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Floodplain Styles of the Lower Pánuco Basin, Mexico

Paul F. Hudson

*Department of Geography
University of Texas at Austin*

Abstract

Floodplains exhibit a variety of styles because of the dominance of specific fluvial processes. This study examines the spatial diversity of floodplain styles in the lower Pánuco basin, a large river system that drains east-central Mexico and empties into the Gulf of Mexico at Tampico, Tamaulipas. Changes in mean stream power ($W m^{-2}$) and surficial floodplain environments are considered for distinct valley segments. Valley width and channel width increase downstream, although lithologic controls result in the floodplain width being highly variable. Mean stream power decreases from 375 ($W m^{-2}$) in the Río Moctezuma valley in the upper portions of the coastal plain, to 14 ($W m^{-2}$) in the lower reaches of the Río Pánuco. Channel deposits are more significant to floodplain construction in the upper coastal plain. In the lower Moctezuma the valley width abruptly increases and floodplain gradient decreases, which results in a more diverse suite of floodplain deposits. In the lower Pánuco valley overbank processes characterize the floodplain, which is manifest as wide natural levees and large backswamp basins.

Key words: *Pánuco basin, Mexico, floodplain style, stream power*

Resumen

Las llanuras de inundación presentan una variedad de estilos de acuerdo con los específicos procesos fluviales. Este estudio examina la diversidad espacial de los estilos de la llanura de inundación dentro la cuenca baja del río Pánuco, un sistema fluvial grande de drenaje del centro-este de México que sale al Golfo de México cerca Tampico, Tamaulipas. Cambios en el poder medio de la corriente ($W m^{-2}$) y la superficie de la llanura de inundación son analizados en distintos sectores del valle. La anchura del valle y del canal del río aumentan río abajo, aunque los controles litológicos resultan en una anchura muy variable. El poder medio de la corriente se disminuye de 375 ($W m^{-2}$) en el valle del río Moctezuma, río arriba, a 14 ($W m^{-2}$) en los tramos bajos del río Pánuco. Los depósitos del canal son más importantes en la construcción de la llanura de inundación en la planicie costanera superior. En el río Moctezuma abajo la anchura del valle se amplía abruptamente y el declive de la llanura se disminuye, lo que trae como resultado una serie de depósitos aun más diversa. En el río Pánuco abajo, la llanura de inundación se caracteriza por los procesos "overbank", (inundación), que se manifiestan como anchos diques y cuencas pantanosas.

Palabras clave: *cuenca del Pánuco, México, tipos de llanuras de inundación, potencia del corriente*

Introduction

Rivers are important components of coastal plain settings. The alignment

and orientation of large coastal plain river systems provides structure and form to a subtle landscape by incising into Pleistocene and Tertiary surfaces. Coastal plain river valleys commonly include meandering rivers having broad floodplains (Thornbury 1965, Walker and Coleman 1988). Although floodplains are often considered homogeneous surfaces, they usually include a variety of distinctive floodplain environments (Figure 1). The relative proportion of these environments provides insight into the significance of specific fluvial processes to the floodplain landscape.

Figure 1. Principal floodplain deposits of a meander belt. The combination and proportion of individual floodplain deposits within an alluvial valley is dependent on the dominant fluvial processes, and determines the floodplain style. After Saucier 1994.

Although having received much less attention than its U.S. counterpart, Mexico's Gulf Coastal Plain includes several large river systems (Hudson 2000, Hendrickson *et al.* 2003). In addition to flowing within a narrower coastal plain, these river systems differ from U.S. coastal plain fluvial systems because of the influence of adjacent large mountains, and because of their tropical climatic regime. The Pánuco is a large basin in eastern Mexico that drains into the Gulf of Mexico at Tampico, Tamaulipas (Figure 2). River valleys within the lower Pánuco basin have a diverse suite of floodplain environments. This study examines the variability in floodplain styles within the lower Pánuco basin. The study area extends from the upper portions of the coastal plain, where the river exits the mountains, to the Gulf of Mexico.

Controls on Floodplain Styles

Floodplains are mosaics of depositional environments constructed by distinct fluvial processes that can be categorized as either vertical or lateral accretion (Wolman and Leopold 1957). Vertical accretion floodplain construction occurs due to flood

Figure 2. Major Mexican Gulf Coastal Plain river systems, and the Pánuco drainage network. The study area includes the Lower Río Moctezuma (#2) and the Río Pánuco (#1).

sedimentation and tends to be associated with low energy environments. Floodplain construction by lateral accretion processes occurs as a river migrates across its valley. The major floodplain environments created by flood processes include natural levees and backswamps. Natural levees form ridges of coarser sediments aligned along the river channel, sloping toward lower lying backswamps that consist of clayey sediments (Russell 1939, Kolb 1963, Brierly *et al.* 1997). The juxtaposition of natural levees and backswamps may provide several meters of relief in a large river valley, which is significant within the context of floodplain hydrology (Russell 1939, Cazanacli and Smith 1998). Crevasse channels incise into older floodplain deposits during extensive flood events and may result in several meters of relief. Point bar deposits are the single largest type of floodplain deposit constructed by lateral accretion processes and are linked to channel migration and the planform geometry of meander bends (Wolman and Leopold 1957, Allen 1965). On the floodplain surface point bars are topographically manifest as arcuate meander scroll topography (ridge and swale), providing only minor floodplain relief (Hicken and Nanson 1975).

The concept of a floodplain style integrates river channel morphology and dynamics with floodplain deposits, and emphasizes the interrelationships between these fundamental elements of alluvial valleys. A change in the proportion of individual floodplain environments (e. g. Figure 1) within a river valley produces different floodplain styles and, therefore, represents a change in the dominance of specific fluvial processes (Nanson and Croke 1992). At the watershed-scale, streamflow and sediment regime are the major controls and vary due to the input of tributaries draining varying surficial (physiographic, lithologic, land use–land cover) and climatic settings. At the scale of a

river valley heterogeneous lithology and structural controls may alter the valley gradient and valley width, or result in older deposits being reworked and assimilated into the active channel and floodplain.

During the past couple of decades there has been a concerted effort by geomorphologists to integrate a stronger physical basis for understanding the mechanics of fluvial systems. In part this has been in response to criticism of purely empirical approaches that, while often being successful at establishing relationships between various components and processes of fluvial systems, often relied on surrogates for actual physical mechanisms (Knighton 1998). The use of stream power concepts represents a deterministic approach to consider the influence of potential energy expenditure on river systems, and is generally seen as a more rigorous approach for understanding linkages between fluvial forms and processes (see Graf 1983, Rhoads 1987, Magilligan 1992, Lecce 1997). Total stream power is defined as $\Omega = \gamma Q_{bf} S_e$, and is expressed in watts per meter (W m^{-1}). Q_{bf} is the bankfull discharge in cubic meters per second (m^3/s), and is utilized because of its geomorphic significance. Within a humid setting Q_{bf} is generally considered to represent the discharge magnitude that controls floodplain and river channel morphology (Leopold *et al.* 1964). S_e (m/m) represents the hydraulic gradient at bankfull stage, or the slope of the valley. When using valley slope for hydraulic calculations it is important that the surface represent the active floodplain surface, which is morphologically related to the modern streamflow regime. W_{bf} is the bankfull channel width (m), whereas γ is the weight of water, defined as $\mu\varrho$, where ϱ is equal to the density of clear water (1000 kg/m^3) and μ is the rate of acceleration due to gravity (9.81 m s^{-2}). Mean stream power is equal to $\omega = \Omega/W_{bf}$, expressed in watts per square meter (W m^{-2}). Thus, mean stream power becomes independent of drainage area and allows comparisons in stream power to be made between river basins varying in size and physical setting. Because the parameters for calculating stream power include streamflow and valley slope (floodplain slope), the concept is an effective means to integrate local- and watershed-scale controls into a single fluvial index.

Although not widely utilized until a couple of decades ago, the importance of employing stream power concepts at the channel reach scale has been appreciated since the 1960s (e.g., Bagnold 1966). Recently geomorphologists have sought to make linkages between stream power and larger components of fluvial systems, such as channel patterns and floodplain deposits (Ferguson 1987, Nanson and Croke 1992, Miller 1995, Knox and Daniels 2002). Indeed, Costa and O'Conner (1995) suggest that stream power represents a more useful approach than discharge when considering geomorphic "work". Values of mean stream power (W m^{-2}) tends to be highest in small river basins with flashy flow regimes and steep valley gradients, ranging from 500 – 3000, whereas mean stream power tends to be at a minimum in the lower reaches of large drainage systems, with values spanning from 10 – 100 (Costa and O'Connor 1995, Knox and Daniels 2002). Nanson and Croke (1992) examined the linkages between mean stream power and floodplain deposits, and provided a framework for considering how floodplain processes and floodplain styles change with stream power for a variety of physical settings. Because watersheds represent hierarchically organized systems for the transport and storage of energy and mass, considering downstream changes in mean stream power is a useful approach for considering the spatial variation in floodplain deposits. This approach is particularly appropriate for large coastal plain river systems because the dominant processes for floodplain construction (lateral accretion or flood sedimentation) changes with scale towards the drainage outlet (Saucier 1994).

Physical setting

The Pánuco basin (98,227 km²) is Mexico's second largest fluvial system that empties into the Gulf of Mexico (Hudson 2000, Hendrickson *et al.* 2003). The basin drains the arid to semi-arid Central Plateau, the north-south trending Sierra Madre Orientals, and the Gulf Coastal Plain. The highest average annual precipitation of 2400 mm occurs along the eastern slopes of the Sierra Madre Oriental, which is the major contributor of streamflow and sediment to the lower Pánuco drainage system (Hudson 2003 – in press). In the vicinity of Tampico the Mexican Gulf Coastal Plain extends 90-km from the coast and terminates abruptly with the Sierra del Abra, the easternmost ridge of the Sierra Madre Orientals. Coastal plain lithology predominately consists of Tertiary shale and sandstone units (INEGI 1984a, 1984b). Due to significant structural control imposed by the adjacent mountain ranges the topography of the Mexican Gulf Coastal Plain is more complex than the U.S. Gulf Coastal Plain, and influences the pattern of coastal plain drainage systems.

The Pánuco system is supplied runoff and sediment by three major basins, including the Moctezuma (42,726 km²), Tamuín (33,260 km²), and Tamesí (19,127 km²). The río Pánuco forms at the confluence of the río Tamuín and río Moctezuma and meanders 185-km (river distance) across the coastal plain. The río Tamesí drains the northeastern portions of the Sierra Madre Oriental and large portions of the adjacent coastal plain before joining the río Pánuco 20 kilometers upstream of the Gulf of Mexico (Figure 3). A much smaller basin, the Topila (3,114 km²), flows north along the eastern coastal plain and joins the río Pánuco from the south, upstream of the río Tamesí confluence.

Figure 3. Geology of the coastal plain and adjacent Sierra Madre Oriental (data from INEGI 1984). Major valley segments referenced in the text are denoted.

Data and Methods

The data and observations within this paper were obtained over several field seasons between 1999 and 2002. Data sources included field surveying, recent air photos (1:20,000, 1:40,000) and Landsat imagery (1993, 2000; 30 m resolution), and topographic maps (1:50,000). INEGI topographic maps and air photos were scanned, digitized, and geo-referenced within a GIS (ArcView). A valley transect was established from the Gulf of Mexico and used for spatial reference (see Figure 4). Hinge-points in the valley axis occurred at the locations of major tributaries, structural controls, or major changes in lithology. Information pertaining to the geology was obtained from field observations and INEGI (1984a, 1984b) geologic maps (1:250,000).

Figure 4. Relationship of drainage area (km²) with mean stream power and bankfull discharge (Q_{bf}) for the lower reaches of the major tributaries comprising the Pánuco basin.

Mean stream power (ω) was calculated from the formula discussed in the preceding section (see Lecce 1997). Data sources for hydraulic parameters included daily streamflow values (m³/s) from the National Water Commission, topographic surveying with a Sokkia® Total-stations, kinematic GPS surveying, and topographic maps. Daily stage (height of the water surface) records were not available with the daily streamflow data to correlate with Q_{bf} , and field observations and interviews had confirmed that the annual high flow event is generally below bankfull stage. Thus, Q_{bf} was estimated by averaging the maximum three year discharge event. Support for this discharge frequency was provided by National Water Commission stream gauge operators, as well as by residents who live along the river. S_v (m/m) was estimated along each of the major valley segments using the topographic and survey data. W_{bf} (bankfull channel width) was measured directly from air photos and topographic maps at individual meander bends and straight channel reaches (see Goudie 1990) and averaged for the valley segment. W_{bf} , the boundary between the floodplain and channel, can be problematic to define and result in large differences in mean stream power (see formula in preceding section). However,

for rivers located within humid settings, such as the Pánuco, W_{br} is easy to delineate from large-scale air photos because of high channel banks comprised of cohesive floodplain deposits.

Findings and Discussion

The lower Pánuco basin exhibits considerable spatial variability in hydraulic controls and floodplain styles (Table 1). Mean stream power (ω) decreases from a maximum of $375 \text{ (W m}^{-2}\text{)}$ in the upper reaches of the study area, where the río Moctezuma exits the mountains, to a low of $14 \text{ (W m}^{-2}\text{)}$ in the lower portions of the Pánuco valley. Studies considering the spatial variability in mean stream power report decreasing values with increasing drainage area, primarily due to a reduction in valley gradient (Lecce 1997). The data for the Pánuco basin also suggests an inverse relationship between drainage area and mean stream power (Figure 4), although the low gradient (0.00026 m/m) of the lower Tamesí floodplain effectively reduces mean stream power to $26 \text{ (W m}^{-2}\text{)}$. The estimated bankfull discharge (Q_{bf}), which represents a scale dependent (watershed) control on stream power, increases with drainage area (Figure 4) and reflects the general consistency in precipitation between the Pánuco's larger tributary basins; which is important when considering spatial variations in floodplain styles. Valley width and valley gradient are significantly related (Figure 5), which confirms that wide valleys are lower energy settings, which results in greater sediment storage. Valley width ranges from less than 2.0 km where the río Moctezuma exits the mountains, to over 22 km within the central portions of the Pánuco valley (Figure 6). Major fluctuations occur at resistant outcrop, or at confluences with large tributaries. Towards the coast valley width markedly decreases, and is less than 2.0 km upstream of the Gulf of Mexico, where the channel is incised into a ridge of resistant Tertiary deposits (INEGI 1984). Channel width shows wide variability between adjacent reaches (Figure 7), but at the scale of this study shows a predictable increase with drainage area towards the basin outlet.

Río Moctezuma: Río Amajac – Río Tamuín

Downstream of Tamazunchale the río Moctezuma joins the río Amajac and flows north through a structure-controlled valley between the eastern Sierra Madre Oriental and uplifted Paleocene coastal plain units (Figure 8). The mean stream power within this valley segment (between the río Amajac and the río Tempoal) is $375 \text{ (W m}^{-2}\text{)}$, and has an average valley gradient of 0.0011 m/m . The considerable variability in valley width along this segment probably results in significant spatial variability in mean stream power (and valley gradient) because of numerous faults that cross the valley (INEGI 1984b). Channel width averages 106 m along this reach, but is highly variable (Figure 7). For most of this segment the narrow valley restricts the development of a freely meandering river, which effectively limits the complexity of floodplain environments (Allen 1965, Grant and Swanson 1995). As the river exits the mountains it is transporting large cobbles, which are stored within scroll bar and channel bar deposits. The majority of this valley segment is characterized by active lateral migration which results in an undulating morphology to the floodplain surface, and in places produces $\sim 3 \text{ m}$ of floodplain relief (Figure 9).

Although this valley segments is characterized by active lateral accretion, several channel reaches appear to have been stable (based on air photos and field observations), which results in coarse clasts (gravel and cobbles) being capped by $1 - 2 \text{ m}$ of laminated cohesive (silt/clay) flood sediments, producing abrupt variability in floodplain style. For example, where the río Axtla exits the mountains and joins the Moctezuma the river develops an anastomosing (divided channel) pattern for 12 km . In addition to coinciding

Figure 5. Relationship between valley width and valley gradient for the lower reaches of the major tributaries comprising the Pánuco basin.

Figure 6. Valley width along the Moctezuma–Pánuco valleys. Boundaries between major valley segments (designated by arrows) occur with changes in valley alignment and at the junction with larger tributaries.

Valley Segment	Valley distance (km) from Gulf of Mexico	Valley width (km)	S _r (m/m)	W _{brf} (m)	Q _{brf} (m ³ /s)	ω (W m ⁻²)	Floodplain Style*
Lower Río Tamuin: Ciudad Tamuin – Río Pánuco	117.5 – 100	6.1	0.00057	88	2278	145	B – C
Upper Río Moctezuma: Río Amajac – Río Tempoal	209 – 130	3.9	0.00116	106	3483	375	A
Lower Río Moctezuma: Río Tempoal – Río Pánuco	130 – 100	13.3	0.00015	96	4281	66	B
Upper Río Pánuco: confluence – Ciudad Pánuco	100 – 60	15.0	0.00027	149	4974	89	B – C
Lower Río Pánuco: Ciudad Pánuco – Gulf of Mexico	60 – 0	17.2	0.00004	199	4388	14	C
Lower Río Tamesí: axis of anticline – Río Pánuco	50 – 0	8.4	0.00026	150	1499	25	C
W _{brf} (bankfull channel width), Q _{brf} = bankfull discharge, S _r = valley gradient, ω = mean stream power in W m ⁻² (watts per square meter)							
*Floodplain style: A – lateral accretion with scroll bar deposits (limited overbank and absence of ox-bow lakes); B – intermediate between lateral accretion with point bar deposits (most paleochannels not buried), and flood dominated with natural levees (absence of backswamps); C – flood dominated with prominent natural levees and backswamp basins, “yazoo” streams associated with buried paleochannels from older meander belt at a lower surface.							

Table 1. Geomorphic characteristics of valley segments of the lower Pánuco basin, Mexico.

Figure 7. Bankfull channel width (Wbf) and channel distance along the Río Moctezuma and Río Pánuco from where the river exits the mountains to the Gulf of Mexico.

Figure 8. The Río Moctezuma (flowing north) as it exits the mountains and enters the coastal plain, downstream of its confluence with the Río Amajac. Photo at 205 km (see Figure 6).

Figure 9. The Río Moctezuma upstream of the Río Temporal. The arcuate scroll lines indicate former channel positions and represent several meters of floodplain relief. Downstream of this photo the valley widens and the channel develops a meandering pattern. Dashed line indicates floodplain boundary with Tertiary valley margins. Photo at 150 km (see Figure 6).

with a large increase in valley width, to 7.4 km, this segment also likely represents a local reduction in valley gradient (and mean stream power), which is consistent with the conditions necessary for anastomosing channel patterns to form (Nanson and Knighton 1996). Valley width increases considerably towards the río Temporal confluence (Figure 6) and in this portion of the valley meander scroll topography and ox-bow lakes become a more significant component of the floodplain landscape.

The lower río Moctezuma is characterized by both lateral accretion and overbank floodplain construction. Mean stream power declines abruptly to $66 \text{ (W m}^{-2}\text{)}$ downstream of the río Temporal confluence (Table 1). This coincides with a significant reduction in valley gradient, to 0.00015 (m/m) , and an increase in valley width from 11.0 km to 19.5 km. The reduction in mean stream power and increase in valley width provides considerable space for the storage of sediment (e. g. Lecce 1997). Average channel width actually declines by 10 m, to an average of 96 m (Table 1). This represents a change in hydraulic geometry to a lower W/D (ratio between channel width and depth). The reduction in channel width is likely controlled by the large input of silt and clay from

the río Tempoal (6,500 km²), which predominately drains older shale units (Paleocene) from the upper coastal plain. An increase in discharge is usually associated with an increase in channel width, but the increase in cohesive deposits enables steeper (and stable) channel banks to form (e. g. Schumm 1960, Ferguson 1987).

A comparison of air photos with topographic maps suggests that the lower río Moctezuma has been relatively stable during historical times. However, the presence of numerous meander neck cutoffs and abandoned channel courses adjacent to the active meander belt suggests that this represents a recent change in fluvial regime. The paleochannels create a much more diverse floodplain style than the valley upstream of the río Tempoal, and are hydrologically linked to the Moctezuma either through floodplain channels or from groundwater associated with a summer rise in stream stage (Figure 10).

Figure 10. Partially infilled paleochannel within the lower Moctezuma valley. Photo at Km 115 (see Figure 6).

Natural levees become a larger component of the floodplain, and provide several meters of relief (Hudson and Heitmuller 2003). These deposits primarily grade into older point bar deposits, or are burying ox-bow lakes associated with meander neck cutoffs. Most of the lower Moctezuma valley does not contain backswamp deposits, which enables farming (primarily sugarcane) to extend across the entire valley. Backswamp deposits in the lower Moctezuma valley are limited to the confluence with the río Tamuín, which probably represents the influence of backwater sedimentation. The lower reaches of the Moctezuma and Tamuín have few cutoffs, and likely represent a floodplain dominated by overbank sedimentation rather than lateral accretion. The lower Tamuín has a larger mean stream power than the lower Moctezuma due to a steeper valley gradient (Table 1).

Downstream of the Moctezuma's confluence with the río Tamuín, mean stream power increases to 90 (W m^{-2}). The floodplain gradient of the upper Pánuco is 0.00027 m/m, an increase over the lower Moctezuma valley's floodplain gradient (Table 1). The large increase in discharge at the confluence of the río Moctezuma with the río Tamuín results in a 53 m increase in average channel width, from 96 to 149 m (Table 1). However, the average valley width increases by less than 2.0 km, from 13.3 to 15.0 km. In general the Pánuco valley width is highly variable, ranging from 22.0 km to < 5.0 km where resistant Tertiary (Paleocene) deposits are exposed, suggesting that structure represents an important control on floodplain style within the lower reaches of this large basin (e. g. Adams 1980, Schumm *et al.* 2000).

Although the Moctezuma contributes the greatest discharge and sediment load to the Pánuco (Hudson 2003), the floodplain style of the Pánuco valley is dominated at the surface by overbank sedimentation rather than lateral migration, and is therefore more similar to the lower Tamuín valley. Paleochannels in the upper Pánuco have largely been buried by overbank deposits and are manifest on the floodplain landscape as infilled arcuate depressions. Additionally, natural levees form prominent ridges above lower lying clayey backswamp environments (Figure 11).

Figure 11. Natural levee environmental along the Río Pánuco. The levee slopes ~5 m from the river channel to the backswamp in the background. Sugarcane farming occurs only within the upper portions of the levee, and does not extend into the backswamps. Photo at Km 70 (see Figure 6).

Because of their height and being comprised of coarser sediments, natural levees are intensively utilized for agriculture. Unlike in the Moctezuma valley where sugarcane farming extends across the entire valley, the poorly drained backswamp settings in the Pánuco valley are not suitable for farming and are utilized for rangeland during the dry season. An additional indication that flood processes are dominating floodplain

sedimentation in this portion of the valley is due to the increased presence of crevasse channels, which hydrologically link backswamp settings with streamflow during high stage events, and represent mechanisms for the delivery of coarser sediments to low energy backswamp environments.

Towards the confluence of the río Tamesí, the floodplain style of the lower Pánuco valley becomes dominated by flood sedimentation. Mean stream power declines to $14 \text{ (W m}^{-2}\text{)}$ in this segment because of a reduction in valley gradient, which declines to 0.00006 m/m . Thus, over the lower $\sim 75 \text{ km}$ the río Pánuco is only slightly above sea level, and during low flow conditions a salt-water wedge extends almost to Ciudad Pánuco (field interviews and observations). Backswamp basins are a significant component of the floodplain style in this low energy setting and form a lake – marsh system between the active meander belt and Tertiary valley margins. The low rates of lateral migration are likely controlled by the cohesive channel bank deposits (e. g. Kolb 1963). There are very few older point bar deposits exposed along cutbanks, which would easily be reworked. Instead, the channel cutbanks primarily consist of fine-grained (silt/clay) thinly laminated overbank deposits, which likely act as a control on lateral migration and encourage channel stability.

Upstream of the río Topila confluence backswamp lakes are fed by groundwater sapping from the bounding Tertiary terraces and groundwater from the alluvial aquifer. They may also capture local drainage within the floodplain. Small streams draining the northern Tertiary uplands enter the Pánuco valley, but are not competent to join the río Pánuco and thus disappear into backswamp depressions. The smaller streams draining the southern valley margins are able to take advantage of paleochannels and are relegated to “yazoo” style channels, eventually flowing into the río Topila (Figure 12). Near the confluence of the río Pánuco with the río Tamesí, the backswamp basins effectively become large lagoons and encounter diurnal tidal exchanges.

The lower Tamesí valley extends 50 km from where the channel incises through a southerly plunging anticline (an extension of the Sierra de Tamaulipas) to the Río Pánuco, and is the most distinctive floodplain style within the lower Pánuco basin. The mean stream power is $25 \text{ (W m}^{-2}\text{)}$, which is primarily a function of the low valley gradient (Table 1). There is an absence of abandoned channels at the floodplain surface, as the floodplain style primarily reflects overbank construction. The channel is flanked by pronounced natural levees elevated above a series of large lagoons, and which are frequently disrupted by crevasse channels.

Summary and Conclusions

Nanson and Croke (1992) provided a useful framework for considering the relationship between floodplain styles and mean stream power. The data for the lower Pánuco basin do not coincide exactly with the values reported by Nanson and Croke (1992), but do reflect the coarser-scale changes in floodplain styles. Based on the analysis of mean stream power and floodplain styles, the transition from a floodplain controlled by lateral accretion processes to a floodplain dominated by flood processes in the lower Pánuco basin occurs around $\sim 75 \text{ (W m}^{-2}\text{)}$.

In the upper portions of the study area the river flows within a narrow valley having a mean stream power of $375 \text{ (W m}^{-2}\text{)}$. The average width of the valley (3.9 km) does not enable the river to develop a freely meandering river channel, which represents a control on the floodplain style. With the exception of several smaller valley reaches the floodplain is characterized by active lateral accretion. With increasing valley width and decreasing valley gradient mean stream power decreases to $66 \text{ (W m}^{-2}\text{)}$ in the

lower Moctezuma valley. These changes are manifest in a more diverse floodplain style, including natural levees and numerous abandoned channels, and represent a combination of lateral accretion and overbank mechanisms. Although mean stream power increases slightly in the upper Pánuco valley, lateral accretion mechanisms are not as significant to surficial floodplain styles. Instead, overbank mechanisms dominate, and become more significant in the lower portions of the valley where mean stream power declines to $14 \text{ (W m}^{-2}\text{)}$. This is manifest on the floodplain surface by large backswamp basins adjacent to an elevated meander belt, and an absence of meander scroll topography and ox-bow lakes.

Mean stream power (ω) is a spatially explicit hydraulic parameter that is useful for considering watershed-scale changes in depositional processes. For the lower Pánuco basin mean stream power represents a useful approach for categorizing major changes in floodplain styles. This study illustrates that at the scale of a large watershed the reduction in mean stream power with increasing drainage area signifies a change in floodplain style, as well as a change in the dominant processes controlling floodplain construction.

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