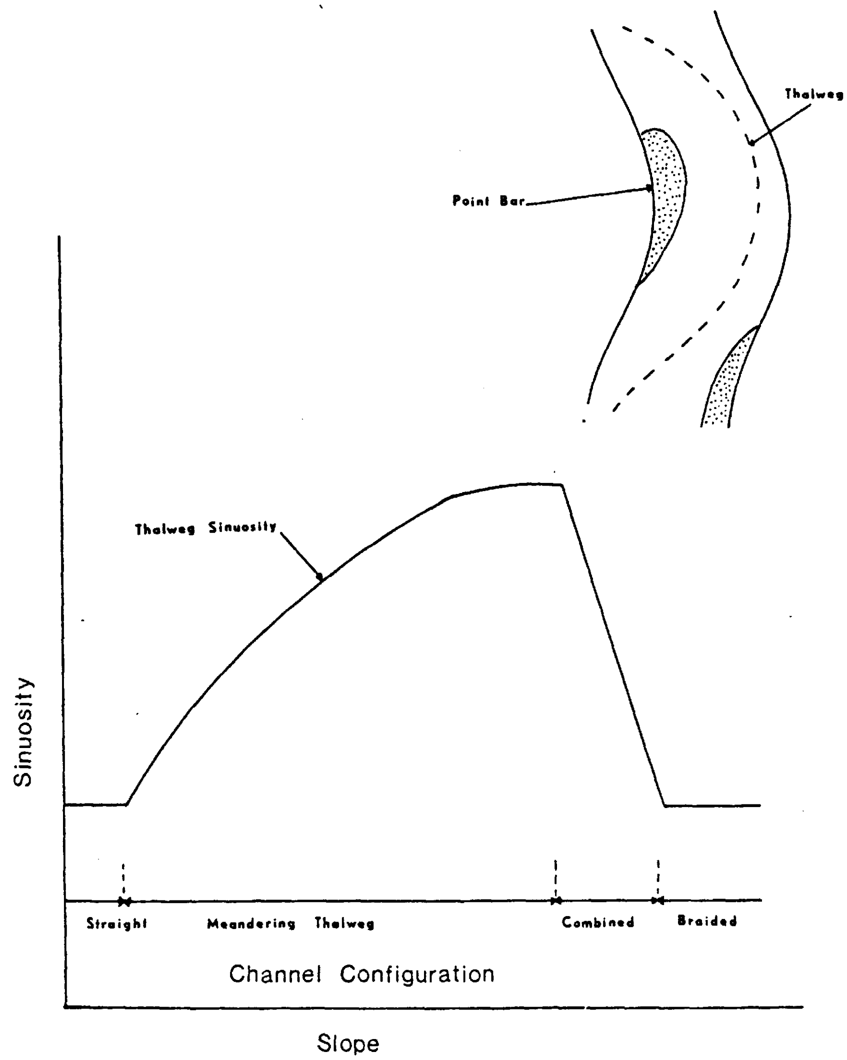


Figure 2.1 Sinuosity vs. slope with constant discharge. After Richardson et al. 1975.

but Leopold et al. (1964) designated single channels with sinuosities, a term to be defined later, greater than 1.50 as meandering where an absolutely straight channel would have a sinuosity of 1.00. Figure 2.1 illustrates differences between meandering and straight channels. Langbein and Leopold (1966) found 10 times the stream width to be the maximum length a natural stream will adopt a straight course.

The term *meander* comes from the word *miandras*, the name of a tortuous stream in Turkey which is known today as Menderes (Langbein and Leopold 1966). The term is generally used to cover all nonstraight, single channels although Matthes (1941) restricted the definition to regular S-shaped waveforms. Lane restricted the definition to include geologically uncontrolled waveforms in unconsolidated alluvium (Skinner 1971). The more general definition of meandering as nonstraight single channels, modifying the word with appropriate adjectives as necessary will be used herein.

The adjective *free* refers to meanders occurring in unconsolidated alluvium (water-deposited material) free to migrate and develop waveforms without constraints from valley walls (geologic factors), terrain, or significant distortion from heterogeneous alluvium (Carlston 1965). Ideal uniform meanders established in flume experiments approximate a natural free meander. A related term is *alluvial river* defined by Schumm (1977) as a river free to adjust its river pattern, hydraulic dimensions, and slope flowing in a channel composed of material presently carried by the river (designated as an alluvial channel). Care must be exercised in using the term *alluvial channel* because of the present turmoil associated with the similar sounding term *alluvial valley floor*, which has a statutory definition.

Other modifiers for categorizing meanders are regular or irregular, simple or compound, and meander bends (curves) that are acute (hairpin) or flat (Chitale 1970) (see Fig. 2.2). *Regular* meanders are composed of bends with uniform curvature and spectral wavelengths (defined later) and if spectrally analyzed as a time series, the meandering would possess a single frequency. Langbein and Leopold (1966) observed that the appearance of meander regularity depends upon the constancy of the ratio of wavelength to radius of curvature. *Irregular* meanders are deformed in shape and may have a varying meander belt width (defined later) and/or wavelength. Terrain, nonhomogeneous alluvium, variable discharges from tributaries, or water loss to permeable strata (stream system factors) may be responsible for stream meander irregularity.

Simple and regular meanders are similar. However, the term *simple* is a more appropriate antonym for compound. *Simple* meanders have one dominant meander belt width and wavelength. *Compound* meanders may originate on streams with more than one dominant discharge. A similar situation occurs with misfit streams. There are cases of meandering valleys containing meandering streams with shorter wavelengths than the valley. The stream is described as *underfit* by geomorphologists with the implication that: (1) there is a definite physical (not merely statistical) relationship between stream discharge and meander wavelength, (2) the valley meanders were formed by a former layer stream, and (3) something caused a significant stream size reduction. The cause for the discharge change is

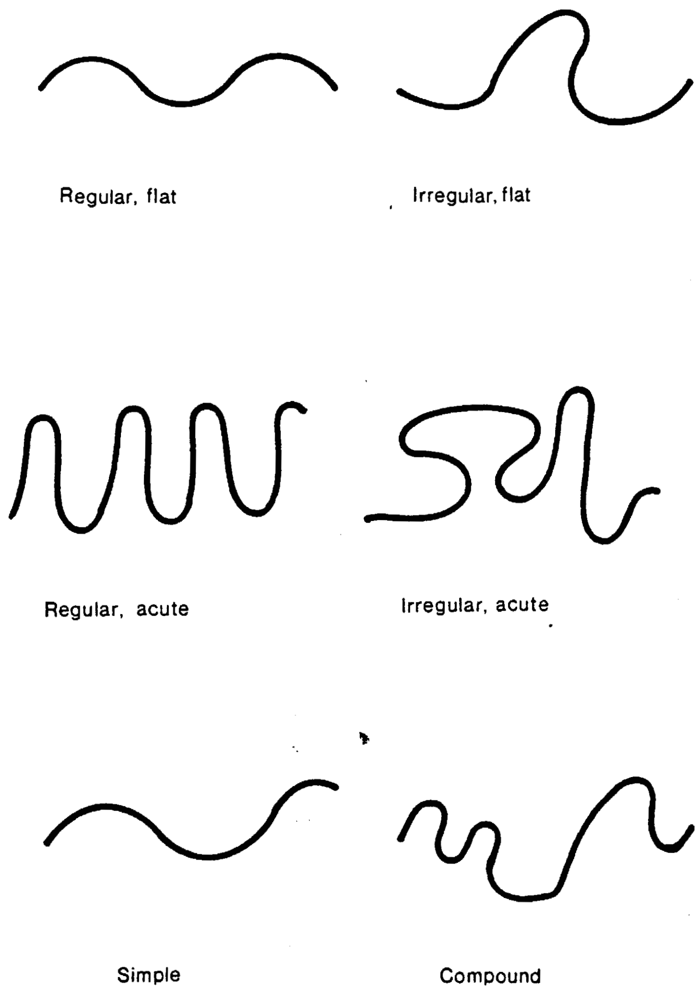


Figure 2.2 Basic meander patterns. Adapted from Chitale 1970.

most likely climatic though stream capture is possible (Dury 1965). Consequently, a compound meander would be a complex shape requiring two or more ideal constant discharges to form. By definition, the *dominant discharge* is the appropriate constant discharge that would be equivalent in developing the present channel shape which was formed from the variable flow of a natural river (Henderson 1966). Determining the most appropriate dominant discharge value for the type of stream under study is difficult. The flow may be hypothetical (such as a two-year recurrence flood) or actual (such as bankfull discharge, the discharge at which a stream first overflows onto its flood plain).

Meander Parameters

In selecting parameters to quantify the meander shapes, wavelength, sinuosity, radius of curvature, and peak to peak amplitude or meander belt width are often used. Figure 2.3 is a definition sketch of the stream parameters most commonly used to describe meanders.

Wavelength has been described as: (1) twice the linear distance between successive inflection points (Leopold and Wolman 1957; Dury 1965), (2) twice the arc distance between two successive inflection points, and (3) the reciprocal of the dominant frequency from spectral analysis (Speight 1965; Ferguson 1975). In this chapter, the first definition will be called *linear wavelength* (λ_1), definition two, the *meander length* (M_1) or band length when referring to one-half of the meander length, and the third definition, *spectral wavelength* (λ_s). When unmodified, wavelength refers to the general concept.

There are advantages and disadvantages to each definition. Comparing linear wavelength (λ_1) and meander length (M_1), the meander length may be intuitively more meaningful a parameter for relating to the actual flow hydraulics since the fluid actually traverses this distance. For linear wavelength, the orientation of the measured line between two successive inflection points may differ significantly

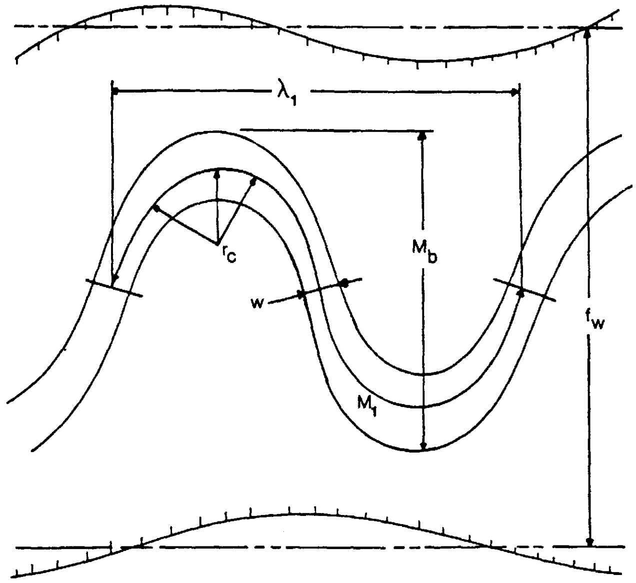


Figure 2.3 Definition sketch of meander terms. λ_1 = linear wavelength, M_1 = meander length, W = channel width measured at crossing (inflection point), M_b = meander belt width, f_w = flood plain width (belt of meandering), r_c = radius of curvature (= ρ, in text).

from the local or regional stream flow direction (Ferguson 1975; Speight 1965).

Meander pattern irregularity complicates the estimation of linear wavelength (λ_l) and meander length (M_l). The investigator must locate a representative, fairly symmetrical meander loop or average over many meander loops. The spectral wavelength (λ_s) is determined using all meander loops in an entire reach and thus eliminates some inherent disadvantages of linear wavelength and meander length. Meanders smaller or larger than a subjectively chosen representative meander are not assumed to be atypical nor does a fairly normal distribution of meander loops have to be assumed for averaging to represent the dominant wavelength.

Spectral wavelength (λ_s) also has the advantage of repeatability. While a skilled researcher could be consistent and reliable in the linear wavelength or meander length determination, two individuals may differ in technique.

Sinuosity or tortuosity (P) is a parameter that also has several definitions. Leopold and Wolman (1957) defined sinuosity as the ratio of stream length or thalweg (lowest thread or deepest part along the flow channel) length to valley length (equivalent to the ratio of valley slope to stream slope). Friedken (1945) defined sinuosity as the ratio of thalweg distance to arc distance. Leopold and Wolman (1966) also used the ratio of arc distance (meander length, M_l) to linear wavelength. For a uniform meander, the definitions are equivalent but irregularity introduces complications. In this chapter, the sinuosity ratio (P) will be as defined by Friedkin because it eliminates the subjectiveness in obtaining valley length or visual wavelength measurements and is easier to program for the computer.

Goodman (1974) defined the *radius of curvature* (ρ) as:

$$\rho = \frac{\left(1 + \left(\frac{dy}{dx}\right)^2\right)^{3/2}}{\frac{d^2y}{dx^2}} \tag{2.1}$$

Equation 2.1 cannot be used for several numerical reasons. First, a derivative requires a single valued function which is not always obtainable for a naturally meandering stream. However, a complex computer program could possibly break the stream into single valued segments. Next, the derivatives must be calculated by numerical differentiation, an inaccurate process. These initial errors are compounded after squaring, cubing, and taking the square root of the first derivative and then dividing by the second derivative. Consequently, the radius of curvature at each point along the stream can be approximated by the radius of a circle which passes through one point and two nearby points. This approximation is similar to that employed by Leighly (1936) and Brice (1973) when circles of various radii were visually fit to mapped meander loops.

The final parameter, *meander belt width* (M_b), is defined as the normal distance between tangents drawn on the convex sides of successive bends (Fig. 1.3). The definition of a free meander stipulates that the width of the confining terrain or consolidated strata be greater than the meander belt width. Meander belt width differs from the peak to peak amplitude of a waveform by the channel width. The technical difference is insignificant and the terms are often used interchangeably. While *meander belt* connotes a region, the term is often used as a synonym of *meander belt width* by geomorphologists. A related term is the *flood plain width* (f_w) or *belt of meandering* which is the approximate width of the stream's valley.

Other Parameters

A few hydrologic and hydraulic parameters are sometimes used to correlate with meander parameters. The main parameters to be used are drainage area (A_{drain}), stream bankfull width (W), discharge (Q), sediment load index (M), stream gradient (S_{ch}), and depth of flow (d). Drainage area and discharge are values which are easily understood and defined.

Stream bankfull width (W) (also defined as indicated on Figure 2.3) is the width where the maximum change in slope of the channel cross section occurs or where the first significant break in slope occurs.

Sediment load index (M) is determined by bed and bank soil samples. The sampling depth should be less than 10 inches and a sample obtained from the bed, bank, and flood plain or first terrace at each cross section considered in a given stream reach. For the minus 200 fraction of soil in the sample, a sediment load index value is determined using Schumm's (1960) equation:

$$M = \frac{C_{bed}\,(W) + C_{bank}(2d)}{W + 2d} \tag{2.2}$$

where

C_{bank} = silt and clay percentages in channel banks
C_{bed} = bed silt and clay percentages

For M to be a valid index, the stream must be stable and alluvial such that the exposed channel consists of material currently being transported.

Stream gradient (S_{ch}) is the change in elevation divided by the channel length between two particular points making up the stream reach. Stable drainages generally exhibit a decreasing slope in the downstream direction. The rate of decrease is most profound near the headwaters of the stream.

The *channel depth* (d) is defined as the maximum depth occurring in the cross-section of the channel. In most streams, this value is slightly greater than the hydraulic depth which is the cross-sectional area divided by the surface width.

Meander Parameter Relationships

Lane (1955), Leopold and Maddock (1953), Santos-Cayudo and Simons (1973), Schumm (1971), and Rechard and Hasfurther (1980) found a number of general relationships between meander parameters, hydrologic parameters, and hydraulic parameters in streams. Some of these relationships are:

1. Depth is directly proportional to discharge and inversely proportional to the bed material discharge.
2. Channel width is directly proportional to discharge and to sediment load.
3. Channel shape (width depth ratio) is directly related to sediment load. This is not true of ephemeral streams, however (Rechard and Hasfurther 1980).
4. Meander wavelength is directly proportional to discharge and to sediment load.
5. Gradient is inversely proportional to discharge and directly proportional to sediment load and grain size.
6. Sinuosity is proportional to valley slope and inversely proportional to sediment load.

These qualitative relationships should give some idea of the response a stream would have to changes imposed upon it. Richardson et al. (1975) have developed a table (Table 2.1) which indicates the response of alluvial channels to change in magnitude of different hydrologic and hydraulic factors.

Lane (1955) suggested that for a stream channel to be stable, water discharge (Q) and slope (S_{ch}) must be proportional to sediment load (Q_s) and bed material size (d_s):

$$QS_{ch} \propto Q_s d_s \tag{2.3}$$

Assume, now, that mining occurred through a stream channel and that the reconstructed stream had an increased slope due to removal of a number of meanders. If water discharge and bed material size are more or less the same after reconstruction, then equilibrium status will have to be achieved by increased sediment load. Once this sediment load is delivered downstream of the mine area, a similar adjustment would have to result in the receiving area in terms of deposition. Equation 2.3 is a true relationship and should be considered in all cases of reclamation design. Meanders must be designed into the reconstructed stream channel so that slope along with discharge and bed material size are not altered significantly from preimpact conditions.

A number of studies have been conducted in order to develop general relationships between measurable hydraulic and hydrologic conditions and meander parameters. Leopold and Wolman (1957) developed relationships for meander length (M_1) and radius of curvature (ρ) in terms of channel width:

$$\rho = 2.42\ W \tag{2.4}$$

and

$$M_1 = 10.9\ W^{1.01} \tag{2.5}$$

Table 2.1 Qualitative response of alluvial channels.

Variable		*Change in Magnitude of Variable*	*Effect on*						
			Regime of Flow	*River Form*	*Resistance to Flow*	*Energy Slope*	*Stability of Channel*	*Area*	*Stage*
Discharge	(a)	+	+	M → B	±	−	−	+	+
	(b)	−	−	B → M	∓	+	+	−	−
Bed-Material Size	(a)	+	−	M → B	+	+	±	+	+
	(b)	−	+	B → M	−	−	±	−	−
Bed-Material Load	(a)	+	+	B → M	−	−	+	−	−
	(b)	−	−	M → B	+	+	−	+	+
Wash Load	(a)	+	+		−	−	±	−	−
	(b)	−	−		+	+	±	+	+
Viscosity	(a)	+	+		−	−	±	−	−
	(b)	−	−		+	+	±	+	+
Seepage force	(a)	Outflow	−	B → M	+	−	+	+	+
	(b)	Inflow	+	M → B	−	+	−	−	−
Vegetation	(a)	+	−	B → M	+	−	+	+	+
	(b)	−	+	M → B	−	+	−	−	−
Wind	(a)	Downstream	+	M → B	−	+	−	−	−
	(b)	Upstream	−	B → M	+	−	−	+	+

Source: Adapted from Richardson et al. 1975 where W is measured in feet. Leopold and Miller (1956) found that meander length could also be correlated to drainage area. Based on studies in New Mexico, the relationship is:

$$M_1 \ \alpha \ A_{drain}^{0.395} \tag{2.5}$$

where $A_{\mathbf{drain}}$ is measured in square miles. Dury (1964) found that meander length could also be expressed as:

$$M_1 = \frac{Q_m^{0.48}}{M^{0.74}} \tag{2.7}$$

where Q_m is the mean annual flood (in cubic feet per second) and M is given by Equation 1.2. Divis (1982) developed another equation for meander length for ephemeral streams, in the Powder River Basin of Wyoming, which included factors of drainage area, channel slope, and elevation difference.

Schumm (1977) related sinuosity (P) to sediment index for alluvial rivers of the Great Plains as:

$$P = 1.38 \ M^{0.17} \tag{2.8}$$

Rechard and Hasfurther (1980) found that, for ephemeral streams in Wyoming:

$$P = 0.94 \ M^{0.25} \tag{2.9}$$

Rechard and Hasfurther also found a relationship for radius of curvature for ephemeral streams. Bhowmik and Stall (1979) developed a relationship between sinuosity and drainage area for the Kaskaskia River in Illinois.

The above studies indicate that relationships do exist between meander parameters and other hydrologic and hydraulic parameters. However, a consistent set of relationships which could be used in the design of reclaimed streams does not exist for large numbers of streams and widely varying conditions. The studies also indicate that meander patterns are important to stream stability and, as a result, should be included in design of reclaimed or disturbed channels.

Studies by Leopold and Wolman (1966), Rechard and Hasfurther (1980), and Divis (1982) suggest that meanders have a fundamental wavelength masked by secondary wavelengths resulting from geologic and hydrologic influences. Divis (1982) proposed that these fundamental wavelengths tend to be related by integers of 2 progressively replaced by a higher multiple downstream. A determination of the fundamental wavelength, then, will be important in design of reclaimed channels.

MEANDER DESIGN

Fluvial morphologists have identified meandering as a primary means of dissipating excess stream energy (Leopold and Wolman 1957; Schumm 1977). Therefore, meandering is a potential design technique to stabilize channels. One proposed method of recreating an appropriate meander channel pattern is to replace the meander exactly as found before disturbance, *the carbon copy technique.* While the technique does have its merits, it is based upon several assumptions which are not always applicable. First, the stream pattern before disturbances is assumed stable and appropriate. Second, the factors affecting stream patterns are assumed to have identical values after stream restoration. However, not all potentially disturbed stream reaches are currently stable nor do all influential factors such as bed and bank material remain constant.

A second method involves the use of *empirical relationships* which are generally not exacting and apply to small geographic regions. The extrapolation of these equations is questionable and potentially misleading. For example, when examining the hydraulic geometry of ephemeral channels in the eastern Powder River Basin, Apley (1976) found very little correlation of bed and bank material to the width/depth ratio in contrast to Schumm's (1977) findings in the Great Plains. While Apley's study did not examine meanders, it did suggest different factors were important to Powder River Basin streams than were found by Schumm for the Great Plains streams. The "regime" equations of Lacey (1930), Blench (1957), and Simons and Albertson (1960) also fall into the empirical category and are strictly engineering-oriented for artificial channels, more than for natural channels. Bhowmik (1981) gave a variation of the regime theory in trying to consider geomorphic principles.

A third method could be classified as a *natural* approach. A valley is created with the reclaimed material and the intent is to allow natural processes to take over and form their own channel and drainage basin morphology. The disequilibrium associated with this approach would cause many more problems than it could possibly solve.

A fourth approach (and the one suggested for use) is a *systems* approach which includes meander analysis and an evaluation of the geomorphology of the disturbed area and its effect on the surrounding undisturbed areas. Lidstone (1982) suggested a similar approach in designing stream channels.

MEANDER ANALYSIS

A natural stream channel is generally constrained to some extent by the geology of the area in terms of relief, slope, and soil material. When the valley area is disturbed and the soil material replaced, a somewhat different relief will exist and the disturbed material will become relatively homogeneous in character. Many of the minor geologic controls, which cause small irregularities in the meander

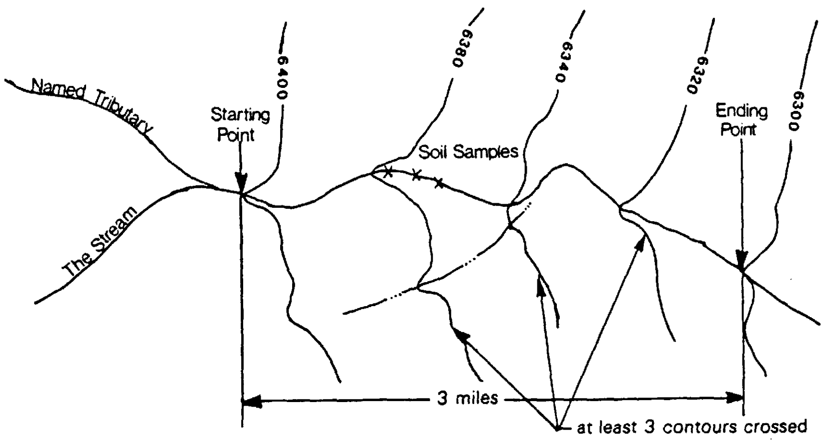


Figure 2.4 A typical stream meander reach and measurements required for Fourier analysis.

pattern, will be removed. The stream channel in the reclaimed area will tend more towards a fairly regular meander pattern which should be characteristic of the fundamental meander wavelength existing before disturbance. Langbein and Leopold (1966) and Rechard and Hasfurther (1980) have demonstrated the existence of these fundamental meander wavelengths. To reclaim the "carbon copy" channel after disturbance would have little purpose since the minor controls have been removed and some new controls created.

The methodology proposed here is to perform a basinwide analysis of the stream channel to determine the fundamental wavelength, mean radius of curvature, and meander belt width in areas determined to be reasonably free of geologic control. These same areas should have measured sinuosity, channel width and depth, and soil bed and bank analysis. Leopold and Wolman (1957), Divis (1982), and Rechard and Hasfurther (1980) have suggested a method of analysis using Fourier analysis of angular departures of a direction of angle transform. This transform involves determining the angular displacement of a given channel segment from the mean valley direction of the channel or another appropriate direction. The angular displacement is plotted as a function of distance along the channel and results in a plot which is appropriate for Fourier transform analysis. Rechard and Hasfurther (1980) and Divis (1982) have developed digitization techniques which allow for quick computation and plotting of the appropriate meander parameters. U.S. Geological Survey 7.5 minute quadrangle maps are appropriate for use with the digitization procedure. At least three stream reaches should be analyzed.

Figure 2.4 displays a typical stream reach while Figure 2.5 shows the analysis of a given reach with the results of the Fourier analysis. The radius of curvature used should be the mean value for the entire plot. Divis (1982) has interpreted the analysis in the following manner:

> The dominant peak of the amplitude plot does not necessarily coincide with the dominant visual wavelength as determined in map view. This effect is readily explained

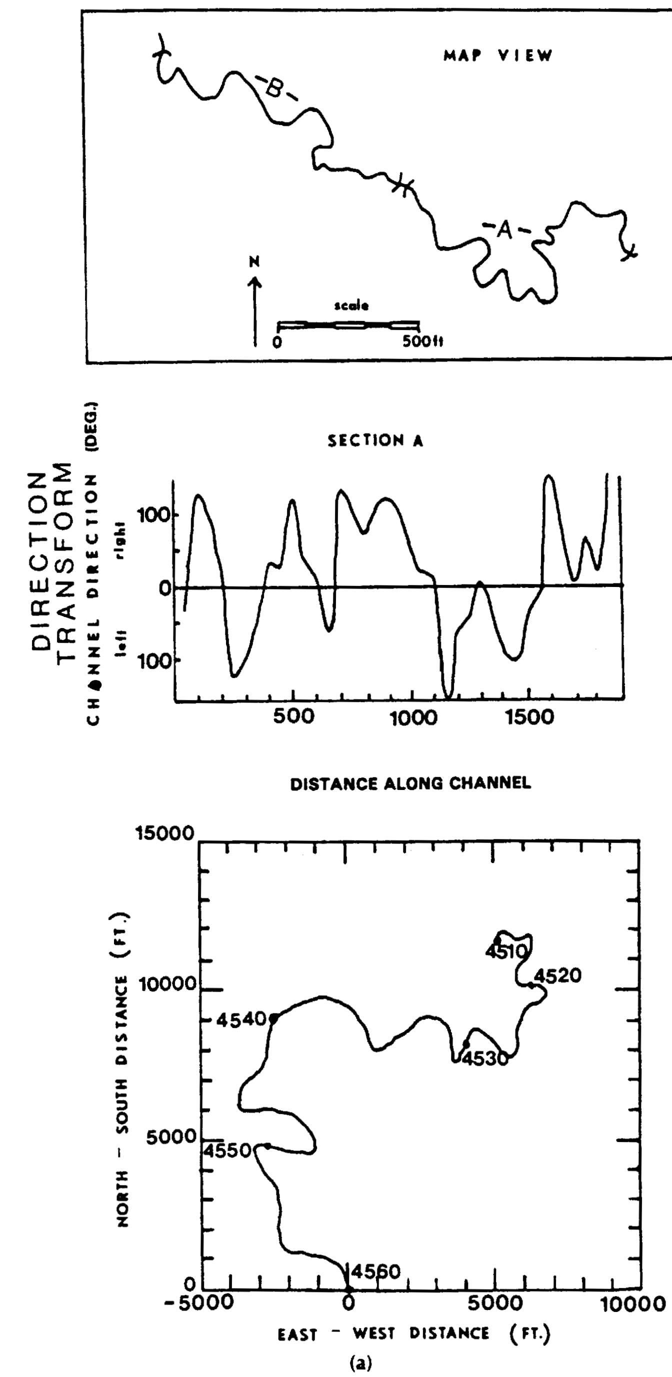
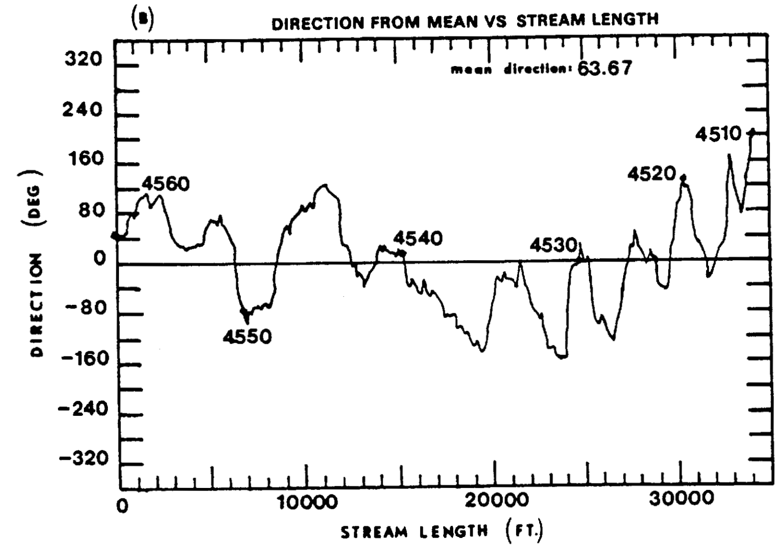
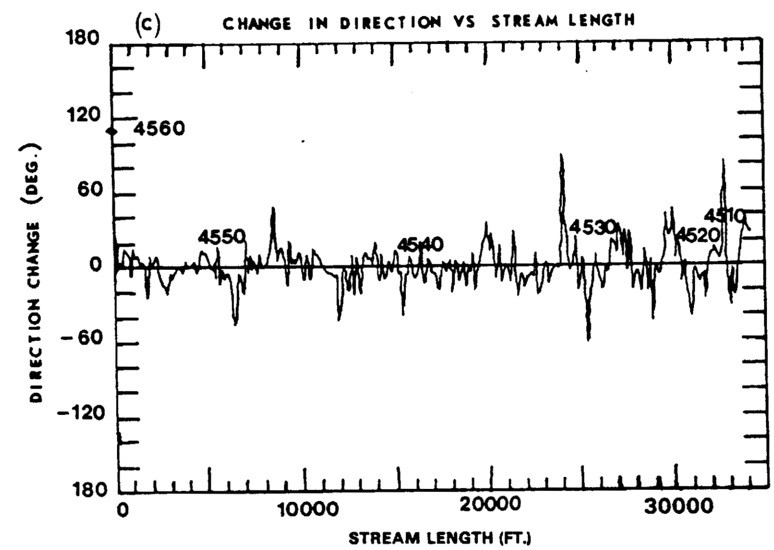


Figure 2.5 Typical Fourier analysis. From Divis 1982.



(b)



(c)

Figure 2.5 (*Continued*)

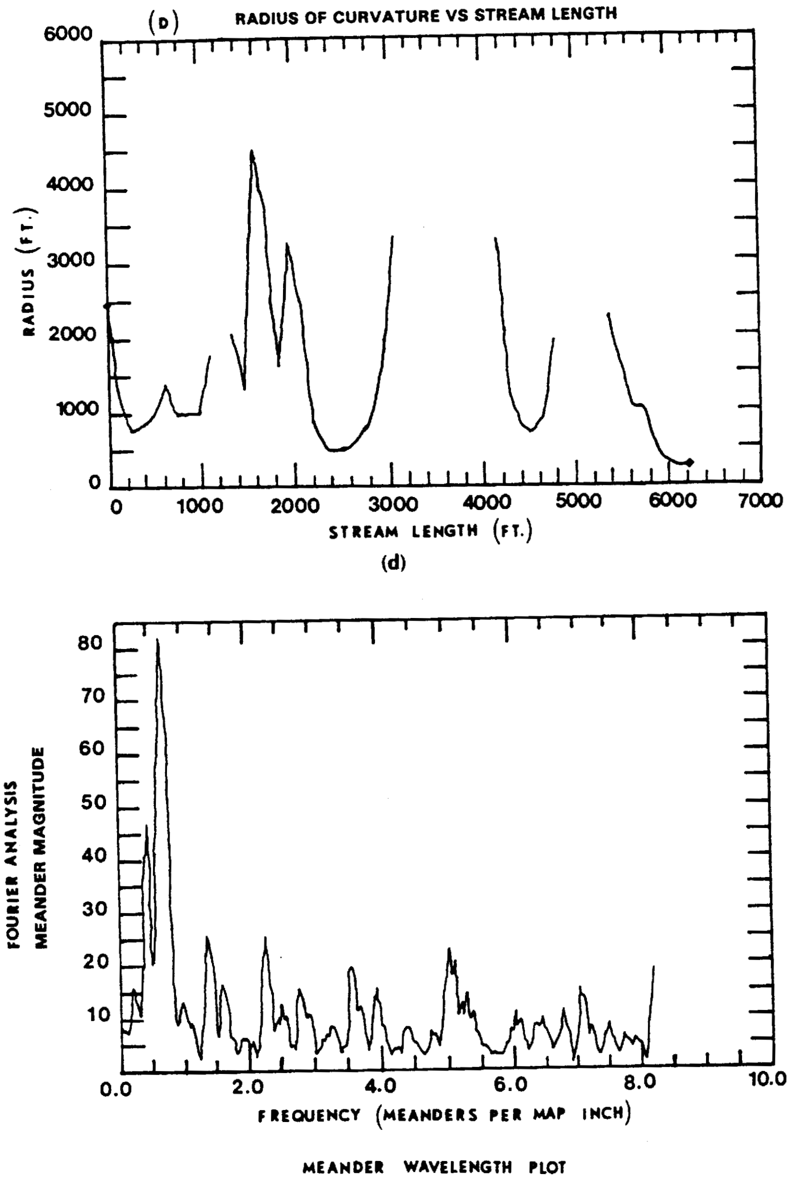


Figure 2.5 (*Concluded*)

> by an examination of the operation of the Fourier transform function. In a combination of several superimposed wavelengths the lower wavelength, or lower frequency, tends to dominate the spectral plot because a greater portion of the data set contains a portion of the long wavelength signal thus, it would not be unusual to expect a fundamental wavelength which is also the dominant visual wavelength to be masked in part by lower and higher order harmonics, particularly lower order harmonics. This effect may be resolved by comparison of several different analyzed sections of a channel and intercomparison of transform angle data and wavelength and amplitude frequency plots. Although some care is necessary interpreting the products of the Fourier analysis it is generally possible to locate the dominant meander wavelength.

If a small regional analysis by the Fourier analysis has been performed, the regional relationships should give values close to the individual basin analysis. This should help in those instances where the design methodology and equipment are not available to the individual designer.

Design Considerations

The use of the fundamental wavelength, mean radius of curvature, gradient restoration (to the same slope as preceded by the disturbance), width, sinuosity, and meander belt width should be used together to develop a stable meander pattern for the entire reach if soil conditions are considered to be approximately the same as predisturbance. If this is not the case, then some adjustment to the pattern should be made with Equation 2.3 as a guide to the action to be taken. Short-term characteristics such as vegetation establishment and slightly higher runoff directly after disturbance should not be considered in the main design. However, short-term solutions (sediment traps or small ponds on tributaries) to handle increased sediment load should be considered until vegetation can be reestablished on the disturbed watershed. The result should be a stable reclaimed section after a short period of time with little effect on the undisturbed portion of the stream and watershed.

Divis (1982) recommended that an inner or pilot channel be constructed with characteristics to hold the mean annual flood. Pool and riffle patterns with an optimum spacing of six times the channel width are suggested for this pilot channel (Leopold et al. 1964). A flood plain should be provided upstream of the pilot channel.

It cannot be overemphasized that the reclamation of a stream is a very delicate process which is complicated by a large number of variables. All stream system factors need to be examined before and after reclamation. If the reclaimed stream channel design has zones of instability, these should be analyzed and corrective measures taken as soon as possible. The newly designed and constructed stream channel will have a period of self-adjustment early which should display only local effects. Gore and Johnson (1980) observed such local effects on reclaimed coal-surface-mined rivers in Wyoming. The ultimate effect, however, will be a hydrologically stabilized channel with controlled sediment deposition and transport, and flow characteristics adequate for the establishment of habitat enhancement structures for aquatic biota.

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