Two types of underfit rivers: both formed during the receding stage of Noah's Flood

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An underfit river is one whose valley appears to have been carved by a larger river than the one which currently occupies it. The purpose of this paper is to explore two common types of underfit rivers, being the 'manifestly' underfit rivers and 'osage' underfit rivers. Though their morphologies are distinctly different, there is an underlying common process of formation. The distinctive characteristics and the formation of these features are highly relevant to biblical geology.

"Nature seems to operate always according to an original general plan, from which she departs with regret and whose traces we come across everywhere" (Vicq D'Azyr, 1784).

Underfit rivers have been studied and discussed for over 100 years.[1] The term 'underfit' originally referred to a valley that appeared to have been carved by a larger river than the one that occupies it now. However, Dury, who undertook much research on underfit rivers during the 1950s–60s questioned, "the customary but too restrictive sense underfit stream is a stream that meanders on a floodplain in a meandering valley".[2–4] Dury identified numerous underfit river forms, and he later proposed the now-accepted terminology of manifestly underfit and osage underfit (these will be defined and described later).[5] Dury noted, for example, that some underfit rivers did not meander within meandering valleys, while other underfit rivers could be found in valleys that did not meander. Given the diversity and complexity of types of underfit rivers, an even simpler definition is today used to define 'underfit'—that it is "much smaller than expected from the size of its valley".[6]

The complexity of forms of underfit rivers, and the difficulty in precisely defining said features, has hindered an understanding of formative processes. Some valleys meander and others do not. Moreover, some rivers may meander within their meandering valleys, but others retain meander patterns that mimic the valley itself.

Detailed subsurface exploration of the valley floors of underfit rivers revealed that buried beneath underfit river floodplains are channels of former and larger rivers that were believed to have carved the valley meanders.[3] Indeed, profiled sections of filled valleys that underly underfit rivers commonly show asymmetry at valley bends, akin to that of the alluvial beds of meandering streams.

While the discharge of the current underfit river can be accurately measured, determining the discharge of the river that carved the valley is difficult. Estimated prior discharges were commonly 80–100:1,[7] though this was later changed to 50–60:1, along with suggested reductions of bedwidth of the channel of 23–248%.[8] Either way, this poses significant challenges for the climate change arguments that are often articulated in this field.

The frequency of occurrence of underfit rivers is also challenging. Following Dury's detailed study of western Europe,[2] he estimated that a minimum of 50% of streams of second or higher orders were manifestly underfit. Manifest and osage underfit rivers are also common in North America as well as across Eastern Australia. The term 'underfit' is thus used in a multitude of geomorphic and climatic settings around the world.

Current uniformitarian explanations for underfit rivers are that drainage has been altered by river capture, that the valleys were created by glaciers, or that there have been variations in climate.[9] The first two arguments are not tenable, as neither river capture nor glacial melt can explain the global distribution of underfit rivers.

Nonetheless, divergent views on their formation continue to be proposed. Underfit rivers have been ascribed to a variety of formative conditions, be they paleoclimates,[2–4] paleotidal environments,[10] major floods,[11] coarse bedload,[12] cohesive banks,[13] bedrock influences,[14] channel abandonment,[15] or the complex interaction of the numerous factors just listed.[16] An argument against Dury's observations and interpretation of the Osage River in Missouri is that structural controls in valley architecture are more important in their formation than changes in hydrology.[17]

As earlier mentioned, the formation of underfit rivers has been researched for well over 100 years, as underfit rivers are common worldwide, regardless of terrain and climatic settings. That underfit rivers are ubiquitous was well articulated by Dury.[2] Thus, if underfit rivers can be found across a multitude of terrains and climatic zones, then specific explanations should not rest solely on features of a valley, such as its structural geology, valley dimensions, and so on, nor on the climate or weather patterns (both past and present). For a feature that is global, many recent 'focused' studies (single catchment, small area—such as those studies listed above) could lead to sampling bias, selection bias, confirmation bias, and so on.

Within the creation literature, an alternative view is expressed—that underfit rivers occupy valleys carved by the receding flow of Noah's Flood. As the continents emerged, water flowing off the land concentrated into numerous routes, thus creating valleys. This has been termed the 'channelized flow phase'.[18] In the final stages of the Flood, sedimentary deposits could have occurred in many valley bottoms, being the final flush of sediment washed off the continental surface (it being not just surface runoff but excessive throughflow from saturated emerging continental sediments). These valley deposits may, in turn, be 'remapped' or reshaped by modern conventional floods, producing diversity in appearance.

This would give rise to what we, today, call 'underfit rivers'—with manifestly and osage forms being the focus of this article. Manifestly underfit rivers have geometric features akin to classic alluvial meandering rivers, but do so in somewhat larger meandering valleys. Osage underfit rivers are those that largely do not meander within their larger meandering valleys.

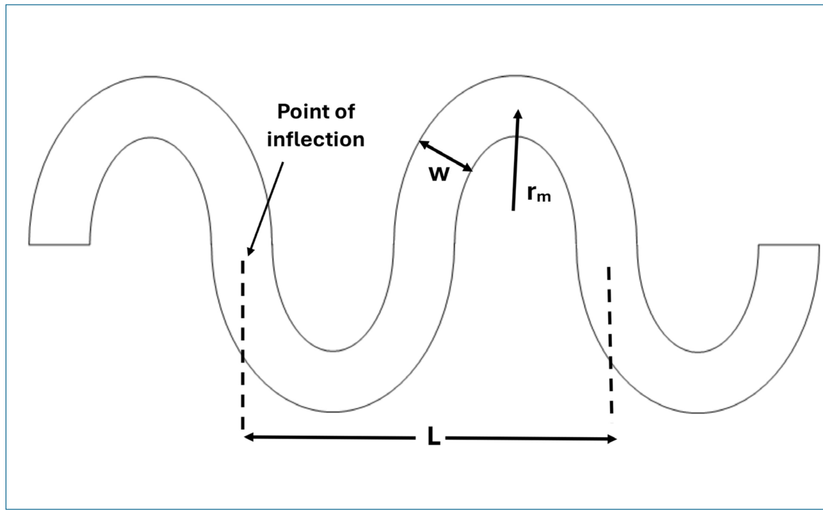

Figure 1. Geomorphic features of a meander

Geometric features of river channels

Before exploring underfit rivers in more detail, it is important to expand upon river morphology (planimetric view) and bankfull flow relations in what has been called 'classic' alluvial river channels.

One of the most pronounced features of meandering river channels on broad alluvial plains is the pattern of meander bend dimensions (such as wavelength and radius of curvature), which are usually proportional to the river discharge.

> "The size of the bend appears to be proportional to the size of the river; large rivers have large bends, and small rivers have small bends."[19]

Streams have typical meander wavelengths (L in figure 1) in the order of 8–12 times the bankfull width (W) of the channel (bankfull width being used as a reflection of discharge). Thus, the mean radius of curvature (r_m) of a meander is typically 3–5 times the distance of the channel width. The relationship between channel widths and meander wavelengths is also largely independent of the channel material type, whether it be alluvium, bedrock, or supraglacial.[20]

Another prominent feature in channels (whether straight or meandering) are pools (deeps with smooth water surfaces), riffles (shallows with turbulent water surfaces), and runs (intermediate features between pools and riffles). These features can be found regularly spaced along channel beds. The pool-to-pool spacing along a channel bed is often observed to be half the wavelength of a meandering river channel (often measured as 5–7 times the width of channels),[19] and pools are usually asymmetrical and found on the apex of the meander and associated with point bars. It is important to recognize that these features *'are not discrete units but form a continuum'*.[21]

Finally, flume studies confirm that meander wavelengths can be rapidly developed in flumes and have wavelengths, widths, curvature parameters and so on in concordance with field observations, whether in fine or coarse bed materials.[22,23]

Geometric features of manifestly underfit rivers

Manifestly underfit rivers were defined by Dury[2] as "meandering streams in more amply meandering valleys." The streams usually exhibit wavelength to channel-width ratios equivalent to those referred to earlier as classic meanders, being typically 8–12:1. They also have pool-to-pool spacing along a channel bed equivalent to half the wavelength of a meandering river channel (often measured as 5–7 times the width of channels). Thus, neither their channel size, meander dimensions, nor pool-to-pool spacing are used to identify these rivers as underfit.

Instead, such rivers are defined as underfit by their relationship with the meandering valley they occupy—a valley believed to have been carved by a much larger flow, such as the Rolling Fork, Kentucky (figure 2).

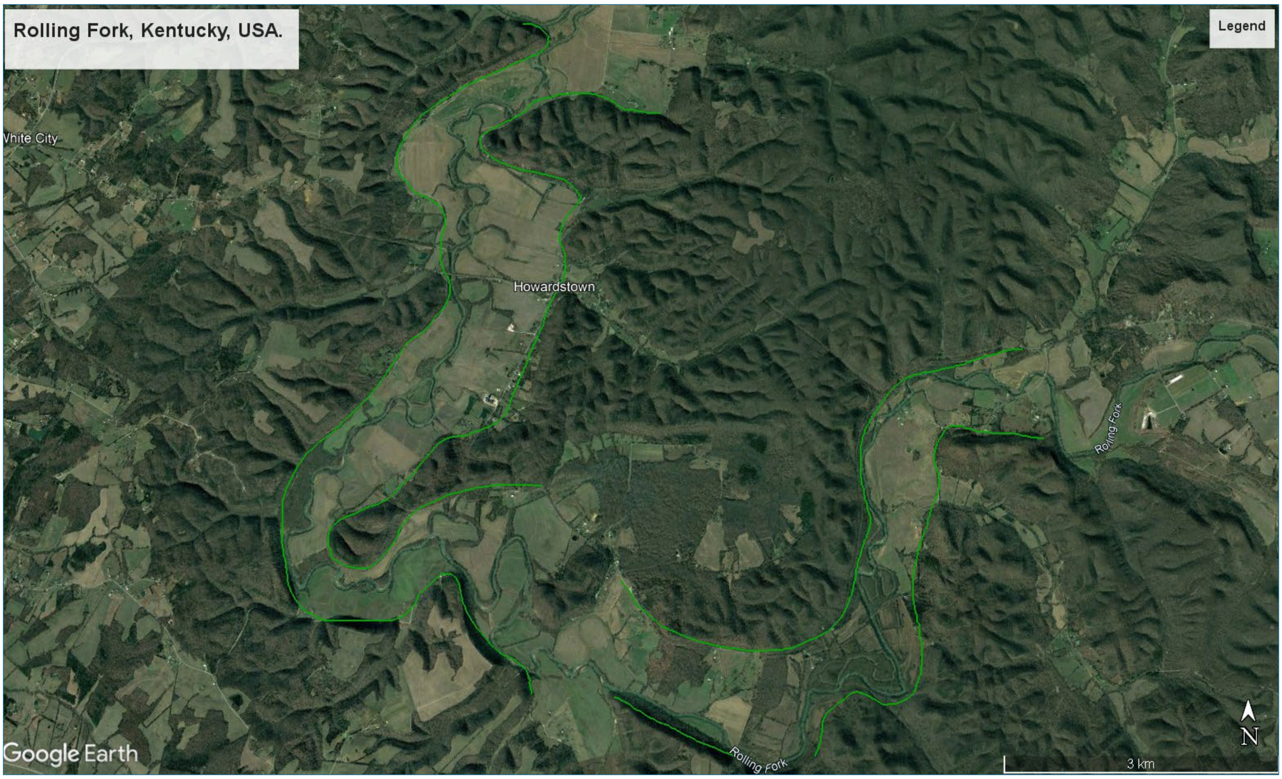

Figure 2. Manifestly underfit Rolling Fork, Kentucky. The river meanders within a meandering valley (marked with a green boundary).

Figure 3. Yanco Creek, NSW, Australia, about 10 kms SW of Morundah. The small meandering channel is clearly visible. The letter 'A' indicates the broader alluvial plain.

Figure 4. The smaller Tapiche River (middle) follows and remaps the original floodplain of the current Ucayali River (now located to the left).

Other excellent examples of manifestly underfit rivers are provided within the Riverine Plain region in NSW, Australia. This region has been extensively studied, and numerous paleochannel stratigraphic models have emerged,[24] reflecting depositional environments across the >70,000 km^2 region. Invariably, these previous studies further point towards a significant reduction in flow rates across eastern Australia, leaving abundant paleochannel meanders and remnants across the region that are currently being reworked by flow-diminished rivers; thus, exhibiting manifestly underfit features. In these examples the evidence of past river channels and the floodplains is distinctly clear.

A good example is Yanco Creek (figure 3). Yanco Creek has developed irregular small meanders along a larger meandering paleochannel (effectively its current valley). The much larger wavelength of the paleochannel clearly indicates a significant reduction in discharge. The broader surrounding alluvial region in figure 3 (marked A) could, at an earlier time, have been an active floodplain, as throughout the region there is the classic upward fining sequence from fluvial gravels and coarse sands to surficial silts and clays.

Caution needed

Since the word 'underfit' is loosely defined and freely used in academic literature, it is important to realize that there are examples where rivers have developed similar patterns to manifest underfit rivers but are not strictly underfit rivers. A large channel on a broad and active floodplain could undergo an avulsion, the sudden abandonment of its course to a new location, with the older (abandoned) channel now utilized by a tributary to the main channel. This tributary may be able to adjust the abandoned channel to one that better reflects the current diminished runoff.

Excellent examples can be found in the Amazon River basin. Rojas *et al.*[25] wrote that "underfit-scavenger meandering rivers are observed in areas where paleochannels from large rivers are found" in the Ucayali region. For example, the Tapiche River relies on a relict belt of the Ucayali River, developing its own smaller meander wavelengths. Figure 4 highlights this well. In another example, in South America, where this feature is identified, Kuerten *et al.*[15] described such channels as 'underfit'. However, the Nabileque River they referred to occupies the abandoned course of the Paraguay River.

The term 'scavenger' is a more suitable term for such streams. In these instances, the major rivers have not undergone reductions in flow rates. They have simply abandoned their previous course and remain active nearby. The previous river channel is now being reworked by a smaller tributary.

Figure 5. Osage River, Missouri, USA, around 20 kms south of Jefferson City

The difference between these two types of streams (manifestly underfit and scavenger) are subtle but important. Streams that are manifestly underfit and scavenger both experienced a dramatic reduction in flow rates that led to channel morphologic changes. In both situations, once the significantly larger flow (that carved the classic large meanders) is removed, smaller streams then redevelop or superimpose their own smaller meander wavelengths over the original pattern. In this regard, there appears to be no difference between these two systems—in both cases, smaller meander wavelengths are superimposed on previously larger meander wavelengths. But the difference is:

a. In the scavenger example, the original (larger) river is still in the valley—it has simply shifted its flow path to another point in the valley. There is no evidence of a reduction in discharge—just a shift in the location of the river.
b. In the manifestly underfit examples, which are abundant worldwide, the original (larger) river is simply not there! This is evidence that there has been a significant reduction in discharge.

The global abundance of manifestly underfit rivers is evidence of the receding flow of Noah's Flood.

Geometric features of osage underfit rivers

Osage underfit rivers are distinctly different to manifestly underfit rivers. When compared to classic alluvial river channels, osage underfit rivers have quite different meander wavelength to channel-width ratios.

Osage underfit streams commonly have meander wavelength to channel-width ratios of 30–40:1, not 8–12:1. The term 'osage' was coined by Dury from his studies of the Osage River in Missouri, USA. It is interesting to note that these unusual meander features of the Osage River were explored, discussed and debated well before Dury's work.[1]

Despite their unusual meander wavelength to channel-width ratios, the pool and riffle spacings along these channels retain their regularity, with pools still occurring 5–7 times the width of the channel regardless of their extended wavelengths. Thus, the pools are no longer primarily found at the apex of the meander but can be found at regular intervals along the extended meander bends. Hence, pool spacing relative to channel width is retained, but not the pool spacing relative to meander wavelength.

Thus, osage underfit rivers such as the Osage River are typically recognized by their unusual meander wavelength to channel-width ratios (figure 5). While some osage underfit rivers appear to be bound within narrow meandering valleys (such as the Osage River), thus seeming to be confined,

Figure 6. Macquarie Rivulet, New South Wales, Australia, just upstream of the town of Albion Park

others are not. Some are found on alluvial floodplains with sufficient valley widths to develop a more sinuous flow pattern.

Such an example is the Macquarie Rivulet in New South Wales, Australia—one that highlights an osage underfit character without being confined by the valley.[26] At the base of the Macquarie Pass State Park (base of the escarpment), the Rivulet begins a series of meanders that are osage underfit in appearance (figure 6).

There are nine meanders along the middle reaches of the Macquarie Rivulet with meander wavelength to channel-width ratios for this section of channel ranging between 16:1 and 49:1, with an average of 29:1, which is typical of other osage-type underfit rivers along the Eastern Australian coastline. Moreover, these wavelengths clearly align with Dury's[4,5] extensive data, globally collected on valley meanders and osage underfit meanders.

Channel bedforms along the Rivulet reflect other osage underfit river bedforms that have been reported elsewhere. Pools and riffles are prevalent, with up to 11 pools being identified along a single meander wavelength (rather than the expected 2). This is a common trait of an osage underfit meander. In addition to pools and riffles, there are extensive sandy shallows ranging in length from 100–200 m. A survey of the channel bed showed that these were extensive deposits of sand (not merely veneers) and that they were remarkably symmetrical in shape, with near vertical banks and flat channel beds. They were possibly extended runs (features found between pools and riffles).

In addition to claims of climate change, another argument to explain osage underfit meanders has been bedrock control.[14] Indeed, joint control has been reported within the neighbouring Shoalhaven Valley.[16] To explore this possibility, the author undertook field work on the Macquarie Rivulet, during which 400 measurements were made of joint and dip alignments. Dip was consistently close to vertical throughout the valley, while dominant joint alignments of 005° and 095° correspond to those reported regionally.[27] Measurements of meander alignment present a quite different pattern with broad orientations of 035°–055°, 095°–115° and 145°–165°. The lack of a relationship between meander and joint alignment (<0.001) along the Macquarie Rivulet was verified by a chi-squared test, thus confirming that bedrock is not a controlling factor of these osage underfit meanders.

On the basis of these findings, the Macquarie Rivulet is clearly an osage underfit river, the meander wavelengths of which, relative to both bankfull widths and bankfull discharges, are unusually large compared to classic alluvial meandering rivers.

An obvious question arises at this point—why do some rivers that have experienced massive reductions in flow rates readjust the original or inherited meander wavelengths (manifestly underfit), while other (reduced discharge) rivers (osage underfit) seem unable to readjust the original or inherited meander wavelengths? The latter have readjusted their pool and riffle spacing but seem unable to adjust the meander wavelengths.

Perhaps this is where previous case-by-case research on osage underfit rivers is useful. Coarse bedload and cohesive banks have been proposed, as has some degree of valley bedrock control. Osage underfit channels are prevalent along the coastal plains of eastern Australia—examples include the Nullica River, south of Eden in southern NSW, the Colo River, north of Sydney, a host of river valleys upstream of Taree in NSW, and the Mary River, upstream of Gympie in Queensland, to name but a few spanning the entire east coast of Australia. Some of these rivers, such as the Colo and the Mary, are renowned for their extreme floods.

Discussion

Because of the global distribution of underfit rivers, commonly accepted uniformitarian thinking is that the volume of flow in underfit rivers was greatly reduced due to climate change.[28] But this is a weak argument because previous secular studies of variations in Holocene climates highlight significant variability between regions. For example, Herzschuh *et al.*[29] show that pollen-derived "Temperature trends show strong latitudinal patterns and differ between sub-continents." They argue that there are strong spatiotemporal patterns and regional drivers. Other researchers also argue that regional differences and variations in temperature and precipitation in the past were affected, as they are today, by a variety of factors such as elevation, latitude, cyclonic frequency, and so on.[30] Given regional variations in rainfall and runoff, and variations over time in rainfall and runoff, how can this explain the worldwide distribution of manifest and osage underfit rivers, regardless of terrain, climatic zone, catchment geology, and so on?

Moreover, the morphometric and planimetric features of underfit rivers indicate massive reductions in river discharge—to an extent that remains unexplainable in secular literature. Dury's estimated previous river discharge rates (that formed these valleys and paleochannels) were in the order of 50 times that of current regimes. A cursory view of flood frequency analyses for any river system illustrates that this is not possible. Moreover, a study initiated by the Corps of Engineers in the United States of America determined, using various assessment techniques, that a 500-year flood (a flood, the volume of which, on average, occurs only once in 500 years, or has a 0.2% chance of occurring in one year) would have a volume 1.3 to 1.7 times larger than a 100-year flood.[31] Even the 100-year floods were only 2.0 to 2.7 times larger in volume than 10-year floods. While these calculations, initiated by the Corps of Engineers, were primarily to assess the effectiveness and accuracy of predicting 500-year floods, these analyses still highlight that discharge volumes 50 times that of current regimes needed to create these valleys and river systems is a stretch of the imagination.

Thus, the global distribution of underfit rivers, and the magnitude of change in flow regimes required to form such features, cannot be explained by either uniformitarian thinking, or multiple catastrophic (extreme) geologic events, which are occasionally used to highlight local and regional features in secular literature.

The formation of these features is best explained by the final stages of the Global Flood event. During the recessive stage of the Flood, the concentration of floodwaters draining off the emerging continents carved meandering valleys and created paleo-floodplains. In essence, these features were created by meandering rivers of inconceivable size. These features became relict with the continued rapid decline in flood runoff. Thus, these valleys and paleochannels still remain largely intact and are being slowly remodelled by today's rivers. In some cases, particularly with osage underfit rivers, the smaller flood and annual discharges experienced today are unable to modify the planimetric features of these past disproportionate meanders and meandering valleys. In the case of manifestly underfit rivers, the flow has successfully reworked much of the surface sediments, but the evidence of past massive channels remains.

The main alternative to this, in a biblical framework, is explaining them as a result of post-Flood catastrophism. Some have suggested that extreme climatic conditions as the earth returned to equilibrium in the aftermath of the Flood, combined with the global prevalence of non- or only slightly lithified sediments immediately after the Flood, indicate that most of the geomorphology we see today is the result of mass wasting processes in the decades after the Flood.[32] However, there are several difficulties with this view.[33] First, the Flood has already removed massive overlying sediments as the continents rose, so there is good reason to think that the Flood would not have left much unlithified sediment rock exposed at the surface. Second, these gorges and valleys within which underfit rivers are now present were essentially carved into lithified rock, not loose sediment. If these formed post-Flood, they formed after all the unlithified sediments were either eroded away or lithified. They could not have formed in the *immediate* post-Flood era, when torrential rain would have been at its peak. Furthermore, as explained above, 500-year flood discharges have been calculated to be in the order of twice that of a 100-year flood—this does not produce the sorts of discharges needed to erode the valleys within which are found underfit rivers.

Thus, the distribution of underfit rivers highlights that a global Flood did once occur—even if they reflect only the receding stage of the Flood. While we often highlight massive canyons, escarpments, impressive water gaps, regional sedimentary structures, and other features as evidence of a global Flood, we still see evidence of the Flood in less conspicuous landforms, such as underfit river meanders.

Conclusions

Manifest and osage underfit streams are found worldwide and have been studied over the past 100 years. The massive reduction in runoff that is clearly evident in morphometric and planimetric features of valleys and underfit rivers worldwide is best explained by the receding stage of the Global Flood.

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