Youth, Maturity and Old Age: Time for Retirement?

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Abstract: The concepts of 'youth, maturity and old age' are used to describe stages of landscape development within the Cycle of Erosion of W.M. Davis. These concepts are still widely taught at second level in Ireland, especially in relation to fluvial (river) landforms. However, it has been widely accepted since the 1950s that the model is outdated, as the underlying assumptions are flawed and its analogy with the stages of human life are inappropriate for what is now known to be a dynamic system controlled by a number of factors that include climate, tectonic activity and geology. This paper outlines the Davisian Cycle of Erosion and discusses the developments in knowledge and understanding that have been made since the model was first proposed, explaining why the model is oversimplified and outdated. The main misconceptions that students who have been taught this theory tend to hold are considered and suggestions are made as to how the material taught in schools might be updated.

INTRODUCTION

The familiar model describing the 'youthful', 'mature' and 'old age' stages of a river was originally developed a century ago by the American geomorphologist William Morris Davis. Since that time major flaws have been uncovered in the underlying assumptions of this model; indeed, it has been widely accepted for over fifty years that Davis' model is outdated and cannot be applied to the real world. Davisian theory has not been taught at third level – with the exception of courses concerned with the history and philosophy of geographical thought – for many years. It is therefore a matter of concern that such archaic material is still taught at second level in Ireland. The main reasons for this appear to be (i) the continued appearance of questions specifically referring to the 'youthful, mature and old age stages of a river' on Junior and Leaving Certificate exam papers, although these terms are not referred to in any of the syllabuses, and (ii) most Junior and Leaving Certificate textbooks include Davisian theory, presumably in response to the content of examination papers.

As a descriptive tool, discussing the 'stages' of a river may appear harmless enough. Unfortunately, due to the analogy with the stages of human life, it is actually causing students to develop serious misconceptions about the form and behaviour of rivers. It has long been known that most rivers do *not* 'age' by slowing down and losing power in a downstream direction from source to mouth, as suggested by Davis. This is of fundamental importance in understanding and managing river systems. Whilst it is true that only a minority of Junior and Leaving Certificate students will continue to pursue geographical study beyond second level, this is more than an academic debate. We can all see how rivers affect our daily lives and for this reason it is important to provide a basic, yet accurate, explanation of their behaviour and form, regardless of the direction in which the second level student subsequently proceeds. This paper explains why there is a problem with the Davisian model of youth, maturity and old age and provides a basic overview of current understanding. The main misconceptions that students who have been taught the Davisian model tend to have are examined and suggestions are made for approaches and methods that can be used to incorporate current understanding into teaching at different levels, including models and demonstrations. The paper has been written in such a way that the following two sections, which discuss the theory underlying the Davisian model, may be omitted if desired.

THE DAVISIAN CYCLE OF EROSION

William Morris Davis developed his model of landscape evolution, usually known as the Cycle of Erosion, between 1884 and 1899 and continued to develop these theories until his death in 1934. In total, he published over 500 articles and books on aspects of geography and geology (Chorley *et al.*, 1973). The theory was developed at a time when evolutionary thinking had permeated the natural and social sciences in Britain and North America, following the publication of Darwin's *Origin of Species* in 1859. Davis argued that, in a similar way to life forms, landforms could be effectively analysed in terms of their evolution through time. In other words, landscapes evolve through a sequence of *stages*, each stage exhibiting characteristic landforms. In his view it was therefore possible to infer the temporal stage of development of a landscape from form alone (Summerfield, 1991). Landforms were thus analysed in terms of their structure, process and stage. The following description of Davis' understanding is broadly based on notes from a series of lectures given by him in 1926-7, and compiled by King and Schumm (1980).

The theoretical starting point for the Davisian cycle is where processes of crustal deformation uplift a smooth, soil-covered lowland that is underlain by a uniform geology. This results in an inclined surface that slopes from a central divide towards the coast. This uplifted surface is then gradually denuded (see glossary of terms at end of article) over time, with a progressive decline in slope angles and stream gradients that ultimately leads to the formation of a 'peneplain', a low-lying and slightly undulating surface. During the early stages of denudation, the uplifted highland is described as *young* and is characterised by rivers that have excavated narrow valleys and flow as torrents in their upper courses. The high ground between the valleys has undergone little change at this stage, apart from rill erosion and some dissection by side streams. Over time a *mature* landscape develops; this is deeply dissected by numerous branching valleys and the general *relief* (see glossary) is at a maximum, being strongest (i.e. with the greatest differences in height) at the divide and weakest near the coast. The high ground between the valleys has lost little of the initial altitude provided by uplift but the streams are *graded*; they have adjusted their channel gradient by eroding and depositing to form a smooth profile from source to mouth. The *late mature stage* occurs when the drainage divides have been degraded below their height at maturity, although there is still considerable relief. The valleys have been widened and the fall in altitude over the upper course of streams has decreased. The *old age stage* is characterised by further reductions in relief and in the angle of valley side slopes, and is accompanied by a decrease in the activity of all processes of degradation. The divides between the valleys are now only vaguely defined, as hills are rounded off to lower and lower profiles, stream gradients decrease and soil depth increases. The *peneplain*, described by Davis as 'almost-a-plain', is the end product of the process of *peneplanation* described above. It is characterised by broad-floored river valleys separated by low, rounded hills and is barely above sea level, although if the area is large, residual mountains and hills may endure inland, rounded and with gentle slopes. If the uplifted land stands indefinitely after upheaval has occurred, the mountains and hills will be worn lower and lower, leading eventually to a soil covered plain of degradation drained by slow flowing rivers of very low gradient which flow in broad valleys, divided from each other by faint swells in the surface. If renewed uplift occurs at any stage during the cycle, the landscape will undergo *rejuvenation*, resulting from increased rates of downcutting by rivers, giving rise to a *polycyclic* landscape where youthful forms co-exist with older forms.

In describing the process of peneplanation, the terms youth, maturity and old age are analogous to those of human life forms. These refer to changes through time, although the familiar model of the stages of a river, i.e. changes through space, is defined by Davis (1889):

> 'It is only during maturity and for a time afterwards that the three divisions of a river, commonly recognised, appear most distinctly; the torrent portion being the still young head-water branches, growing by gnawing backwards at their sources; the valley portion proper, where longer time of work has enabled the valley to obtain a greater depth and width; and the lower flood-plain portion, where the temporary deposition of the excess load is made until the activity of middle life is past.'

In devising the model, Davis made a number of assumptions, the most questionable of which was the occurrence of a period of rapid uplift followed by a long period of stability. Further assumptions included the existence of a uniform or only slightly varying underlying lithology and geological structure, and a humid temperate climate similar to that of the north-eastern USA. Davis accepted that the detailed nature of landform evolution under different prevailing climates would not be the same because of corresponding variations in the intensity of geomorphic processes, and he later developed 'arid' and 'glacial' versions of the model. He also suggested that different drainage patterns would develop in response to lithological and structural controls, although these controls would become progressively less significant as the cycle progressed. Despite these complications, however, Davis maintained the value of regarding landscapes primarily in terms of their evolutionary stage in a unidirectional sequence through time.

PROBLEMS ASSOCIATED WITH THE CYCLE OF EROSION

The Davisian model, while widely accepted by Anglo-American geomorphologists, never gained universal support. Geomorphologists in mainland Europe found its assumptions, especially with regard to the proposed nature of uplift, greatly over-simplified. The only other significant theory of landscape evolution put forward before the Second World War was that of the German geomorphologist, Walther Penck. He argued that active uplift could continue over long periods of time in orogenic belts, and that the Davis evolutionary scheme, assuming only a short period of uplift, was of dubious value. Using evidence from sedimentary sequences flanking the Alps, Penck suggested that rates of active uplift initially increased, before reaching a maximum and then decreasing again. Penck considered that in certain circumstances the balance between rates of uplift and rates of denudation might be reflected in a variety of different slope forms.

Davis was never very specific about rates of uplift and denudation due to a lack of quantitative data, although he did give estimates of 20-200 million years for the development of the fault block mountains of Utah (Summerfield, 1991). Our current knowledge of rates of uplift suggests that few areas of the world remain stable for periods of more than tens of thousands of years, meaning that polycyclic landscapes are the norm rather than the exception. A further tectonic effect neglected by Davis is that of isostatic uplift resulting from the unloading of the land surface through time by processes of denudation (Summerfield, 1991).

A further complication is that of climatic change. We now know that there have been frequent and rapid changes in climate during the Quaternary (the last 2.5 to 3 million years) leading to glacial and interglacial periods. These changes have been global in extent and have in turn resulted in major changes in sea level on a frequent basis. As a result, it is very unlikely that landscapes anywhere can be realistically viewed as representing simple unidirectional sequences of forms.

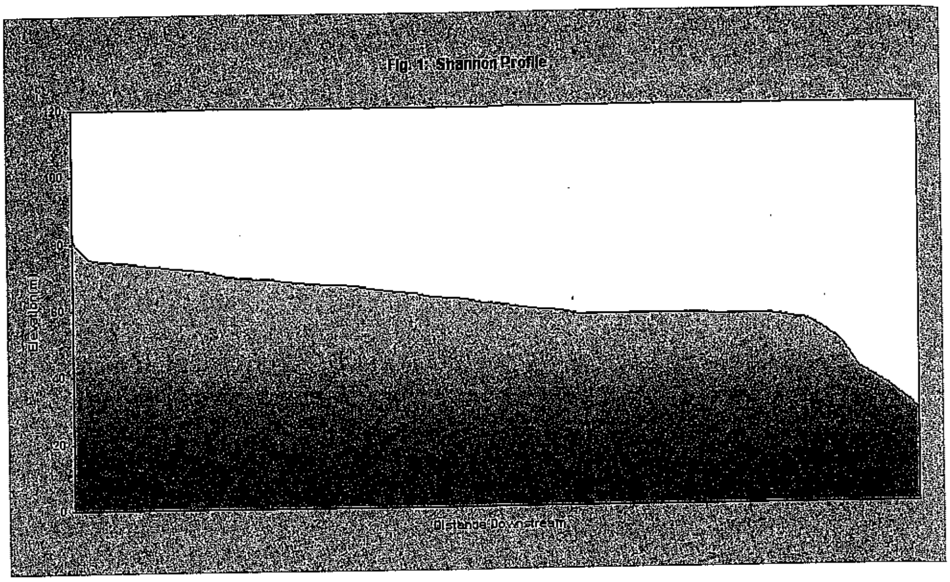


Figure 1: Shannon Profile

MISCONCEPTIONS AND SOME RECOMMENDATIONS

Students entering third level education frequently have certain misconceptions about river behaviour and form, although some of these, such as the 'slowing down' of a river as it moves downstream, are not obvious and may result from casual observation of the appearance of flow in rivers known to the student. These misconceptions are outlined here with explanations of how they arise, why they are in error and a brief overview of current understanding.

Rivers have Youthful, Mature and Old Age Stages

In common with most of the rivers that drain the Irish midlands, the Shannon does not fit the Davisian model of youth, maturity and old age. Figure 1 shows the longitudinal profile of the river. It can be seen from this that over much of its length the Shannon has a very gentle slope and flows sluggishly, dropping only 15.5 m over 220 km. Between Lough Derg and Limerick, however, the river drops 30 m in just 30 km (Davies and Stephens, 1978) and there are sections of bedrock channel in the steep Killaloe Gorge, so it could be said that the river displays characteristics associated with 'youth' in its 'old age'. A possible explanation might be that the river has undergone some kind of 'rejuvenation', another Davisian concept, This would, however, be an erroneous oversimplification as the history of the Shannon is complex; the long-term development of the river, like all rivers, has been affected by a number of controls including geology, tectonics, climate, vegetation and land use. For example, over the last three million years there have been frequent and dramatic changes in global climate leading to cycles of glaciation separated by interglacials. The huge influence that recent glaciations have had on the devélopment of Ireland's landscape is well known, yet the Davisian Cycle of Erosion does not incorporate climate change because the nature of these changes was unknown at the time.

Despite these complexities it *is* acceptable for teaching purposes to identify characteristics of a 'typical' river along its length, although it is recommended that the terms *upper course*, *middle course* and *lower course* be used instead of the Davisian terms as these imply a spatial division rather than a sequence of development through 'stages' (time). In doing this, it is important to note two things:

i) Not all rivers fit this pattern, especially in Ireland, where variations in geology and topography from place to place influence the form and behaviour of different rivers, and where many rivers have been greatly affected by changes in climate over time; recent glaciations have had a major impact on many of Ireland's rivers leading to diversions (e.g. River Liffey) and vast amounts of glacially-derived sediment for rivers to rework and transport over time. Climate also affects vegetation cover, flow regime and sediment load, all of which in turn affect river processes and form. Over the last 5,000 years, human activity and land use change have had an increasing impact on fluvial systems.

ii) The river should be viewed as a whole, rather than as discrete sections; processes occurring in the hill slopes and channel of the upper course affect water and sediment delivery to the middle and lower courses; changes in the lower course, such as adjustments resulting from a change in sea level, affect the operation of processes in the upper course.

These are points worth making, as a holistic approach to the drainage basin is of fundamental importance in successful river basin and channel management.

The mean velocity of flow decreases in a downstream direction

It might be surprising to learn that, with the exception of some rare examples, mean velocity does *not* decrease downstream. Since the pioneering work of Leopold and Maddock (1953) on downstream changes in river channels, a large volume of field evidence has been built up which demonstrates that the *mean* velocity of the vast majority of rivers actually *increases* slightly as one moves downstream, or shows little change (these data do not include velocity measurements in the tidal reaches of the rivers studied). This can seem counter-intuitive; after all is velocity not related to channel slope? Surely a river flows faster in its steep, turbulent upper course than it does as it meanders placidly through the alluvial channel of its lower reaches? While it is true that, all else being equal, flow velocity does indeed increase with increasing channel slope, all else is not equal. Resistance to flow, resulting from friction with the bed and banks, must also be taken into account. Put simply, if the channel is rough (e.g. rocky and filled with boulders) the water will not be able to flow as fast as in a smooth channel (e.g. lined with clay). Thus the resultant velocity actually depends on several factors, the dominant ones being:

i) The steepness of the channel slope

ii) The resistance to flow in the channel

These can counteract each other and must both be considered; despite the steep slope of a rocky mountain stream, the velocity will be reduced by the roughness of the channel, whereas in its lower course although the slope of the channel may be gentle, its smoothness offers less resistance to flow. The frictional resistance also lessens as the depth of flow increases (see glossary), again reducing the resistance to flow in the lower reaches. The net result is that the mean velocity increases slightly or stays much the same from source to mouth. It is only very occasionally that a decrease is seen. It should be noted that the water also has to overcome a certain amount of internal resistance as it moves; these *internal friction* forces are significant and result from turbulent structures within the flow and, at a smaller scale, water molecules moving past each other. However, it is not really necessary to deal with this idea when providing an explanation suitable for second level students.

The idea that the flow of a river slows down from source to mouth is a general observation that is widely made, even by those who have never heard of Davis, and can be difficult to dispel, as Stannard (2002), writing about the teaching of geography to second level students in the UK, points out:

> 'How much time do we, as geographers, have to spend convincing students of all ages and abilities that rivers do not (necessarily) slow down as they go from source to mouth? The answer is not obvious, and demands an understanding that several factors are involved, sometimes reinforcing and sometimes counteracting each other.'

Despite the fact that the answer is not obvious, it is possible to provide a basic explanation that can be understood at Junior Certificate level and can provide a valuable opportunity to encourage students at all levels to think about and question the evidence before them (See 'Ideas for classroom activities' for suggestions). It is important to challenge this misconception at second level because of the huge impact that rivers have on human society and the need to appreciate their basic characteristics. One example of how this understanding is applied is in the design of channel modifications for flood protection. Urban channels are often lined with concrete in order to increase flow velocity by reducing friction with the bed and banks, allowing floodwater to pass downstream more rapidly and away from the area at risk.

The power of a river decreases in a downstream direction

As well as encouraging the misconception that rivers slow down over their journey from source to mouth, the model of youth, maturity and old age also implies that there is a corresponding decrease in energy, in accordance with the analogy of the different stages of human life. We now know that the main controls on stream power are slope, as might be expected, and the discharge (or volume) of flow. This can be illustrated in general terms by considering the Brahmaputra River, which rises in Tibet and flows through India before entering Bangladesh, where it meets the Ganges. By the time the Brahmaputra enters Bangladesh, despite the fact that it has travelled many hundreds of kilometres from its source high in the Himalayas and now flows across a vast, low lying floodplain-delta complex, it is far from being old and weak. The river continuously migrates across its floodplain, eroding its banks at rates of up to 2 km a year and destroying everything in its wake: farmland, factories, hospitals, schools, businesses and homes. Managing such a large and powerful river in any way is practically impossible because of the prohibitive cost and maintenance of engineering works at this scale coupled with the fact that our understanding of such rivers is far from complete.

Incidentally, only about 5% of a river's available energy is used to carry out transportational and erosional work (Morisawa, 1968). This is because the vast majority of available energy is used just in order for the water to flow. Before the river can carry out any erosional or transportational work it must overcome a considerable amount of frictional resistance; friction with the bed and banks and internal friction within the body of the water.

IDEAS FOR CLASSROOM ACTIVITIES

When new ideas are being explored, it is often helpful for students to be able to actually see (or preferably) experience these for themselves. Many of the concepts presented in this paper can be explored through fieldwork and suitable references are provided at the end of this paper. However, field experiences are not always possible and so the following section provides some suggestions for 'hands on' experiences to be provided in the classroom. While these activities do generally model the processes, it is important to emphasise to students that reality is more complicated than in these simple experiments and that events shown by the model are not always *exactly* what is happening in reality.

Exploring the effects of slope on stream velocity

Teaching point: the steeper the slope the higher the velocity of the stream.

Materials required:

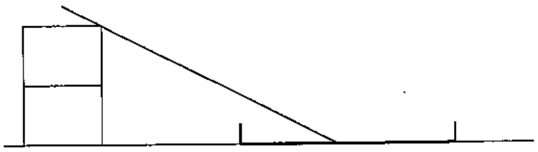
- Preferably a piece of guttering, 1-2 m in length. If this is not obtainable, you can use a flat tray, although this means that the range of slope angles in limited.
- Sand or sugar. A viscous liquid, such as glycerine or oil, would be more realistic, but would be much messier, and harder to 'recycle' for the next experiment.
- Tray, e.g. cat litter tray.
- Books/ blocks.

Method:

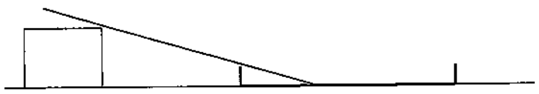
- Set up equipment as shown in Fig. 2(a).
- Ask students to observe what happens.
- Pour the sand onto the top of the trough/tray.
- Remove one block and repeat the experiment (see figure 2(b)).
- Again ask students to observe what happened.
- Debrief students on learning – the higher the angle of slope the faster the sand moved.

Figure 2: The effects of slope on velocity

(a) Steep slope



(b) Shallower slope



Effects of bed roughness

Teaching point: the rougher the bed/ banks the greater the friction between water and these surfaces and, hence, the slower the velocity of the river. Rocky streams have some of the greatest roughness values, as such a channel is likely to be lined with poorly sorted sediment and gravel and smaller boulders which, although they can not be seen above the water surface, will cause significant frictional resistance. The river also uses up much of its energy in flowing around boulders. Vegetation can also increase roughness considerably.

Materials required:

- As for Effects of Slope.
- *Either* (best) another piece of guttering 1-2 m in length with pieces of gravel / sand glued to the 'channel' sides and bed, to form a rougher bed.
- *Or* a piece of coarse sandpaper – large enough to line the guttering or tray.

Method:

- Explain to students that while slope is important, there are other factors which are also important in determining how fast water moves in a river.
- Ask the students if they have any ideas about what this might be (if they don't, tell them that one of these is how rough the river bed is).
- Explore with them what factors they can identify which might affect the degree of roughness (rocks in the bed, type of material, in-channel vegetation).
- Explain that an experiment is now going to be carried out to test out this idea.
- Students can be asked to suggest ideas about how this could be done.
- The suggested method is given below (but if your students have better ideas, why not use them?).
- Set up equipment as in Fig.2. If this experiment does not follow immediately from that exploring angle of slope, you may need to repeat the first experiment to remind students about how fast the sand flows down a smooth surface.
- Place the sandpaper in the trough/ tray – and pour the sand onto the top of the trough/tray. Students should observe the speed of flow (or, more likely, even that some of the sand does not flow at all).
- The students should be asked to explain why the sand flowed much more slowly on the rougher channel than on the smooth surface (i.e. roughness makes it much harder for the 'water' to flow).

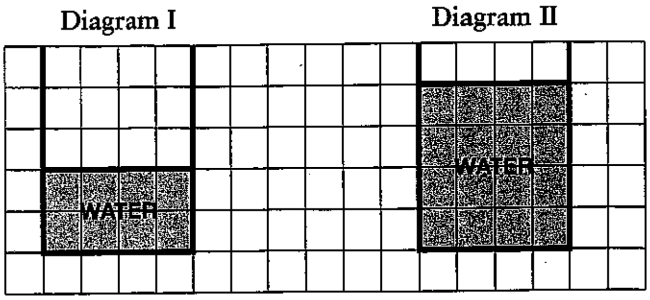
- Link this to river channels:
  - If the channel is smooth, then the river will flow more quickly than in a rough channel with a similar slope and cross-section. Hence, the frictional resistance of a typical lower course channel (where channels are likely to be smoother) would be less than in a typical upper course channel (where the channel is likely to be rougher). If all else is equal, the more frictional resistance there is, the lower the velocity will be. Conversely, less frictional resistance results in higher velocities.
  - However, as seen in the first experiment, slope has an effect on velocity – the higher the angle of slope, the faster the water will flow, so overall, the mean velocity only shows a slight increase, or remains the same downstream.
  - The main point to stress is that the mean velocity does not **generally** decrease in a downstream direction.

Effects of wetted perimeter

Teaching point: The wetted perimeter of a stream is the combined length of the bed and banks which is in contact with the water. The smaller the proportion of the channel cross-section (water) which is in contact with the bed and the banks of the channel, the less the water is slowed by the frictional resistance of the channel boundary (lower the friction between water and surface and so the faster the velocity of the stream). While both bed width and bank height are involved, it is probably easier to illustrate this point by looking at just depth. The following simple exercise helps students to understand how increasing depth can affect wetted perimeter (and, hence, friction).

- Students should 'measure' the combined length of the bed and banks in the channel in Diagram I [i.e. count the squares, remembering to count both the bank- and bed-sides at the corners] – this is the wetted perimeter and is equal to 8 units.
- Students should then 'measure' the combined length of bed and banks of the channel in Diagram II, when there is more water in the same stream, and the depth of the water has doubled. The wetted perimeter is now 12 units.
- The **depth** has doubled [from 2 units to 4] , but the wetted perimeter has **not** doubled. This means that a smaller proportion of the water is in direct contact with the bed/ banks and so friction is lower and the average velocity of the stream is greater.

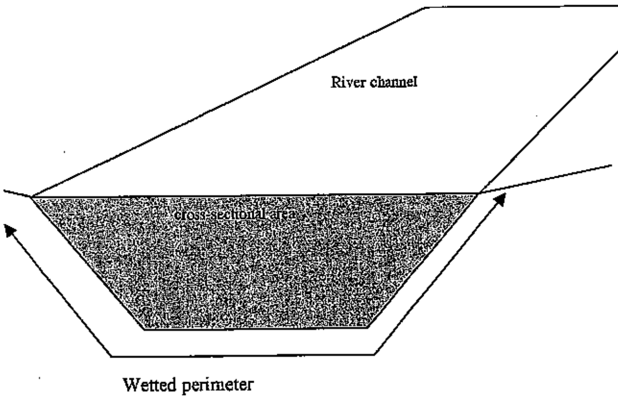
Figure 3: Channel depth and wetted perimeter



To examine the difference between channels the measurement of the wetted perimeter is compared with the cross-sectional area of the channel [Fig. 4]. The relationship between these two measurements is called the hydraulic radius and it is calculated from:

$$\text{Hydraulic radius} = \frac{\text{cross-sectional area}}{\text{wetted perimeter}}$$

Fig. 4: Channel measurements required for calculating the hydraulic radius (channel efficiency)



To compare the effects of wetted perimeter on channel efficiency [hydraulic radius]

Materials required:

- Copy of handout (with answers [marked ~~ab~~] removed!) (see Appendix).
- Acetate with the same diagrams.
- Pencil per student.
- Calculator.

Method:

- Distribute the handout to students.
- Students should complete the initial sections, to remind them of what they already know about the topic.
- After a briefing them about the task, students should complete the calculation for the first channel.
- Check that they have got the correct answer and they can then complete the second calculation.

- When this is complete the calculations should be reviewed and then they should complete the final section. It is probably a good idea to check their answers, to make sure that they have actually understood the main teaching point – the higher the hydraulic radius, the lower the friction and the higher the velocity of the stream – for a given slope angle and bed roughness.

Fieldwork

Many of the ideas here can be tested out in the field. If you want to do this, useful references are provided at the end of this article. You will need to find a suitable stream, which is shallow enough for your students to work in and includes sections where conditions are found, e.g. steeper and shallower channel slopes, different bed/ bank conditions.

CONCLUSIONS

The Cycle of Erosion proposed by W.M. Davis made the assumption that landforms develop sequentially through time, starting with a land surface that is uplifted over a relatively short time and which is then eroded over time, progressing through various stages of development (youth, maturity and old age), leading to a gradual reduction in relief. Over the last century, advances in knowledge and understanding have shown that the assumptions underlying the Davisian model - such as a brief period of uplift followed by a long period of stability, or unchanging climatic conditions - are invalid. In addition, there have been major developments in our understanding of how geomorphological systems operate. We now know that landforms, including fluvial landforms, are the net result of several different controlling factors that include climate, tectonics, geology and human activity. For example, most of Ireland's rivers, including the Shannon, have been greatly affected by recent glaciations brought about by climatic fluctuations and do not 'fit' the Davis model. The continued teaching of this model leads students to develop misconceptions about the form and behaviour of rivers. These include the idea that all fluvial systems exhibit the same characteristics along their length, that time is the only control on the development of fluvial landforms, and that rivers slow down and lose power from source to mouth. It has long been known that none of these is in fact the case and some basic recommendations have been made for the incorporation of updated material into teaching, textbooks and examination papers.

It should be remembered that the Cycle of Erosion came at an early stage in the development of geomorphology; a time at which there was very little accumulated knowledge on stream discharge data, no aerial views and several decades before the development of plate tectonic theory. As Pitty (1971) points out:

> 'It seems, on the basis of an increasingly large body of evidence, no disservice to W.M. Davis to say that his simplified teaching model is out of date, but also too easy to criticize his work simply because of the time at which he was writing.'

Davis was without doubt an outstanding geomorphologist in his time and had an enormous influence on the early development of the discipline. However, as in all areas of scholarship, continued enquiry and research has led to the development of new ideas, increased understanding and a greater insight into the operation of geomorphological systems, especially river systems. One needs only to reflect on the damage caused by recent and widespread episodes of flooding in many parts of Ireland to appreciate the importance of river systems in our daily lives. Today's Junior and Leaving Certificate students will become tomorrow's planners, engineers, policy-makers, developers, farmers and homeowners. Should they not be provided with an up to date understanding of the fluvial system rather than one that is over a hundred years old and very outdated?

Glossary of Terms

Denudation refers to the combined agents of weathering and erosion and to the removal of solid and dissolved material. The term is still valid and is widely used.

Relief refers to the difference in height over an area as distinct from its elevation or altitude above a fixed datum such as sea level. Thus an area over which there is little variation in height is described as being of low relief whether it is just above sea level or is at a high-altitude.

Depth is related to the *hydraulic efficiency* of the channel; this is basically a description of how much the water comes into contact with the bed and banks; a wide, shallow channel is less efficient than a narrower, deeper channel with the same cross-sectional area.

Further Reading

For those wishing to develop a deeper understanding, the relevant chapters in Summerfield's excellent book *Global Geomorphology* are recommended. This book is written for first and second year undergraduate students.

Fieldwork References

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Appendix: Finding the hydraulic radius of a river (Student Handout)

The speed of flow of a river [velocity] is affected by two factors i) ~~slope~~ and ii) friction (friction is affected by the ~~roughness~~ of the bed and banks and the hydraulic radius).

Look at the two channels below. To find out which one would have the most friction between bed/ banks and water you need to find the hydraulic radius. To do this you must:

1. Find the cross-sectional area of each of the channels by counting the number of squares within each one.

   Write your answers in the first row [cross sectional area] of the table below.

   Each square is 1m x 1 m and so each one has an area of 1 m^2

   and so the total number of square given the area in square metres.

2. Find the wetted perimeter of each of the channels by counting the number of edges of squares (i.e. number of metres) along the sides and bottom of the channel.

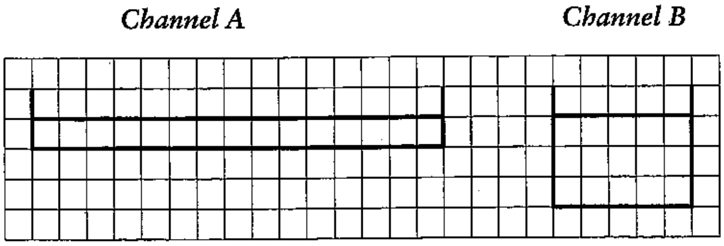
   Write your answer in the 2nd row of the table [wetted perimeter]

   Hint: Don't forget to count two sides of the squares at the edges of the channels. One of these squares has been highlighted to remind you.

3. Find the hydraulic radius using the formula

$$\text{Hydraulic radius} = \frac{\text{cross-sectional area [A] m}^2}{\text{wetted perimeter [WP] m}}$$

   Write your answer in the 3rd row of the table



squares are 1 m x 1 m therefore one square ∫ 1 m^2

The value of the hydraulic radius is high for hydraulically efficient channels (i.e. ones where there is less friction) and low for less hydraulically efficient (i.e. where there is more friction) channels.

4. Which channel is more efficient? ~~Channel B~~
5. Explain in your own words why water would flow more quickly in the more hydraulically efficient channel, i.e. one with a higher hydraulic radius. ~~Less efficient channels, i.e. lower hydraulic radius, are rougher and so there is more friction between the water and the bed/banks and so the water flows more slowly.~~

	Channel A	Channel B
Cross-sectional area (m^2) [A]	~~15~~	~~15~~
Wetted perimeter (m) [WP]	~~17~~	~~11~~
Hydraulic radius (A / WP)	~~0.88~~	~~1.36~~