05 - FLOWS, SEDIMENTS AND HYDRAULIC HABITATS: INTERACTION IN A DYNAMIC RIVERINE ENVIRONMENT

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Abstract

Knowledge of river hydrology, hydraulics and geomorphology (together termed hydromorphology) is essential for sustainable river design and management. It facilitates the assessment of risk, increases understanding within the Environmental Impact Assessment process, helps alleviate flooding impacts and informs in-stream flow requirements, system restoration and ecology. Water body hydromorphology represents a measure of the dynamic interaction between geomorphology, hydrology and local hydraulics and sedimentary character. All of these factors are fundamental to the creation and maintenance of system ecology and function, influencing species distribution and abundance.

The hydrological cycle sums up the movement of water from the catchment along the rivers and to the sea. When this movement is sufficiently energetic material derived from weathering processes in the catchment may be picked up and delivered to the river channels and this is then also moved downstream. The rate of movement is governed by the character of the material (size, cohesiveness etc.) and its location (river bed, bar top, floodplain etc.) and the overall process of sediment transport has been likened to a 'jerky conveyor belt' with frequent halting of movement and potential sediment stabilisation. The rate and pattern of movement is of fundamental importance to the instream and riparian ecology which is continually responding to system change.

As such the more traditional view of upland sediment sources, transporting zones in middle reaches and depositional lowland zones is too simplistic for general use on rivers in the UK and Ireland and the relative importance of all sediment sources within a catchment before making statements concerning likely morphological and ecological response to modification and management actions. All rivers are acting to try and balance the sediment and water flows to maintain equilibrium, disturbances anywhere within the system prevent this from happening and generate a response to try to restore the equilibrium or to move to a new equilibrium.

This disturbance pattern is reviewed with respect to engineering and management practice in the UK and Ireland and examples of good and bad practice are given illustrating the impacts of not considering the flow and sediment regime as an interlinked set of processes and illustrating how this can have lasting impacts lasting many decades. Positive and negative feedback mechanisms operating between river morphology and ecology are also investigated and approaches towards river naturalisation are appraised with respect to the overall integration of hydrology, hydraulics and geomorphology and ecology assessing their overall potential dynamic sustainability.

1. IMPORTANCE OF SEDIMENT AND SEDIMENT TRANSPORT

The bed and banks of alluvial rivers in the UK and Ireland are composed of deposited sediment. This varies in character from boulders through so silts depending on the supply character and the local hydraulics. Fine sediment is moved through rivers as suspended load and material is moved downstream during elevated flows. Coarser sediments are moved as bedload rolling and saltating along the channel bottom in response to less frequent higher energy flood flows. This latter process strongly influences the physical nature of the river creating a dynamic morphology. Disruption to sediment transport processes, particularly those relating to coarse sediment movement, can have a significant impact on river form and stability (Milan et al 2001).

The supply and movement of sediment in fluvial systems fundamentally impacts on the system ecology. Bed and bar features are composed of a variety of sediments and the nature and distribution of this mixture defines the habitat template on which the ecology exists (Figure 1). Coarse deposits can be said to characterise gravel bar features and finer sediments influence berm surfaces and backwaters, however, the pattern is often more complex with sub-unit sedimentological changes seen across individual bar features (Heritage & Milan 2009). This pattern of sediment distribution is controlled by a complex interaction between biotic and abiotic processes linked principally to sediment supply and sediment transport processes. Disruption to these processes leads inevitably to morphological response and potential habitat degradation. Such degradation has been recorded in the Water Framework Directive River Basin Management Plans published in 2009 and significant lengths of UK watercourses are classified as degraded with sediment management issues flagged as the primary cause (Figure 2).

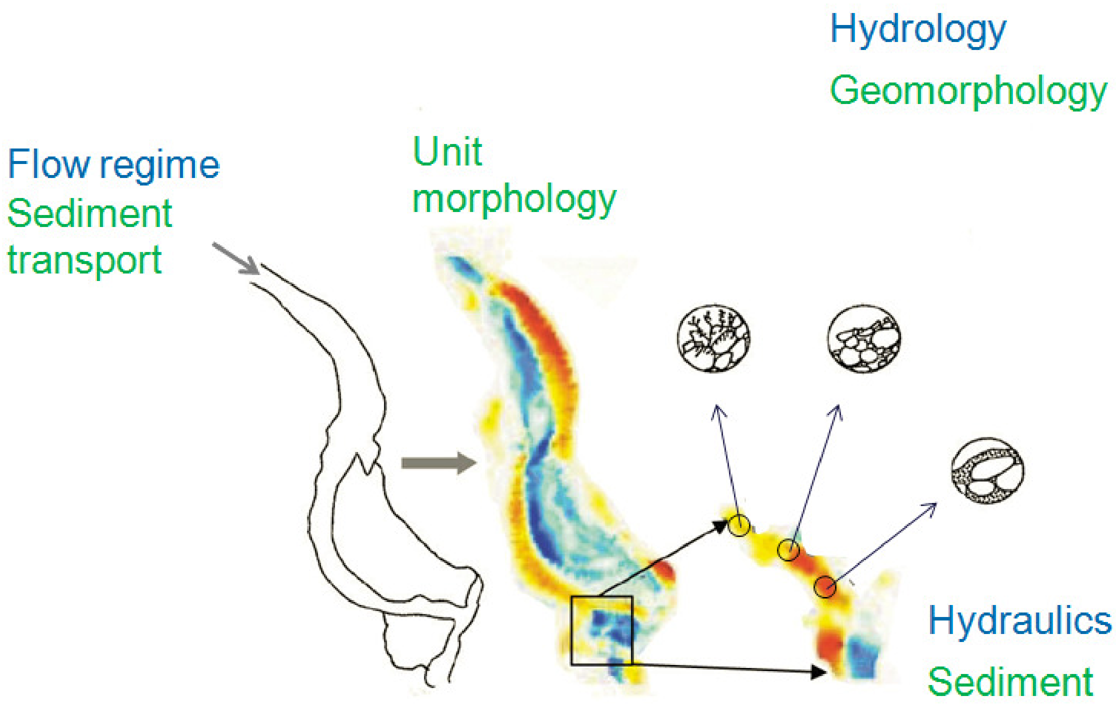

Figure 1: *The role of sediment in defining river habitat (modified after Newson & Large 2006)*

This paper reviews the nature of sediment supply, storage and transport along UK and Irish rivers and looks at the recorded impact of engineered alterations to watercourses relating river response to sediment transport. It will demonstrate the sensitivity of UK and Irish rivers to sediment disruption and illustrate the long term changes to system stability that can occur as a result.

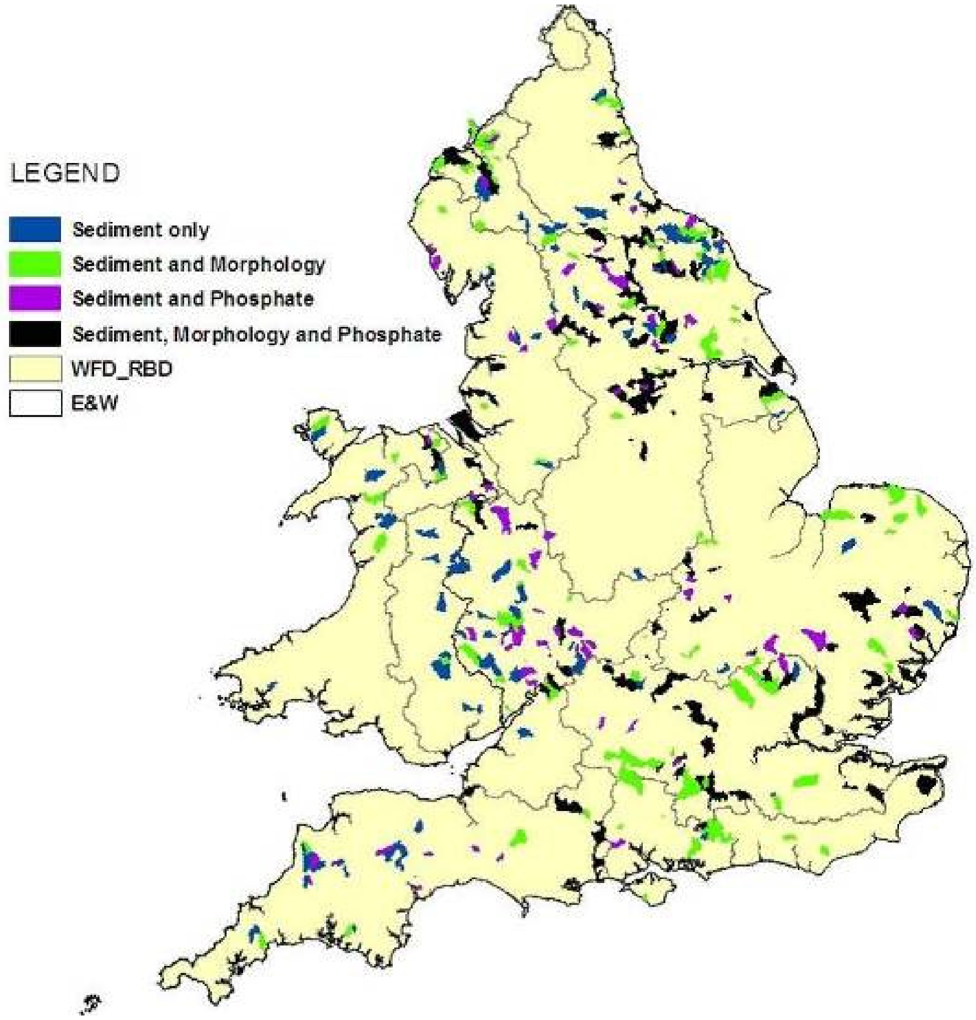

Figure 2: *Watercourses in England and Wales suffering from sediment related degradation.*

2. PATTERNS OF SEDIMENT TRANSPORT

Erosion and deposition affect all rivers to varying degrees. Rivers fundamentally act as conduits for the movement of water and sediment from their source through to the sea. This process is not uniform either in space or time and discontinuities create the landforms we see today. Most of the time river flows do not have sufficient energy to bring about change and the landforms in the catchment remain stable. However, higher magnitude events generated by precipitation events in the catchment will cause change as a result of flooding and sediment redistribution (Knighton 1998). All rivers are acting to try and balance the sediment and water flows to maintain an equilibrium, disturbances anywhere within the system prevent this from happening and generate a response to try to restore the equilibrium or to move to a new equilibrium.

In many temperate systems like those that exist across Ireland the degree of change over time is not dramatic, oscillating around a steady state (Figure 3a) or progressing along a slow trajectory (Figure 3b). In other systems more prone to extreme events changes may be more dramatic and may result in long-term system switching (Figure 3c) major system oscillation (Figure 3d) or system resetting (Figure 3e). As a result temperate river systems do not exhibit widespread destabilisation following flood events, however, the potential for significant local change linked to an altered sediment transport regime remains.

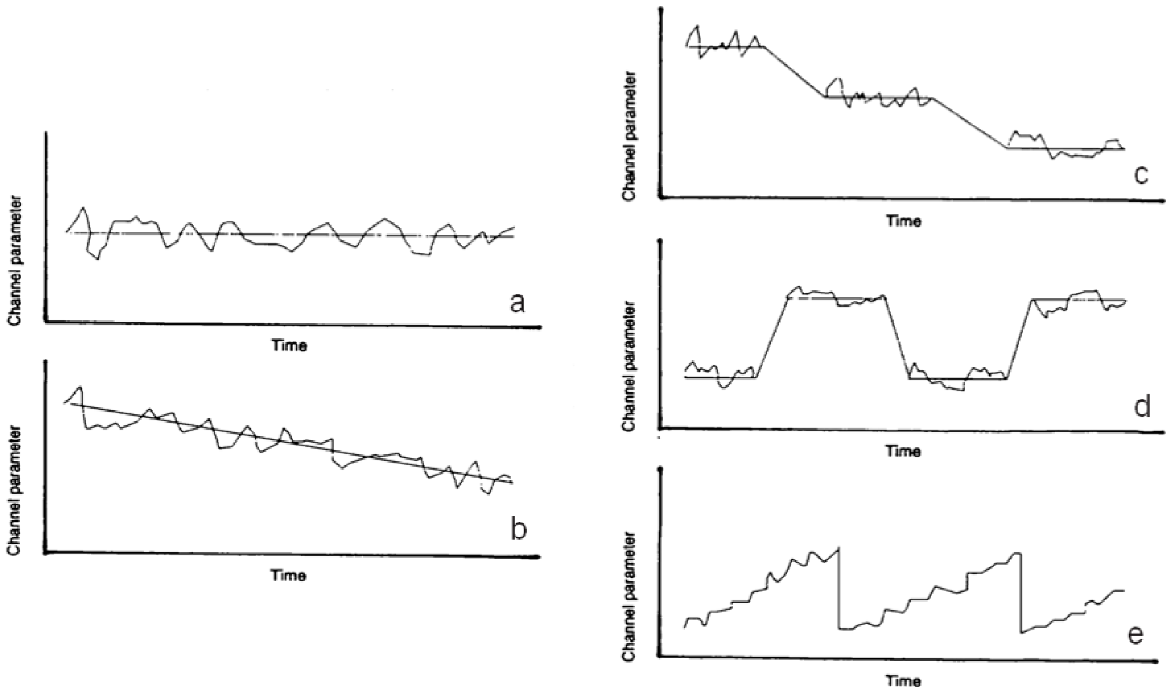

Figure 3: *River equilibrium and patterns of river channel development (after Petts and Foster 1985).*

The nature of river flows means that the most dramatic changes occur during floods, however, it should be borne in mind that small scale changes are happening within the catchment slowly over time. The hydrological cycle water sums up the movement of water from the catchment along the rivers and to the sea. When this movement is sufficiently energetic material derived from weathering processes in the catchment may be picked up and delivered to the river channels and this is then also moved downstream. The rate of movement is governed by the character of the material (size, cohesiveness etc.) and its location (river bed, bar top, floodplain etc.) and the overall process of sediment transport has been likened to a 'jerky conveyor belt' with frequent halting of movement and potential sediment stabilisation. The rate of movement may be generally linked to the location of the sediment in relation to the main channel (Figure 4).

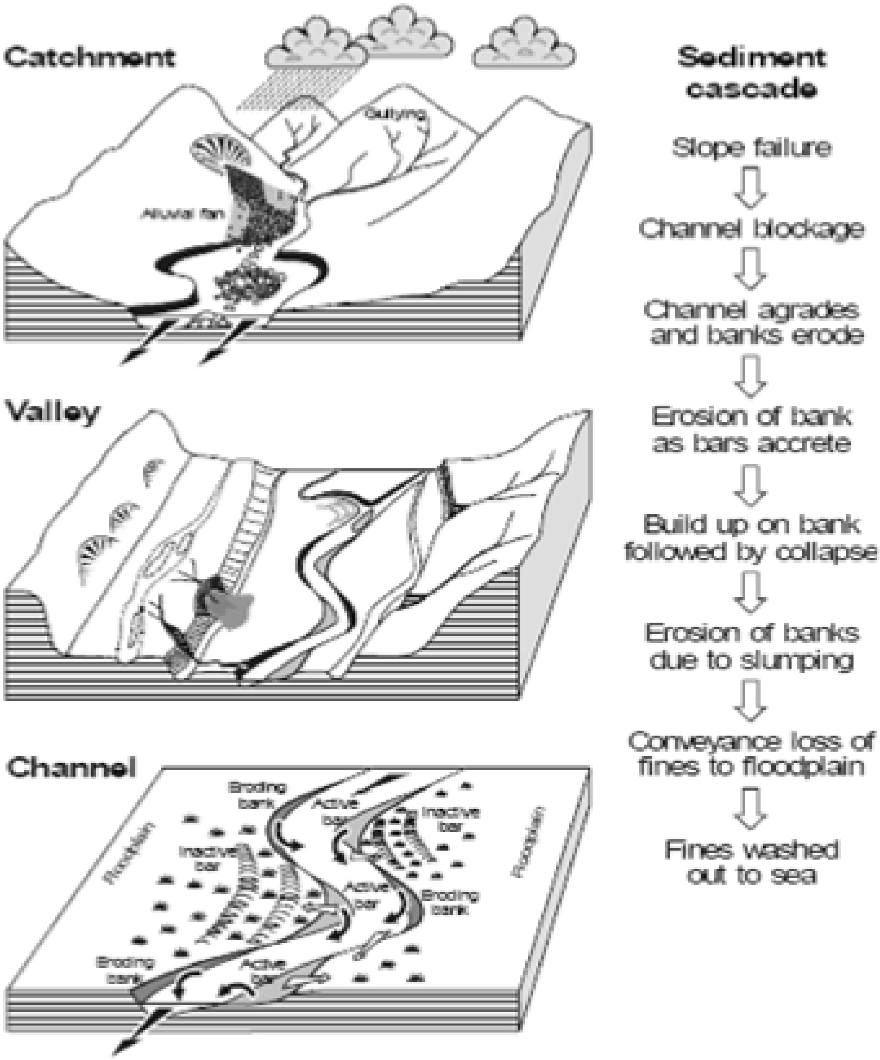

Figure 4: *The sediment cascade through a river catchment and rates of landform change (after Sear et al 1995).*

At one extreme material generated in the catchment may be disconnected from the channel system and is stored for very long periods (Figure 5a) and at the other extreme fine sediment moving rapidly as suspended load within the main channel (Figure 5d). In between sediments may be stored on valley sides and floodplains (Figure 5b&c).

Figure 5: *Examples of the sediment cascade, a) Catchment, b) Valley side, c) Floodplain, d) River channel.*

Sediment derived from the catchment moves through the system from one river reach to another with each reach behaviour influencing subsequent reaches downstream. As such a cascading sediment pathway may be conceptualised for any catchment and sensitive reaches established. The complexity of this cascading process, coupled with the often sparse knowledge of individual processes and potentially dramatic alterations in the catchment makes the prediction of likely change difficult.

3. CAUSES AND CONSEQUENCES OF SEDIMENT TRANSPORT DISRUPTION

Potential disruption to the sediment transport regime is possible through a number of engineering and management interventions associated with a river and its catchment. Measures include direct protection and indirect management of the variables acting to cause the problem. The potential effects are summarised briefly below:

> *Impoundment:* Flood flows attenuated and sediment transport severely disrupted. Clear water flow downstream likely to cause erosion and trigger temporal erosion/deposition cycle downstream.
>
> *Floodplain storage areas:* Floodwater stored naturally across floodplain areas, peak flows attenuated, sediment transport allowed to occur. Little impact downstream.

Floodbanks & 2 stage channels: Flood flows retained in narrow strip adjacent to main channel. Local energy levels increased, heightened risk of erosion and sediment transport. Transported material may deposit downstream.

Channel widening: Channel capacity increased, flood flow depths and flood energy reduced, deposition likely. Oversized channel may also fill with sediment as river acts to revert to original capacity linked to bankfull discharge.

Channel deepening: Flood flow depths increased. Local energy levels increased. Heightened risk of erosion and sediment transport. Transported material may deposit downstream. Potential for erosion to progress upstream.

Channel straightening: Channel gradient and local energy levels increased. Heightened risk of erosion and sediment transport. Transported material may deposit downstream. Potential for erosion to progress upstream.

Flood bypass channel: Flood flows split. Peak discharge and flow energy reduced, deposition likely. Original channel may also fill with sediment as river acts to adjust to new flow regime.

Partial Dredging: Channel capacity increased with no change to river flow and sediment delivery regime. Effects likely to be temporary as new sediment will accumulate at old depositional sites where conditions favour bar development.

Catchment management of sediment source: Sustainable option treating the source of the problem rather than the symptoms. Often part of a long-term strategy. May cause unexpected river response due to multivariate nature of the system.

Upstream sediment trapping: Acts to intercept sediment before it enters the depositing reach. Traps prone to local instability. Clear water flow downstream likely to cause erosion and trigger temporal erosion/deposition cycle in previously depositing reach.

Direct sediment removal: Dredging of deposited material restores channel design capacity but sediment delivery issue remains untreated leading to renewed deposition.

All of the approaches listed above will cause a reaction as the river attempts to adjust to the changed conditions. The rate and style of reaction will depend on the energy available to the river and may be usefully divided into upland, mid reach and lowland river response (Table 1).

Table 1. *Engineering feedbacks to channel process/morphology*

Engineering work	Upland boulder-bed steep channel	Transfer gravel-bed moderate channel	Lowland sand-silt/clay channel
Straightening & deepening	Destabilises channel especially in large floods. High maintenance frequency.	Upstream incision and downstream aggradation. Shoaling reforms. High maintenance frequency.	Encourages downstream aggradation and upstream incision. Bank erosion increases siltation and maintenance.
Dredging to grade	Difficult to maintain.	Riffles/pools/bars are natural features, high frequency of upstream and downstream adjustments.	Upstream incision, downstream aggradation. Channel silts up. Banks need protection.
Close set embankments	Increased stream power.	Increased erosion and deposition, migration.	Bank and bed erosion. High maintenance frequency.
Set back embankments	Limited value in these channels.	Accommodates floods and allows migration.	Leaves low flow hydraulics natural.
Two-stage channel	Limited value.	Berm unstable.	Must accommodate meanders.
Culverting	High strength required. Costly.	Dredging required. High cost.	Rapid siltation. Bed can aggrade downstream.
Trapping	Protection required downstream. Fills on flood	Site on riffles. Needs regular maintenance.	Large trap required. Bed mobility problem.
Hard bank protection	Environmentally unacceptable. High cost. Short life.	High cost. Limited success. High maintenance.	High cost. Limited success.
Soft bank protection	Encourages vegetation.	Success dependent on installation procedure.	Needs time to colonise.
Grade control (rock dams/piling)	Used to stop incision. Can cause bank erosion.	Can increase instability. Mobile bed/bank problems.	Flood scour problems.
Underpinning bed/banks	High cost.	High cost. Additional bank protection required.	Deep working required. Additional bank protection.

4. EXAMPLES OF RIVER RESPONSE TO ALTERED SEDIMENT REGIME

The general effects listed in table 1 have been recorded on many UK rivers. The following examples illustrate this in more detail.

On the River Wharfe in North Yorkshire active delivery of coarse sediment to the main river means that cobble and gravel bar deposits are common after it enters the lower gradient piedmont zone downstream of Hubberholme and locally these deposits are causing planform instability forming an incipient wandering channel system. This type of behaviour is a response to the present flow and also to a gravel dredging, enbankment and realignment programme carriedout on the river in the 1980s. It has been recognised that river instability has been triggered through engineering disruption to sediment transport processes and long term remedial sediment management activities have been instigated in the upper catchment include degripping of moorland areas and planting of headwater gills to help stabilise soil creep processes. However, the volume of sediment currently mobilised within the catchment is large compared with the present size of the bar deposits in the main channel and it is likely that localised sediment source zones will remain active supplying coarse material to the river and promoting local instability in the short and medium term. Prediction of longer term channel response to reduced sediment loads (JBA 2009,) has proved difficult, however, the active high energy nature of the system means that change is inevitable. Sediment starvation generally results in excess energy available to remobilise sediments stored in the channel bed and banks possibly leading to a rationalisation of the channel network within the instability zones, bed lowering and enhanced outer bank erosion. Adjustment to the new sediment regime is likely to be slow and complex due to the continued availability of sediment and the indeterminate effectiveness of the management measures.

The Bandon River flows through County Cork and displays a moderate gradient. It is characterised by an alluvial bed of gravels and cobbles forming a pool-riffle sequence. The pools are characteristically long and often quite shallow, separated by shorter gravelly riffles. Bedrock influences the channel profile outcropping as rapids intermittently along the channel (Figure 6). Gravel supply to the main channel is at low but natural levels given the stability of the catchment. Gravel transport along the river is intermittent and spatially variable, being controlled by the frequency of flood flows. Fine sediment transport is much more frequent but is having little overall immpact on system morphology.

Figure 6: *A typical bedrock influenced rapid on the River Bandon.*

A recent hydromorphic audit (JBA 2011) suggests that during periods of low flood frequency sediments are able to accumulate locally as bar features and these features may become stabilised following the growth of vegetation. Deposition sites include natural low energy zones such as the inside of meander bends and in the lee of upstream obstructions (figure 7). Artificial low energy zones created by channel modification (weirs, bridge piers and widening) also promote sediment deposition. This is particularly notable at bridge crossings and through the town of Bandon where the channel has been widened. Flood flows may cause both sediment stripping, particularly across bedrock influenced rapids, and deposition as transported sediment is dropped out as the flood recedes. The continuous low level supply of sediment and the numerous small in-channel storage areas for gravels indicates that the River Bandon is, and will continue to be, an active gravel transporting river highly sensitive locally to changes to sediment transport processes. Disruption to these processes will have impacts locally and on the wider channel dynamics due to the interlinked nature of process and form along the river.

Figure 7: *Natural bar deposition sites on the River Bandon (Images © Google Earth).*

5. CONCLUSIONS

Sediment transport processes and patterns fundamentally influence river channel and floodplain morphology and ecology and these are summarised in figure 8.. Disruption to the sediment transport regime, particularly that for coarse sediment, can have significant complex and long term impacts on channel stability. Major disruption must be avoided both to avoid protracted management issues and to comply with the objectives of the Water Framework Directive which states that sediment transport continuity should be maintained in order to move towards the goal of good ecological status for all of Europe's water bodies by 2027.

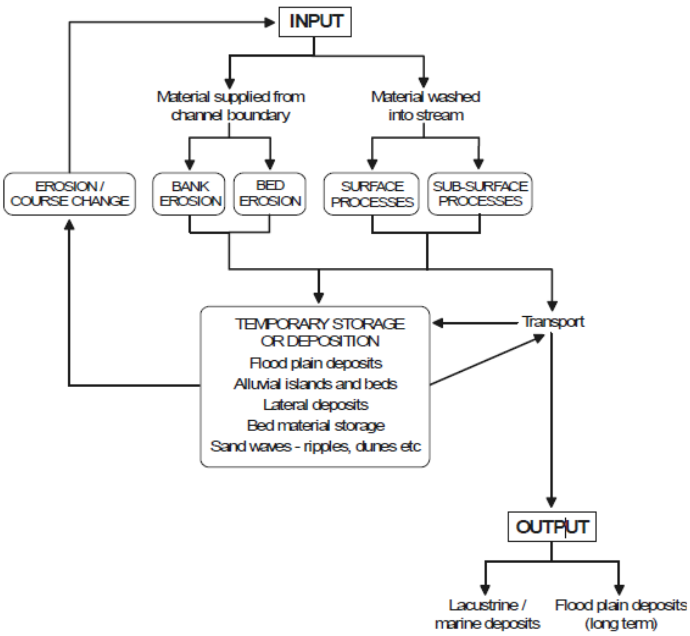

Figure 8*: A linked model of channel morphology and catchment sediment dynamics (after Heritage et al 2001),*

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