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ALASKA DIVISION OF MINING REFERENCE MANUAL FOR CHANNEL MORPHOLOGY

by

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INTRODUCTION

An understanding of the effects of placer mining on the morphology of creeks being mined is critical to the codification of reclamation techniques, and to the further development of environmental regulations for placer miners. Critical parameters for the evaluation of streams and channel morphology can be analysed by earth scientists, and can be utilized to predict the impact of various reclamation styles upon the channel morphology of a given stream. This paper is a review of some important aspects of channel dynamics and stream hydraulic parameters, compiled in order to help recognize the effects of placer mining and predict preferred reclamation procedures.

THEORY

REVIEW OF STREAM HYDROLOGY

A review of stream hydrology is necessary to understand how streams are affected by placer mining and how mined streams may be restored to a condition which approximates that of the pre-mined stream. Beschta (1989), offers an excellent review which is included here in paraphrased form. Critical concepts in understanding stream hydrology include fluvial geomorphology, hydraulic characteristics, stream power and adjustments, and flood frequency analysis.

FLUVIAL GEOMORPHOLOGY

Fluvial geomorphology studies the ways in which streams alter landforms. Geomorphic and hydrologic function, classification of stream networks, longitudinal profiles of streams, geologic controls, floodplains and terraces, and general types of channels are components of fluvial geomorpholgy. An understanding of these components is crucial to any study involving the effects of placer mining on fluvial systems.

First, geomorphic and hydrologic function need to be understood. The processes of erosion, transportation, and deposition of sediments are most relevant in fluvial geomorphology. Stream systems generally erode material in the steeper upper reaches. This material is transported via stream channels and eventually deposited in the lower reaches of a stream system, and ultimately into oceans. Whether a given stream reach is erosional, transportational, or depositional depends on several hydraulic characteristics which are discussed in a later section.

Classification of stream networks is based on stream orders and on hierarchical classification. Stream order is a measure of the number of tributaries feeding any given fluvial system. Hierarchical classification considers stream network patterns, stream reach, and stream channel units.

A single, small channel with no tributaries is classified as a first order stream (Strahler, 1946). A second order stream is formed by the juncture of two first order streams. Two second order streams combine to form a third order stream, and so on

(Figure 1).

Hierarchical classification includes the stream networks overall patterns and the characteristics of the stream reach. Overall stream network patterns include radial, trellis, and dendritic and are controlled by variables such as bedrock lithology and structure. Dendritic, radial, trellis, and blocky Stream network patterns are common, and are controlled by bedrock (Figure 2). Dendritic patterns are typical of most stream networks. Areas with bedrock domes are typified by radial network patterns. Highly folded bedrock results in trellis stream network patterns. Where bedrock is highly faulted, stream network patterns are blocky.

Contiguous sections of channel with similar overall characteristics are defined as stream reaches. Upper stream reaches are generally steeper with higher gravitational potential than lower stream reaches.

Channel units are delineated as recurring variations in channel dimensions along a particular stream reach. The most commonly identified channel units are pools and riffles, although there are others (Figure 3).

Drainage density is another parameter which helps to define overall stream network patterns and may be expressed as number of streams per unit area of drainage basin. Drainage density is higher for low permeability substrates, drainage basins with a low percentage of forest cover, and high amounts of precipitation. Conversely

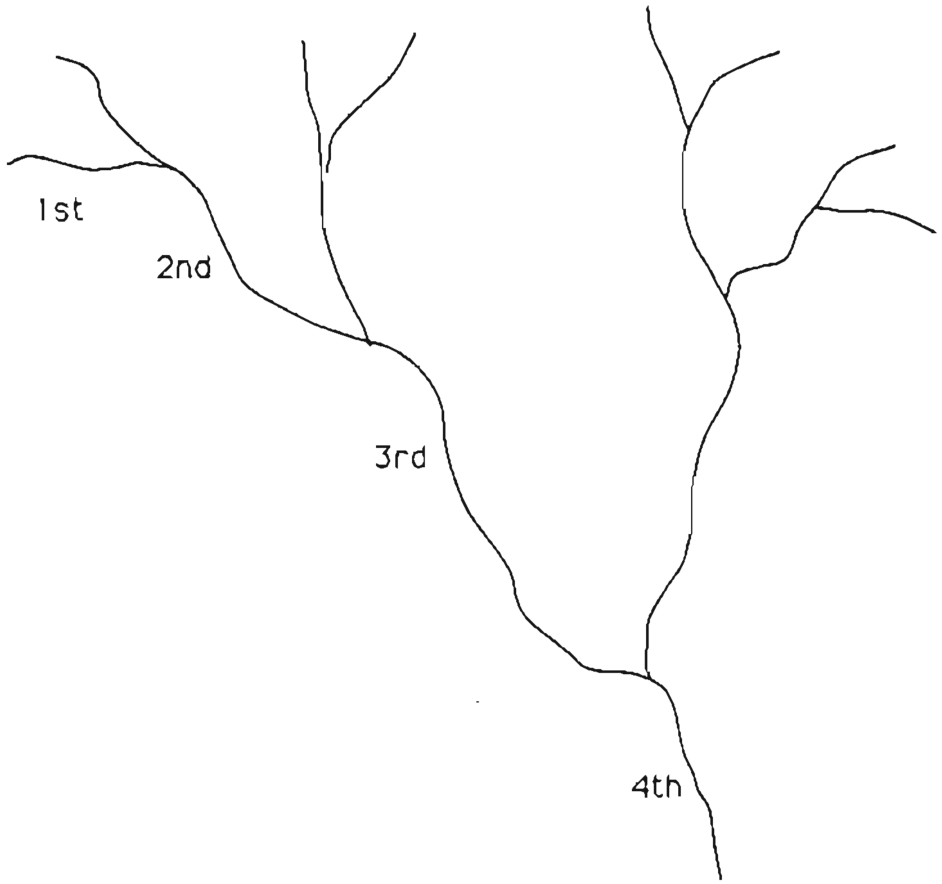
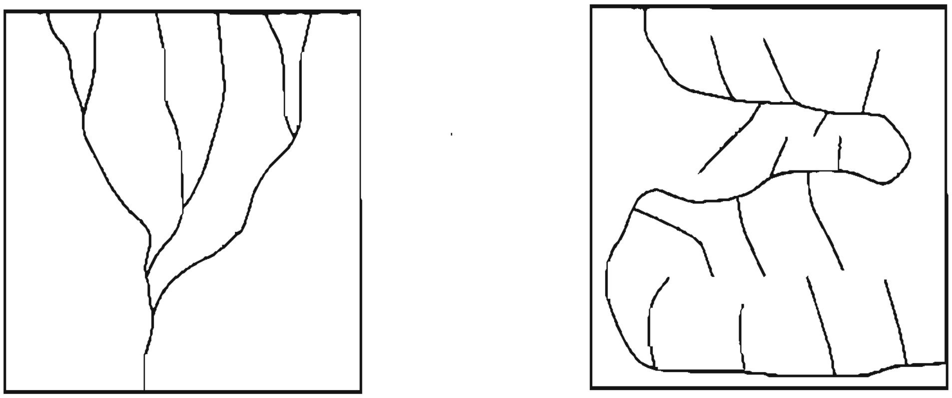


Figure 1. Stream order classification (after Straehler)

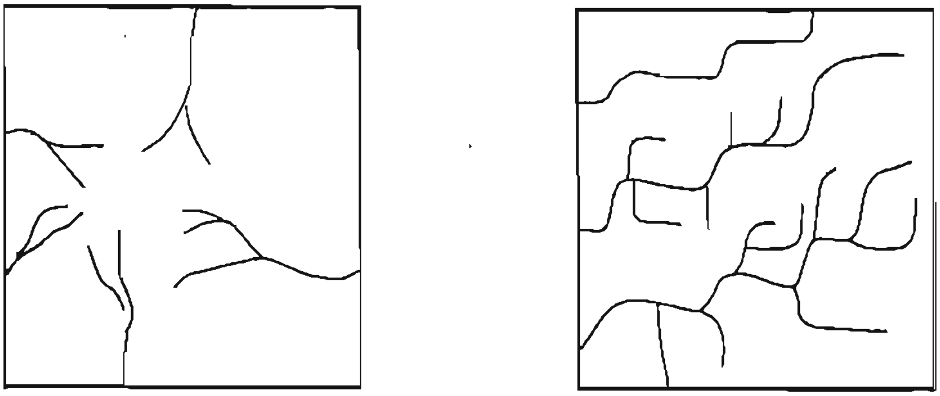


1. Dendritic

Most common

2. Trellis

Folded bedrock



3. Radial

Dome controlled

4. Blocky

Faulted bedrock

Figure 2. Effect of bedrock geology on drainage patterns.

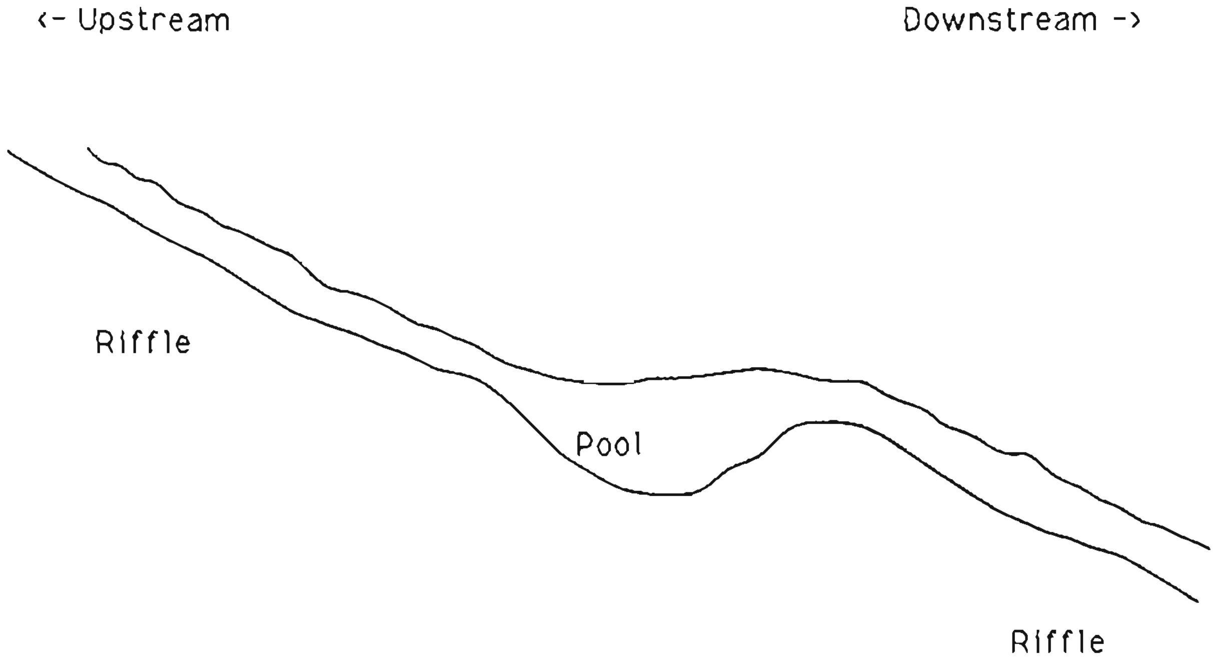


Figure 3. Pool and riffle channel units. Vertically exaggerated.

drainage density is lower for highly permeable substrates, areas with high percentage of forest cover, and low precipitation rates (Figure 4).

Another descriptive aspect of fluvial geomorphology is longitudinal profile. Longitudinal profile is represented by a plot of stream elevation versus horizontal distance. Usually longitudinal profile indicates steep headwater reaches, and the flattening out of a stream away from headwater reaches.

Geologic controls are important to the development of stream geomorphic characteristics. A bedrock knickpoint is said to exist where a stream bed is in contact with bedrock. In addition to the controls on stream network pattern and drainage density, bedrock knickpoints can influence local stream gradient and size of clasts along the stream bed.

An important concept in stream hydrology is that of a constrained versus an unconstrained stream. Where bedrock, colluvium, alluvium, or other deposited weathered bedrock prevents the lateral migration of a stream, that stream is said to be constrained. Streams which are free to migrate laterally are unconstrained (Figure 5).

Floodplains and terraces are important geomorphological features associated with streams. Floodplains are flat areas adjacent to streams where sediment can be deposited when a stream overflows its banks. These areas tend to moderate flow by storing water during flooding and contributing water, which has been stored in their soils, during periods of low flow. Terraces are flat

1. Low Precipitation
Permeable Substrate

3. High Precipitation
Permeable Substrate

2. Low Precipitation
Impermeable Substrate

4. High Precipitation
Impermeable Substrate

Figure 4. The effects of precipitation and substrate permeability on drainage density.

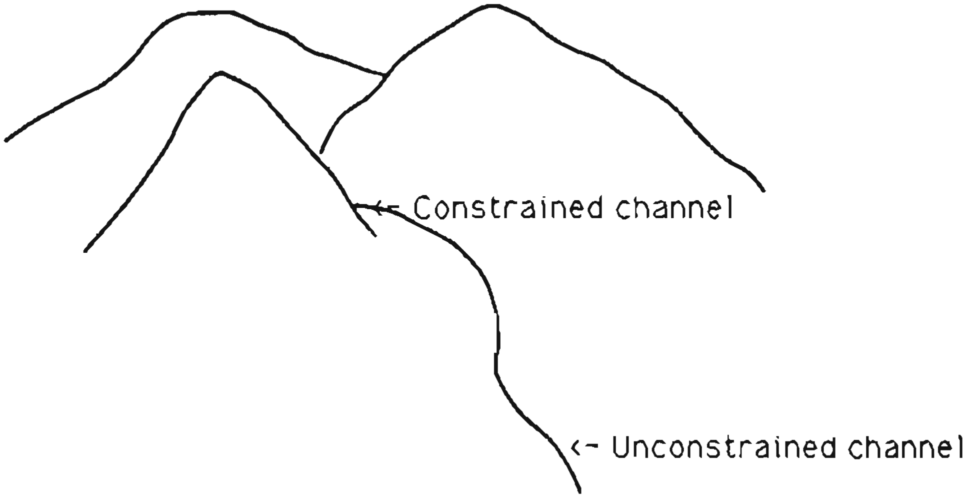


Figure 5. Constrained versus unconstrained channels. Bedrock, alluvium, or colluvium may limit the lateral migration of a channel, causing it to be constrained.

landscape features higher than floodplains. Terraces are often remnant erosional or depositional surfaces. Remnant depositional terraces containing old stream channel deposits may contain important bench placer deposits (Figure 6).

Three general channel types occur, although most streams have reaches belonging to more than one channel type. The three types are straight single channel, meandering channel, and braided channel (Figure 7).

Straight single channels are typical of mountain streams and typically lie on bedrock or coarse (cobble and boulder) substrates. High gradient and low sinuosity are characteristic of straight, single channels. During periods of very low flow the straight channel, "mountain streams" may develop meandering thalwegs within the bankfull channel. However, once median flow is restored the low flow thalweg is washed out and the stream fills the less sinuous median flow channel.

Mountain streams with correspondingly straight channels also tend to occupy steep valleys according to Rundquist and others, 1986 and Beschta, 1989. This suggests that in the low order mountain streams encounterd in most placer mining operations in Alaska, bypass channels and restored channels would also require low sinuosities.

Meandering channels are more characteristic of lower gradient streams and rivers. Meandering streams have higher sinuosities, higher form roughness, and generally a higher proportion of fine sediment than other channel

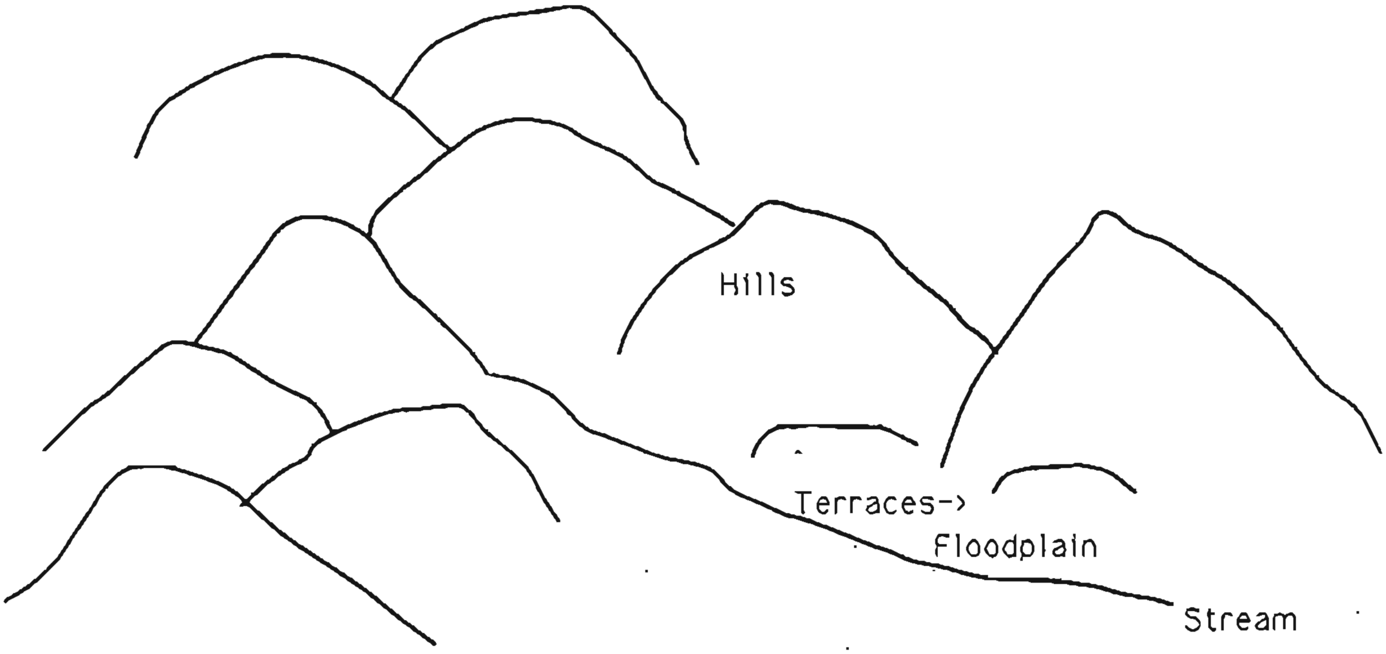


Figure 6. Terraces and floodplain. Some terraces are sources of placer gold.

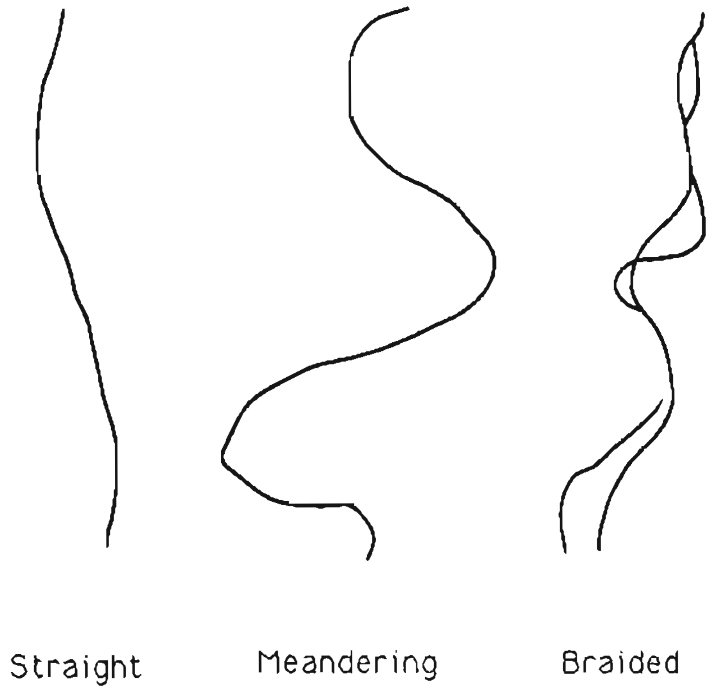


Figure 7. Straight, meandering, and braided channel types (after Rundquist et al).

types.

Braided channels contain complexes of bars and islands and can shift channels often. Abundant bedload and variable discharge are among the factors which produce braided channel patterns.

IMPORTANT HYDRAULIC PARAMETERS

Critical parameters in channel hydraulics include roughness, valley, bank, floodplain, and stream channel slopes, sinuosities, mean velocity, top width, mean depth, bankfull depth, bankfull width, width of valley floor.

Roughness is the ability of a given surface to slow the flow of water. Roughness can be divided into form roughness and skin friction for any given channel. Form roughness includes stream channel units such as pools, riffles, and meanders. Skin friction roughness relates to the type of material comprising a channels substrate. Manning's roughness coefficient (Manning's "n") is a numerical assignment expressing skin friction roughness, and is higher for floodplains and channels with large rocks and vegetation, and lower for smooth channels (Figure 8). Velocity is related to Manning's n, to hydraulic radius (R), and to channel slope (S) as $V=1.49/(n*R^{2/3}*S^{1/2})$.

(The Manning Equation)

Some examples of Manning's n for channels and flood plains with different types of surfaces are given in table 1.

Valley slope is a direct control on channel slope. Where valleys are steep, channels tend to have a steep gradient as well.

Bank and floodplain slopes are important to a stream's

Low Manning's n

High Manning's n

Figure 8. Manning's roughness coefficient, n, is higher for channels with large cobbles, boulders, and vegetation. Smooth channels have less abilty to slow flow.

carrying capacity at flood stage. If bank and floodplain slopes are steep, then at flood stage most of the flood water is restricted to the channel and immediately adjacent areas, increasing depth and velocity in the channel. If, however, floodplain and bank slopes are relatively flat, then the floodplain is able to help reduce the effect of flooding, and channel velocity increases by a lesser amount.

Gradient of a stream is important to the streams ability to erode or deposit material. Generally steeper, higher energy, low order mountain streams cause erosion in the incisive regime on upper reaches. As material is moved downstream, sediment is deposited in low gradient reaches where stream energy and carrying capacity are lower.

Sinuosity of a stream is defined as the distance measured along a stream in the middle of the stream channel divided by the straight line distance for that same stream. Sinuosity is never less than one (Figure 9).

Width of a stream is measured from bank to bank in a direction perpendicular to the direction of flow. The measurement of width will vary with the point on the stream at which it is taken. This measurement also can be taken at any given time, or alternatively the bankfull width can be measured from the high water mark on one bank to the high water mark on the opposite bank (Figure 10).

Valley width can determine how much area is available for floodplains, and can determine whether a stream is constrained or unconstrained.

Depth of a stream is

Figure 9. Decreasing sinuosities for stream channels

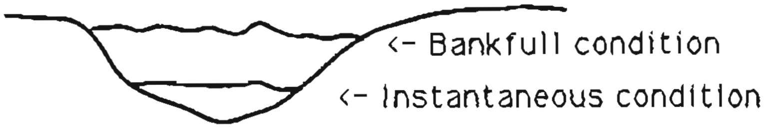


Figure 10. Stream parameters may be measured at any given time, but often it is more meaningful to discuss bankfull conditions.

usually defined as mean depth. Depths are taken at regular spacings along a line perpendicular to the direction of flow, and these depths are averaged to find a mean depth. Depth measurements, similar to width measurements, are different for different points along a streams course. These measurements also may be for depth at a given point in time, or for mean bankfull depth.

Depth and width define other parameters as well. Cross sectional area (A), wetted perimeter (P), and hydraulic radius (R) are related to width (W) and depth (D) as

$$A = W * D$$

$$P = 2 * D + W$$ (Figure 11)

$$R = A / W * P$$

Velocity of a stream is equal to length travelled divided by time required to travel that length.

$$V = L / T$$

Discharge (Q), is a measure of flow and is related to other hydraulic parameters as

$$Q = A * V = W * D * V$$

Discharge, like width, depth, velocity, and other hydraulic parameters, varies at any given point on a stream through time.

Stream channel parameters are mathematically related through a series of equations outlined by Rundquist and others (1986). Rundquist includes equations from Parks and Madison, 1984, Bray, 1982, Emmett, 1972, and Leopold et al, 1964, among others.

EROSIONAL VS DEPOSITIONAL REGIMES

Whether a stream has an erosional or depositional character depends on a number of factors. These factors

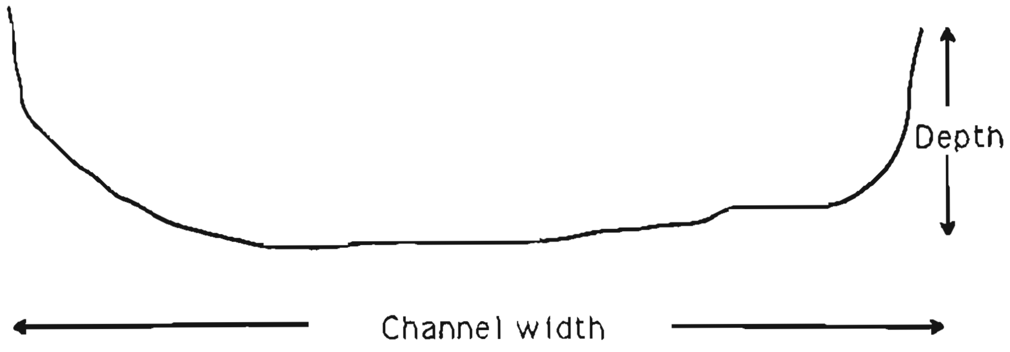


Figure 11. Width and depth define other parameters as well:
Area = width * depth
Wetted perimeter = (2 * depth) + width
Hydraulic radius = Area / width * wetted perimeter

include stream discharge, gradient, sediment load, and nature of stream bed.

Discharge for most placer mining creeks in Alaska varies on diurnal, annual, and long term climatic cycles. Diurnal cycles are most noticeable in areas of permafrost and during the early thaw season. Flow rates are lower in the morning when the daily temperatures are low and much of the water available for discharge is tied up as snow or ice. During afternoon and evening hours, as temperatures rise more snow and ice melt and discharges increase. Annual cycles are controlled by the climatic elements of temperature and precipitation. Discharges peak during spring runoff and during summer storm events. Discharge for any given creek reaches a minimum in winter (when streams are frozen) and during periods of minimal precipitation. The controls on long term cycles are not readily understood. However, it is apparent from looking at the discharge records from any given creek that there are wet years and dry years. The desire to be able to anticipate and predict the repurcussions of these year to year fluctuations has led to studies which attempt to predict flood frequency. The diurnal, annual, and long term cycles of discharge in Alaskan placer mining streams have the effect of creating an erosional regime when discharge, and consequently and the streams' ability to transport material are high. When discharges are at minima these stream have a more depositional nature due to lower carrying capacity.

The amounts of suspended, saltated, and bed loads play critical roles in determining the erosional or depositional character of any stream. The more material a given stream has available for deposition, the less erosional and more depositional that stream will be.

Bed stability is the propensity for the channel surface to resist erosion. Factors which help to determine roughness also contribute to channel stability. Larger clast size and denser vegetation increase channel stability as they raise the value of Manning's n. Boulders and cobbles require more energy for transport than do gravel and sand and resist winnowing. Root systems and mats of vegetation act as anchors for finer sedimentary constituents and stabilize flood plains as well as channel beds.

Discharge fluctuations, stream gradient, amount of material available for transport, and character of stream bed all crucially affect the erosional or depositional character of streams.

Many previous workers have studied erosional versus depositional regimes. Concepts describing these relationships include stable channel balance (Lane, 1955), a complex response concept (Schumm, 1977), and degrees of freedom (Beschta and Platts, 1986).

FLOOD FREQUENCY

Flood frequency and flood magnitude need to be understood in order to predict future flow rates for a given stream. The most commonly used method for analysing flood frequency is at a station. This method consists of obtaining historical flow data, ranking flows, calculating return periods, and establishing discharge versus return periods.

There have also been a number of studies which use regression analysis to determine equations suitable for predicting regional peak flows. The key parameters for most are drainage basin area and precipitation.

An excellent evaluation and description of the complex relationships in this network of hydrologic parameters is the summary in Beschta, 1989.

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