“The size of the bedload, the capacity of the stream to transport it, and the relative stability of the channel banks are key variables in the identification of channel patterns and controlling factors. The relation between planform geometry and sediment calibre depends on channel gradient and discharge.”

Analyse how these controls on stream channel segment geometry adjust to downstream variations in water discharge, sediment load & potential energy.

The geomorphological discourse surrounding fluvial processes has evolved steadily since Playfair’s observations in the 1800’s. The scotsman’s discovery - that the river system displayed a ‘natural adjustment’ such that no tributary joined the principal valley on too high or too low a level - formed the foundations for further qualitative and quantitative fluvial research. A fundamental principle in fluvial geomorphology arose; the concept of equilibrium, which distinguished that a river channel’s form - cross sectional shape, gradient and planform - is adjusted to the prevailing watershed conditions that control the amount of sediment and water delivered to the channel (Leopold, 1979). All rivers, it was posited, tended to move towards this state of dynamic equilibrium, larger streams attaining it relatively early in the geomorphic cycle, smaller streams at progressively later stages. In striving for dynamic equilibrium, and as A. Robert contends, rivers were inclined to adjust their channel segment geometries and sediment calibre proportionally, and in line, with the external changes in discharge and gradients.

Streams are natural linear configurations in the land surface that transport water and sediment. River channel processes are characterized by water, moving under gravity and frictional forces, that flows through defined channels to progressively lower elevations. The critical stages of this process encompass the initial weathering to form soil particles, erosion by water to yield waterborne sediment; and the transportation and deposition of sediment within and through the watershed. Overland flow consists of water from precipitation that does not infiltrate into the soil and moves over the surface of the landscape. Stream flow is the water running within a drainage feature such as a stream channel. Overland flow transports eroded particles to streams where many of the particles are transported as sediment in the water column. Stream flow can then transport the sediment load downstream. The processes of erosion, transport and deposition of sediment can lead to degradation—lowering the elevation of the land surface, or aggradation—increasing the elevation of the land surface. In the formational processes of morphologically distinct alluvial streams, hydrodynamic forces are exerted on the sediment particles at the bed surface. An increase in flow velocity induces an increased magnitude of hydrodynamic forces. Consequently, sediment particles begin to move. This initiation of sediment motion only occurs if and when hydrodynamic forces go beyond the threshold (critical condition). Once bank condition is changed, the channel will change into the successor state.

These changes in river style and planform may be intrinsically generated, involving processes inherent to river activity such as channel migration, cutoff development and avulsion, but other changes commonly are a response to extrinsically driven modifications of discharge and sediment supply resulting from climate change, tectonics, or human activities such as catchment land use, river engineering, and management practices. Pattern connotes the planform geometry of a river and the processes operating within a reach; each pattern represents a mechanism of adjustment that is closely linked with changes in channel cross section and gradient. Streams are dynamic in maintaining their basic characteristics of average width, depth, gradient, meander geometry and sediment amounts.

Channel gradient is the most important variable in determining whether an incised channel is straight or meandering; channel gradients are predominantly controlled by bedrock lithologic resistance to erosion. Reaches characterized by steep gradients and straight planform geometries are typically underlain by highly resistant bedrock, while reaches exhibiting moderate gradients and meandering planforms are underlain by bedrock lithologies which are moderately to weakly erosionally-resistant. The mechanical behaviour of laminar and turbulent water affect the morphological characteristics of the channel. Discharge is regarded in the following equation:

Discharge (Q) = Mean Width (w) x Mean Depth (d) x Mean Flow Velocity (v)

In a simplified example, if the discharge is constant, the empiric relation is such that at a given discharge, an increase in width at constant velocity is accompanied by a decrease in suspended- sediment load; conversely, at constant discharge and velocity, an increase in width is accompanied by an increase in bed load. Flow competence further plays a key role in determining river morphology in headwater and upland valley gravel-bed rivers. Downstream, sand and finer sediment may be mobilised over a wide range of flows, so that competence becomes less significant. The balance of sediment supply and transport capability – how far the river exceeds the competence threshold – influences the bed structure and the style or pattern of the channel, creating distinctive physical habitats in different parts of the river. Moving along the channel system, a sequence of thresholds is established by significant changes in the processes by which sediment is moved and stored. Similarly streamflow changes in transient, seasonal weather establish a sequence of temporal threshold crossings in channel environments. In alluvial channels, the interaction is evidenced in the relationship between water level and the adjacent riparian zones.

Clastic sediments in transport customarily are classified on the basis of the mechanism by which they are moved, the principal categories in rivers being suspension and bed load. Suspended sediment is supported in the water column by upwardly directed turbulent water motions. A stream's velocity depends on position in the stream channel, irregularities in the stream channel caused by resistant rock, and stream gradient. Progressing downstream, discharge increases because water is added in progressively greater amounts from tributaries and groundwater. As discharge increase, the width, depth and average velocity of the stream increase whilst the gradient falls. Velocity increases in the downstream direction because the flow is laminar as a pose to being turbulent at the steep source regions. When the flow is turbulent, it takes longer for water to travel the same linear distance, thus the average velocity is lower.

Classification of water flows as either turbulent or laminar are determined by Reynolds number formula ($Re = V.d/v$ where V is velocity of flow; d is depth of flow and v is fluid viscosity.) Less than 500 suggests laminar flow; above 2500, turbulent. Bed load transported effectively in turbulent and laminar flows, progresses by rolling, sliding, or bouncing over the river bottom, its weight remaining principally supported by the bed. Such material is apt to travel only a short distance in one movement. Saltation is a third category of motion in which particles are launched into the water column but then return relatively quickly to the bed following a ballistic trajectory. In river channel morphology, sediments are more appropriately divided into bed material and wash material. The former is relatively coarse material that makes up the bed and lower banks of the river channel and is of major importance in determining river channel morphology. The latter is fine material that, once entrained, travels out of the reach. Wash material is “not normally found in significant quantity in the bed and lower banks of the channel, although it may occur interstitially within bed material deposits” (Lane, S., 1995). It is deposited in slack water on bar tops and overbank during floods, and therefore may be an important constituent of the upper banks. There is a correlation between fine sediments moving in suspension and meandered rivers on low gradients, and a contrasting one between coarse sediments moving in traction and rivers of low sinuosity on relatively high gradients,

Alluvial channels respond to changes in physiography, hydrology and sedimentology by adjusting their cross-sectional geometry, planform and gradient, such that river styles vary across a broad spectrum that includes straight, meandering, braided and anabranching. Change in the position of the channel in the floodplain commonly occurs through: lateral migration (where the outer bank is eroding with deposition on the inner bank); avulsion (where the shift in channel position to a new course is rapid and usually initiated by overbank flow during a large flood); meander neck cut-off (where bank erosion at the apex of a sinuous meander bend breaks through to the channel at the other side of the bend, forming a direct channel); and downstream movement of meander beds through erosion and deposition of the banks.

All streams try to move towards a state of dynamic equilibrium, such that the amount of sediment delivered to the channel from the watershed is in long-term balance with the capacity of the stream to transport and discharge that sediment. At equilibrium a river attains the condition of grade, in which its “slope [and channel characteristics] have delicately adjusted [and settled] to provide, with available discharge, just the velocity required for the transportation of the load supplied from the drainage basin.” (Mackin, 1948) Sediment suspended in water eventually equals sediment settling out of the water column or being deposited. A graded stream can have depositional and erosional events but overall the sediment transported and supplied to the stream is balanced over long periods. Disturbance of the equilibrium leads to unstable streams that are degrading (eroding) or aggrading (depositing). Degrading streams have a deficit of sediment supply, while aggrading streams have an excess of sediment supply. (Robert, A., 2003) In both degrading and aggrading streams, the stream is trying to adjust its slope based on the sediment supply. A stream often exhibits all three equilibrium states in various reaches along the same stream.

A stream’s dynamic equilibrium can be expressed with the “stream power proportionality” equation developed by Lane, an American hydraulic engineer in the 1950’s. Lane represented the equilibrium or graded condition for an alluvial river channel (the condition in which it passes the imposed water and sediment fluxes without net change in form) by the simple qualitative statement $QS \sim Q_SD$, in which Q is discharge, S is channel gradient, Q_S is sediment flux, and D is sediment caliber. The relation states that, for given flow energy, so much sediment of some specified size can be transported. Discharge chiefly determines the scale of the channel and gradient determines the rate of energy expenditure, whereas, for the given scale and gradient, the character of alluvial morphology is chiefly determined by the caliber and quantity of sediment delivered to the channel. The balance of the governing conditions also determines the stability of the channel, the propensity for aggradation or degradation and the style and rate of the lateral movements which create distinct channel patterns.

At the simplest level, channel patterns may be distinguished as either single- thread or multiple-thread. Single-thread channels may be either straight or sinuous, and either laterally stable or actively migrating across a floodplain. Sinuosity is an important variable for describing stream meanders. It is “the ratio of channel length to the straight length between beginning and end of the same channel”. (Bridge, J.S., 2003) Streams are considered meandering if sinuosity is higher than the ratio of 1.5. Straight channels are rare as they require a linear zone of weakness in the underlying rock, like a fault or joint system. Even in straight channel segments water flows in a sinuous fashion, with the deepest part of the channel changing from near one bank to near the other. Velocity is highest in the zone overlying the deepest part of the stream. In these areas, sediment is transported readily resulting in pools. Where the velocity of the stream is low, sediment is deposited to form bars. The bank closest to the zone of highest velocity is usually eroded and results in a cutbank.

Meandering channels form due to the “velocity structure”of a straight stream at low gradients with easily eroded banks. Erosion will take place on the outer parts of the meander bends where the velocity of the stream is highest. (Horton, R.E., 1945) Sediment deposition will occur along the inner meander bends where the velocity is low. Such deposition of sediment results in exposed point bars. The continual erosion on the outer meander bends and sediment deposition along the inner meander bends equates to back and forth bank migrations across the floodplain. Erosion on the outside meander bends often precipitates into its isolation and cutting off from the rest of the stream. The cutoff meander bend, still a depression then collects water, forming as an oxbow lake.

Braided channels occur in streams with erodible banks and highly variable discharge. The deposition of sediment to form bars and islands (that are often exposed during periods of low discharge) occurs. In such a stream the water flows in a braided pattern around the islands and bars, dividing and reuniting as it flows downstream. During periods of high discharge, some of the submerged islands erode, with the sediment being re-deposited at areas of lower discharge. Islands may become resistant to erosion if they become inhabited by vegetation. Anastomosed channels are a subcategory of the braided-island pattern and are generally more stable due to such vegetation which creates cohesive banks. Furthermore low width to depth ratio channels, and gentle channel gradient that exhibit little or no lateral migration, maintain stability. The threshold between meandering and braiding is caused by changes in discharge and gradient, with secondary causation in bank erodibility, flow strength and bed material size. Meandering channels will replace straight channels, as flow strength increases relative to bed or bank erosional resistance. Temporally, such pattern transformations are often gradual (“transitions”) yet interlaced with rapid anomalies (“transitions”).

High energy fluvial systems, such as active, braided channels, are subject to frequent change by processes which occur annually and “repeatedly cross intrinsic thresholds” (Bridge, J.S., 2003). The individual landforms are frequently destroyed but the overall geomorphic system is robust since the new landforms which are created are recognisably similar to the old. In such an occurrence, the morphology is stable but not static; the channel is geomorphologically robust. If, however, the imposed disturbance causes the system to cross an extrinsic threshold into a new process regime in which a wholly different assemblage of landforms develops then the initial landform assemblage is deemed to have been geomorphologically responsive to the imposed change. The transition from braided channels to meandering channels across the North European plain during the Lateglacial and Holocene, exemplifies a geomorphically responsive riverine landscape.

Fluvial systems undergo perpetual metamorphoses. A. Robert’s statement, “the relation between planform geometry and sediment calibre depends on channel gradient and discharge” is strongly evidenced in the temporal processes of readjustment in channel shape and sediment load, once a threshold has been crossed. In essence, variations in river style result from the interactions between valley gradient, discharge, bank strength and sediment caliber, in creating the distinct planforms and sinuousities of a river.

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Rob Krawczyk