River Dynamics 101 - Fact Sheet

River Management Program
Vermont Agency of Natural Resources

Overview

In the discussion of river, or fluvial systems, and the strategies that may be used in the management of fluvial systems, it is important to have a basic understanding of the fundamental principals of how river systems work. This fact sheet will illustrate how sediment moves in the river, and the general response of the fluvial system when changes are imposed on or occur in the watershed, river channel, and the sediment supply.

The Working River

The complex river network that is an integral component of Vermont's landscape is created as water flows from higher to lower elevations. There is an inherent supply of potential energy in the river systems created by the change in elevation between the beginning and ending points of the river or within any discrete stream reach. This potential energy is expressed in a variety of ways as the river moves through and shapes the landscape, developing a complex fluvial network, with a variety of channel and valley forms and associated aquatic and riparian habitats. Excess energy is dissipated in many ways: contact with vegetation along the banks, in turbulence at steps and riffles in the river profiles, in erosion at meander bends, in irregularities, or roughness of the channel bed and banks, and in sediment, ice and debris transport (Kondolf, 2002).

Sediment Production, Transport, and Storage in the Working River

Sediment production is influenced by many factors, including soil type, vegetation type and coverage, land use, climate, and weathering/erosion rates. Once the sediment enters the fluvial system it will be transported and/or stored within the system including the flood plains.

The watershed through which a river flows or drains dictates the sediment types and amount, that will be transported and/or stored. Within the watershed there are locations where sediment is produced, transported,or stored. These zones are often referred to as: source (production), transfer (transport), and response (storage or deposition) (Figure1).

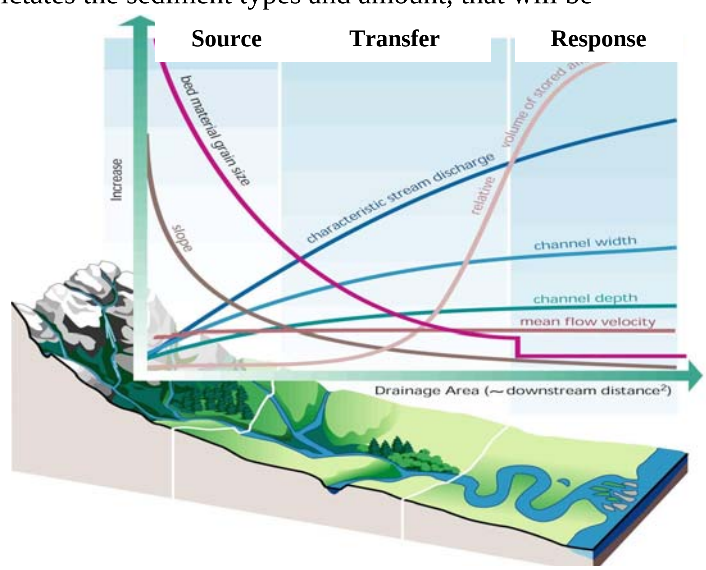


Figure 1 Watershed sediment source, transport and deposition locations. (from the Stream Corridor Restoration Manual, Federal Interagency Stream Restoration Working Group, 1998).

- **Source streams**: Primarily where non-alluvial sediments (colluvial material) enter into the stream system, from landslides and mass wasting failures, and transported with debris during large and infrequent flow events.
- **Transfer streams**: Geomorphically resilient with high sediment transport capacity. These streams are able to convey limited increases in sediment loads and will change little in response to reduction in sediment supply. Generally, the sediment volume supplied to transport reaches is balanced by the sediment exported from the reach.
- **Response streams**: Storage reaches in which significant geomorphic adjustment occurs in response to changes in sediment supply. Zones of transition from transport to response or storage reaches are locations where changes in sediment supply may result in both pronounced and persistent channel instability.

After the sediment enters the fluvial system, the movement of sediment is influenced not only by the zone of the watershed the river is in, but also the local conditions of the river. The sediment transport **capacity** refers to the amount and size of sediment that the river has the ability, or energy to transport. The key components that control the sediment transport capacity, are the **velocity** and depth of the water moving through the channel. Velocity and depth are controlled by the channel slope and dimensions, discharge (volume of flow), and roughness of the channel. Changes in any of these parameters will result in a change in the sediment transport capacity of the river.

The specific characteristics of the sediment **load** is another key factor influencing channel form and process. The load is the total amount of sediment being transported. There are 3 types of sediment load in the river: dissolved, suspended, and bed load. The dissolved load is made up of the solutes that are generally derived from chemical weathering of bedrock and soils. Fine sands, clay, and silt are typically transported as suspended load. The suspended load is held aloft in the water column by turbulence. The bed load is made up of sands, gravel, cobbles, and boulders. Bed load is transported by rolling, sliding, and bouncing along the bed of the channel (Allan, 1995). While dissolved and suspended load are important components of the total sediment load; in most river systems, the bed load is what influences the channel morphology and stability (Kondolf, 2002).

By comparing the sediment transport capacity with the sediment load, some general assumptions can be made as to whether a river will erode more sediment, deposit extra sediment, or be in balance with the amount of erosion and deposition happening. For example:

- If the capacity is greater than the load, erosion would be expected. {capacity > load = erosion}. This is due to the river having the excess energy needed to transport more sediment than is currently being transported.
- If the capacity is less than the load, deposition would be expected {capacity < load = deposition}. The amount of excess energy needed to move the extra sediment is not available in the system, so the sediment is deposited in the channel.
- If the capacity equals the load, no net change in erosion and deposition would be expected. {capacity = load = no net erosion/deposition}. River systems, or reaches ,are considered **in equilibrium** when there is a balance between the amount of sediment load being supplied to the system and the capacity of the system to carry that sediment load (Field, 2002).

Another way to view this concept is to use Lane's Diagram (Figure 2). Lane's balance diagram demonstrates how the channel may respond to a change in various parameters, such as sediment load, channel geometry, channel slope, erosion resistance, and discharges (hydrologic load). For example, by increasing the amount of sediment load the scale will tip toward aggradation (sediment deposition); to bring the scale back in balance a change in either the channel geometry, slope and/or hydrologic load would be needed. There are natural fluctuations in the balance of any of these inputs; such as flood events, valley wall slope failures increasing sediment loads, beaver dams or debris jams causing changes in channel geometry, etc. Human caused changes in this balance are also occurring in the watershed, along the floodplains, and in the channel. The degree and type of adjustment will depend on whether it is a source, transfer or response reach, the sediment transport capacity, and the type and magnitude of change that was introduced to the system.

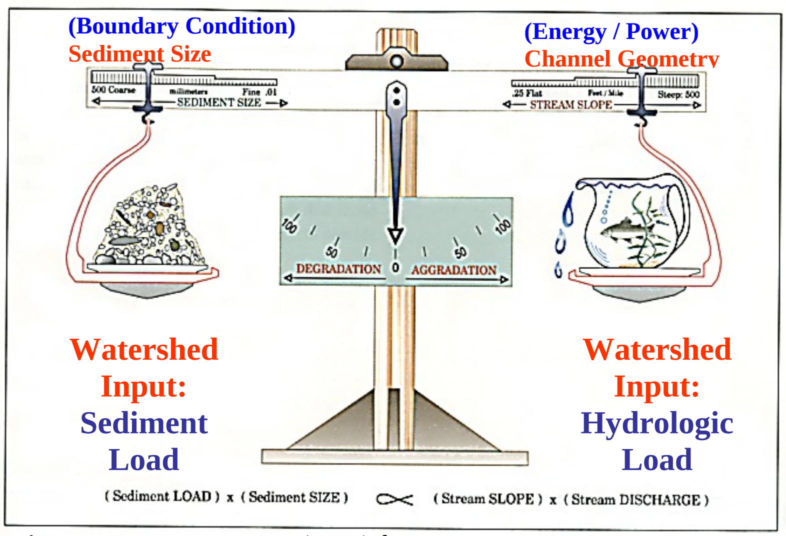


Figure 2: Lane's Diagram (1955) from Rosgen 1996

Types of Channel Adjustments in the Working River

When the balance of sediment load, hydrologic load, and/or channel geometry and slope is changed there is often a response, or adjustment of the fluvial system as it attempts to re-establish the equilibrium condition. Of the types of rivers typically seen in Vermont, the process of adjustment is predictable. Schumm's Channel Evolution Model (1984) in Figure 3 illustrates the most commonly encountered channel adjustment or response sequence in Vermont. The channel evolution model is helpful in demonstrating the response of the river to climate driven or human imposed changes within its watershed, floodplain, and within the channel itself. It is also valuable in demonstrating that rivers are not static systems; rivers will respond and adjust as the input variables to the system are changed.

Stage II Incision, downcutting, and degradation are all words used to describe the process whereby the stream bed becomes lower in elevation relative to its flood plain through erosion, or scour, of bed material, channel management activities such as dredging or straightening, or flood plain filling or encroachment. Some streams incise so deeply they become entrenched streams (losing access to their floodplains altogether). Channel incision may occur when there has been a significant increase in flows, a significant decrease in sediment supply, a significant increase in slope due to a reduction of channel sinuosity or loss of floodplain access. Active incision is energized by high flow events or triggered by a significant reduction in the channel bed (boundary) resistance.

Stage III Widening usually follows the channel degradation process. The containment of higher flows within an incised channel increases available energy and typically leads to erosion of one or both banks. Alternating stages of widening and aggradation occur as the stream forms a new floodplain at a lower elevation. An over-widened channel is also an outcome of the sediment aggradation process (Stage IV). When the stream becomes incapable of transporting its sediment load, sediments collect on the stream bed, forming mid-channel or point bars that concentrate flows against the banks, and lead to a wider channel. In situations where bed scour resistance is significantly greater than bank erosion resistance, the channel response to an increase in flows, decrease in sediment supply, or channel straightening, may skip over Stage II incision, or express incision only to a minor or inconsequential degree.

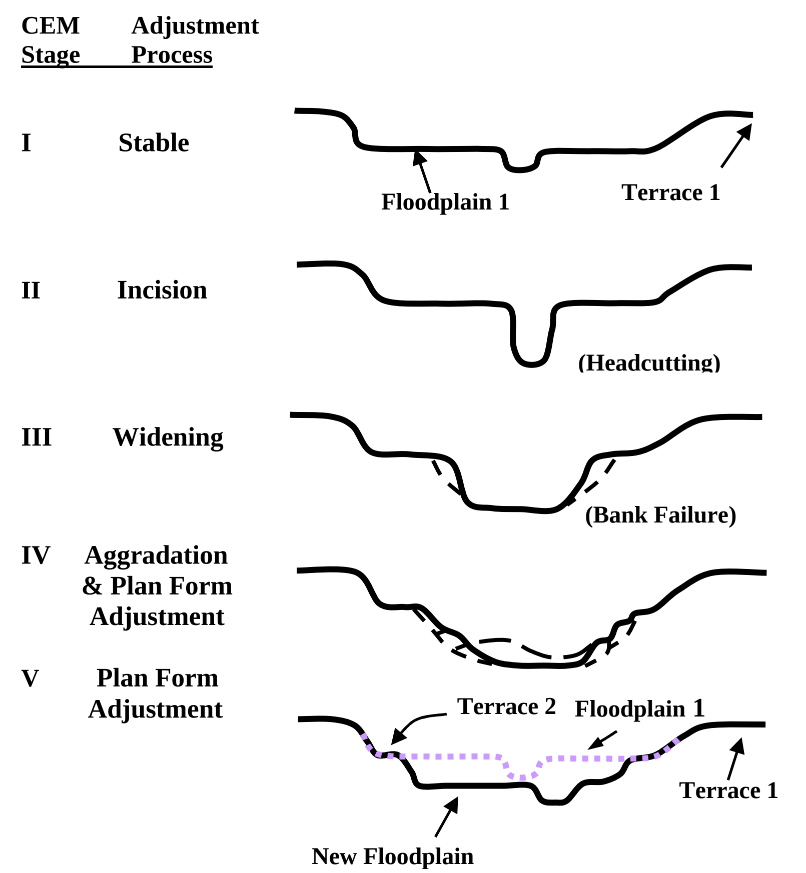


Figure 3: Five Stages of Channel Evolution (CEM) (Schumm, 1984), the channel condition and adjustment often observed during each stage

Stage IV Aggradation is a term used to describe the raising of the bed elevation through an accumulation of sediment. Channel aggradation may occur when there has been a significant decrease in flows, a significant increase in sediment supply, or a significant decrease in slope due to meander elongation or downstream hydraulic constrictions, such as bridges and culverts. Depending on upstream processes and the boundary conditions of the reach, channel widening may occur in association with channel aggradation.

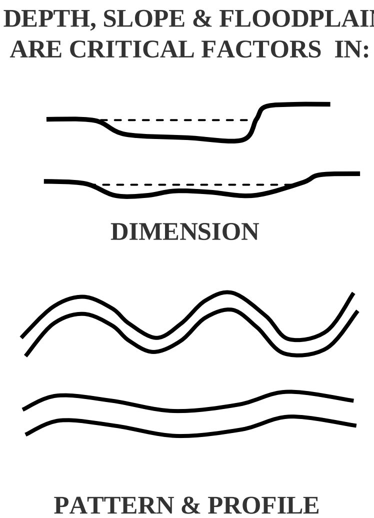
The **Planform** is the channel shape as seen from the air. Planform change can be the result of a straightened course imposed on the river through different channel management activities, or a channel response to other adjustment processes such as aggradation and widening. When a river changes planform and cuts a new channel, a change in channel slope usually results, sometimes initiating another channel evolution process. This evolution process will start with degradation if the channel slope is increased, or with aggradation if the slope is decreased.

When a stream is in adjustment, it is evolving toward equilibrium or working to reestablish balance with its watershed inputs (VT Stream Geomorphic Assessment Phase 3 Handbook, 2004). Using the fundamental relationship offered by Lane (Figure 2) an understanding may be gained as to how different land uses, management activities, or natural events (i.e. floods) “tip the balance.” The time required for a stream to adjust to a given disturbance is difficult to predict owing to the fact that they are influenced by boundary conditions, climate, and history or persistence of disturbance (Center for Watershed Protection, 1999b) but can take decades or centuries.

Rivers are a metaphor for "change." Every fluvial system changes in time. **Sensitivity** refers to the likelihood that a stream reach will respond to a watershed or local disturbance. The exercise of assigning a sensitivity rating to a stream is done in the context that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment. A stream's inherent sensitivity may be heightened when human activities alter the setting characteristics that influence a stream's natural adjustment rate including: boundary conditions; sediment and flow regimes; and the degree of confinement within the valley. Streams that are currently in adjustment, especially degradation or aggradation, may be acutely sensitive.

The Dynamic River

Knowing that rivers are a dynamic system and are sensitive to change (Figure 4), the types of management strategies considered for the watershed and the river must evaluate the short and long term effect(s) of that management strategy on the fluvial system. The geomorphic condition of the stream can be used as both an indicator and predictor of watershed function and health. Applying the science provides tools to manage fluvial conflicts between river processes and human investments by recognizing streams as a continuous system, rather than a collection of unrelated problem sites.



HOW STREAMS WORK

- **↓ Dynamic equilibrium is achieved through sediment continuity (Sediment In = Sediment Out)**
- **↓ Sediment continuity is achieved when the stream has the power to move the size and quantity of sediment delivered to the stream reach**
- **↓ Stream power is a function channel slope and discharge**
- **↓ Channel slope is a function of floodplain width and meander pattern**
- **↓ Flow velocity and channel area are functions of discharge and are determined by channel and floodplain dimensions (width and depth)**

Figure 4. "How Streams Work" to achieve sediment continuity and dynamic equilibrium.

References:

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