Module
2
The Science of Surface and Ground Water

Lesson
10
Sediment Dynamics in Alluvial Rivers and Channels

Instructional Objectives

On completion of this lesson, the student shall be able to learn the following:

1. The mechanics of sediment movement in alluvial rivers
2. Different types of bed forms in alluvial rivers
3. Quantitative assessment of sediment transport
4. Resistance equations for flow
5. Bed level changes in alluvial channels due to natural and artificial causes
6. Mathematical modelling of sediment transport

2.10.0 Introduction

In Lesson 2.9, we looked into the aspects of sediment generation due to erosion in the upper catchments of a river and their transport by the river towards the sea. On the way, some of this sediment might get deposited, if the stream power is not sufficient enough. It was noted that it is the shear stress at the riverbed that causes the particles near the bed to move provided the shear is greater than the critical shear stress of the particle which is proportional to the particle size. Hence, the same shear generated by a particular flow may be able to move of say, sand particles, but unable to cause movement of gravels. The particles which move due to the average bed shear stress exceeding the critical shear stress of the particle display different ways of movement depending on the flow condition, sediment size, fluid and sediment densities, and the channel conditions.

At relatively slow shear stress, the particles roll or slide along the bed. The particles remain in continuous contact wit the bed and the movement is generally intermittent. Sediment material transported in this manner is termed as the ***contact load***. On increasing the shear stress, some particles loose contact with the bed for some time, and hop or bounce from one point to another in the direction of flow. The sediment particles moving in this manner fall into the category of ***saltation load***.

Contact load and saltation load together is generally termed as ***bed load***, that is, the sediment load that is transported on or near the bed.

The further increase in shear stress, the particles may go in suspension and remain thus due to the turbulent fluctuations and get carried downstream by stream flow. These sediment particles are termed as ***suspension load***. In most natural rivers, sediments are mainly transported as suspended load.

Bed load and suspended load together constitute, what is termed as, ***total load***. A knowledge of the rate of total sediment transport for given flow, fluid and sediment characteristics is necessary for the study of many alluvial river processes. Engineers always need to bear in mind the fact that alluvial streams carry not only water but also sediment and the stability of a stream is closely linked with the sediment and transport rate. Alluvial channels must be designed to carry definite water and sediment discharges. In effect, the rate of total load transport must be treated as a variable affecting the design of a channel in alluvium. Knowledge of total sediment transport rate is essential for estimating the amount of siltation in the reservoir upstream of a dam or the erosion and scour of the river bed below a dam, as discussed in Lesson 2.9.

Analysis of suspended load and the corresponding bed materials of various streams for their size analysis have shown that the suspended load can be divided into two parts depending on the sizes of material in suspension vis-à-vis the size analysis of the bed material. One part of the suspended load is composed of these sizes of sediment found in abundance in the bed. The second part of the load is composed of those fine sizes not available in appreciable quantities in the bed. These particles, termed as the ***wash load***, actually originate from the channel bank and the upslope area.

2.10.1 Regimes of flow

It has been explained in Lesson 2.9 that when the average shear stress due to moving water on the river bed exceeds the critical shear stress, individual particles or grains making up the bed start moving. Since the particles are generally not exactly alike in size, shape or weight and also since a flow in a river with random turbulent fluctuations, all the bed particles do not start moving at the same time. Some particles move more than the rest, some slide and some hop depending on the uncertainties associated with the turbulent flow field and also the variation of drag due to particle shape. Gradually, a plane channel bed develops irregular or regular shapes of unevenness which are called bed forms which vary according to the flow conditions and are termed as "Regimes of flow" (Garde and Ranga Raju 2000), which is explained further below in this section. Regimes of flow will considerably affect the velocity distribution, resistance relation and the transport of sediment in an alluvial river or channel. The regimes of flow can be divided into the following categories:

1. Plane bed with no motion of sediment particles
2. Ripples and dunes
3. Transition, and
4. Antidunes

Plane bed with no motion of sediment particles:

When the sediment and flow characteristics are such that the average shear stress on the bed is les than the critical shear stress, the sediment particle on the bed does not move. The water surface remains fairly smooth if the Froude number is low. Resistance offered to the flow is on account of the grain roughness only, and the Manning's equation can be used for prediction of the mean velocity of flow.

Ripples and Dunes:

The sediment particles on the bed start moving when the average shear stress of the flow exceeds the critical shear stress. This results in small triangular undulations as the channel bed and is known as ripples (Figure 1).

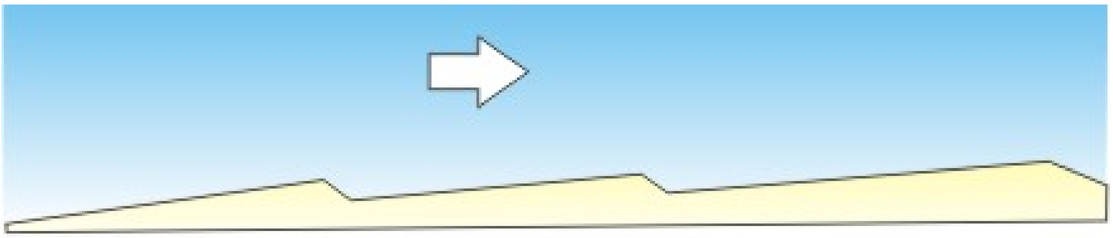

FIGURE 1. Ripples on the bed of alluvial river or channel for low flow velocity

Ripples do not occur for sediment particles coarser than 0.6 mm. The distance between the successive crests of the ripples is usually less than 0.4m and the height from the crest to the trough is usually less than 0.04m. The sediment movement is confined in the region near the channel bed.

With increase in discharge, and consequently the average bed shear stress, the ripples grow in sizes which are then termed as dunes (Figure 2).

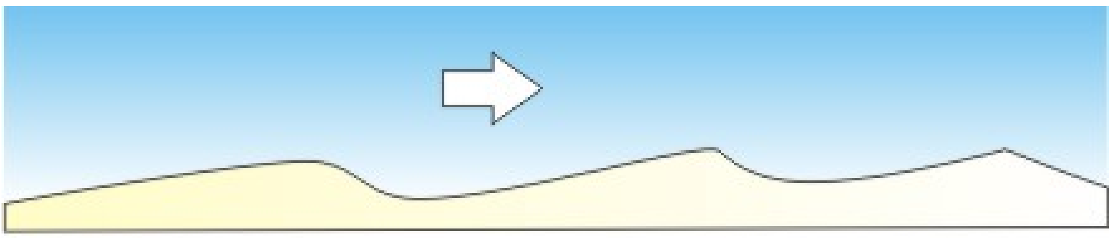

FIGURE 2. Dunes or channel bed for higher velocities

Dunes are also triangular in shape but are larger than ripples. The triangular sections are not symmetric and the upstream face is inclined at about 10 to 20 degrees and downstream face at an angle of about 30 to 40 degrees with the horizontal. In rivers, dunes may be quite long and also the height (vertical distance between the crest and troughs) may be great. For example, the dunes found in Lower Mississippi river have been found to be about 12m height on an average and length of the order of few hundred meters (Garde and Ranga Raju, 2000). These bed forms are not static, which means that they gradually move forward with time, of course at a very slow and creeping velocity much less than the velocity of flow.

Transition:

With further increase in discharge over the dune bed, the ripples and dunes are washed away, and only some very small undulations are left. In some cases, the bed may become nearly flat but the sediment particles remain in motion. With slight increase in discharge, the bed and water surfaces attain a shape of sinusoidal wave form, which are called standing waves (Figure 3).

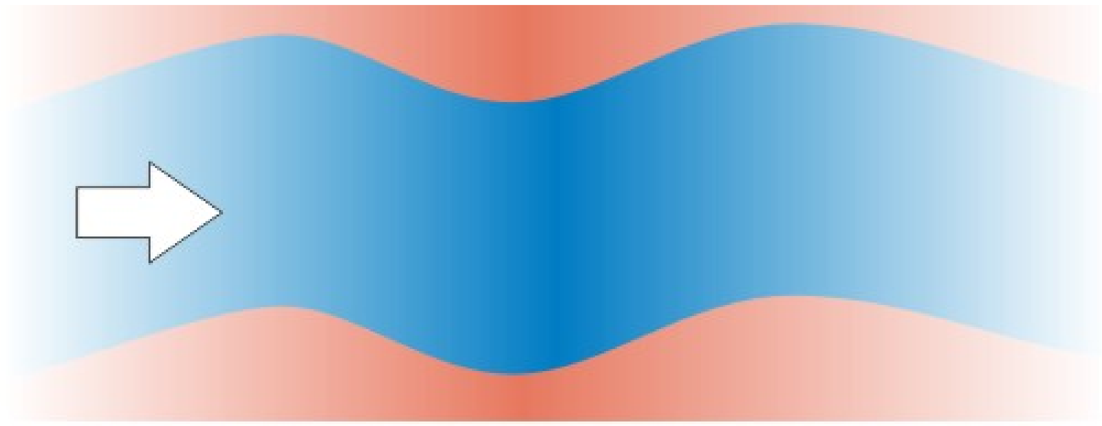

FIGURE 3. Standing waves or symmetrical sand waves and water surface waves in phase for even higher velocities

These waves form and disappear and their size doesn't increase much. Thus, in transition regime, rapid changes in bed and water configuration occur with relatively small changes in flow conditions. The Froude number is relatively high but the flow conditions are sub-critical.

Antidunes:

When the discharge is increased further and the Froude number increases to more than one, indicating super critical flow, the standing waves, which are symmetrical sand and water waves in the phase, move slowly upstream and break intermittently. These are called antidunes because the movement of the direction of dunes is backwards compared to the direction of flow. Since supercritical flow is rare in case of natural streams and channels, this type of bed forms do not occur generally in nature.

2.10.2 Quantities of sediment transport rates

There are various formulae predicting the amount of sediment transported as

- Bed load
- Suspended load
- Total load

From water resources engineering point of view one generally requires the sediment transport rate of total load, and hence, the methods for predicting this would be discussed here. Of course, in many practical situations, the suspended load is measured or estimated, through the equation proposed by Einstein (1942), as this constitutes about 80 to 90 percent of the total load. After estimating suspended load a certain percentage of it is added to estimate total load. [Please note that the researcher Einstein mentioned here is Hans Albert Einstein, the son of the famous physicist Albert Einstein].

Though there are probably over a dozen total load relationships essentially using a single representative size of the sediment mixture. While some of the methods may be considered semi-empirical, most of them are based on dimensional analysis and graphical plotting or regression analysis. Hence the basis for the choice of an appropriate sediment transport relation in practice can only be the relative accuracy of these methods. Yang (1996) has shown through examples that the prediction of total load by different formulae may vary by as much as four times of one another. According to Garde and Ranga Raju (2000), the methods proposed by the following researchers give better results than other methods:

- Ackers-White (1973)
- Engelund-Hansen (1967)
- Brownlie (1981)
- Yang (1973)
- Karim-Kennedy (1990)

There are other methods like that proposed by Van Rijn (1984a and b) which estimate the bed load and suspended load components of the total load separately.

Some of the methods to calculate total load are mentioned in the following sections.

2.10.3 Ackers and White (1973) method

Ackers and White (1973) postulated that one part of the shear stress on the channel bed is effective in causing motion of coarse sediment, while in the case of fine sediment, suspended load movement predominates for which total shear stress is effective in causing sediment motion. This method can be applied by following the steps mentioned below:

1. Determine the value of d_*, the dimensional particle diameter, defined as:
2.

$$d_* = d\left[\frac{g}{\upsilon^2}\left(\frac{\gamma_s}{\gamma}-1\right)\right]^{1/3} \qquad (1)$$

Where the parameters on the right hand size of equation (1) are:

- *d*: Average particle diameter
- *g*: Acceleration due to gravity
- υ: Kinematic Viscosity of water

- γ_s : Specific weight of sediment
- γ : specific weight of water

3. Determine the values of the coefficients c_1, c_2, c_3 and c_4 as:

For $1 < d_* < 60$

$$c_1 = 1.00 - 0.56 \log d_*$$

$$c_2 = e^{\left[2.86 \log d_* - (\log d_*)^2 - 3.53\right]}$$

$$c_3 = \frac{0.23}{d_*^{1/2}} + 0.14$$

$$c_4 = \frac{9.66}{d_*} + 1.34$$

For $d_* > 60$

$$c_1 = 0.00 \quad c_2 = 0.025 \; c_3 = 0.17 \quad c_4 = 1.5$$

4. Compute the value of particle mobility number F_g, given by the following expression

$$F_{gr} = U_*^{c_1}\left[g.d\left(\frac{\gamma_s}{\gamma} - 1\right)\right]^{-1/2}\left[\frac{V}{\sqrt{32}\log\frac{10h}{d}}\right]^{1-C_1} \qquad (2)$$

where U_* = Shear velocity = $\sqrt{\frac{\tau_0}{\rho}}$

τ_0 = bed shear stress
V= Average flow velocity
h = water depth

5. Compute the value of dimensionless sediment transport function G_{gr} from the following expression

$$G_{gr} = c_2\left(\frac{F_{gr}}{c_3} - 1\right)^{C_4} \qquad (3)$$

6. Compute sediment concentration, X, in ppm (parts per million) by weight of fluid using the following expression:

$$X = G_{gr}\frac{d}{h}\frac{\gamma_s}{\gamma}\left(\frac{V}{U_*}\right)^{C_1} \qquad (4)$$

7. Compute total sediment load Q_T by multiplying sediment concentration (X), with discharge of the following water Q, that is,

$$Q_T = Q.X \tag{5}$$

2.10.4 Engelund and Hansen's method

Engelund and Hansen (1967) proposed a total load equation relating the sediment transport to the shear stress and the friction factor of the bed. The following steps illustrate the method of application of their theory:

1. Compute the parameter θ, the dimensionless shear stress parameter by the following equation

$$\theta = \frac{\tau_0}{(\gamma_S - \gamma)d} \tag{6}$$

Where

- τ_0 is the bed shear stress
- γ_S is the density of sediment particles
- γ is the density of water
- d is the diameter of bed particles

2. Compute f ' the friction factor of the bed using the following expression

$$f^1 = \frac{2 g S_f h}{V^2} \tag{7}$$

Where

- g is the acceleration due to gravity
- S_f is the energy slope
- h is the depth of flow
- V is the average flow velocity

3. Obtain the total sediment load Q_T from the following equation

$$Q_T = 0.1\left[\gamma_s\left(\frac{\gamma_s - \gamma}{\gamma}\right) g\, d^3\right]^{1/2} \frac{\theta^{5/2}}{f^1} \tag{8}$$

There are several other methods for computing total load or the components suspended load and bed load separately. The interested reader may refer to the book by Garde and Ranga Raju (2000).

2.10.5 Resistance to flow in alluvial rivers

Open channels with movable beds and boundaries are commonly encountered in water resources engineering. In contrast, some artificial channels and hydraulic structures with solid floors constitute a relatively smaller portion where the roughness coefficient can be treated as constant. In these cases, a resistance formula can be applied directly for the computation of velocity, slope, or depth, once a roughness coefficient has been determined. Although this concept is also used for natural channels but strictly speaking, for these kinds of channels, a resistance formula cannot be applied directly without knowledge of how the resistance coefficient will change under different flow and sediment conditions. Extensive studies have been made by different researchers for determination of roughness coefficients of alluvial beds. Their results differ from each other. Most of these studies have been based on limited laboratory data. Uncertainties remain regarding the applicability and accuracy of laboratory results to field conditions.
The resistance equation expresses relationship among the mean velocity of flow ***V***, the hydraulic radius ***R***, and characteristics of the channel boundary. For steady and uniform flow in rigid boundaries boundary channels, the Keulegan's equations (logarithmic type) or power-law type of equations (like the Chezy's and the Mannings equations) are used. Keulegan(1938) obtained the following logarithmic relations for rigid boundary channels:

For smooth boundaries

$$\frac{V}{\sqrt{\tau_0/\rho}} = 5.75\log\left[\sqrt{\frac{\tau_0}{\rho}}\frac{R}{\upsilon}\right] + 3.25 \qquad (9)$$

For rough boundaries,

$$\frac{V}{\sqrt{\tau_0/\rho}} = 5.75\log\left[\frac{R}{k_s}\right] + 6.25 \qquad (10)$$

where

- τ_0 is the bed shear stress
- ***R*** is the hydraulic radius
- ρ is the density of water
- υ is the Kinematic viscosity
- k_s is the grain roughness height
- ***V*** is the average velocity at a point

For the range of 5< R/k_s<700, the Mannings equation is

$$V = \frac{1}{n}R^{2/3}S^{1/2} \qquad (11)$$

This has been found to be as satisfactory as the Keulegan's equation for rough boundaries (equation 10). In equation (11), ***n*** is the Manning's roughness coefficient, which can be calculated using the Strickler's equation

$$\boldsymbol{n} = \frac{k_S^{1/6}}{25.6} \qquad (12)$$

Where, $\boldsymbol{k_s}$ is the grain roughness height in metres.

Another power-law type of equation is given by Chezy in the following form:

$$V = C\sqrt{RS} \qquad (13)$$

Where ***C*** is the Chezy's coefficient of roughness. Comparing Manning's and Chezy's equations, one obtains:

$$\frac{V}{\sqrt{\tau_0/\rho}} = \frac{C}{\sqrt{g}} = \frac{R^{1/6}}{n\sqrt{g}} = \left(\frac{R}{K_S}\right)^{1/6} . \frac{25.6}{\sqrt{g}} \qquad (14)$$

In case of alluvial channels, where the bed is composed of mobile material, like sand, so long as average bed shear stress to on the boundary of the channel is less than the critical shear τ_c the channel boundary can be considered rigid and any of the resistance equations valid for rigid boundary channels would yield results for alluvial channels too. However, as soon as sediment movement starts, undulations appear on the bed, thereby increasing the boundary resistance. Besides, some energy is required to move the grains. Further, the sediment particles in suspension also affect the resistance of alluvial streams. The suspended sediment particles dampen the turbulence or interfere with the production of turbulence near the bed where the concentration of these particles as well as the rate of turbulence production is maximum. It is therefore, obvious that the problem of resistance in alluvial channels is very complex and the complexity further increases if one includes the effect of channel shape, non-uniformity of sediment size, discharge variation, and other factors on channel resistance. None of the resistance equations developed so far takes all these factors into consideration.

The methods for computing resistance in alluvial channels can be grouped into two broad categories.

a) Those which deal with the overall resistance offered to the flow using either a logarithmic or power type relationship for the mean velocity, and
b) Those in which the total resistance is separated into the resistance given by the grains of sand forming the channel bed and the resistance of the undulations in the bed. Thus, in this method, the total resistance is studied as a combination of grain resistance and form resistance.

These two methods are discussed in the following sections.

2.10.6 Formula for total resistance in alluvial channels

One of the earliest resistance relationships for alluvial channel flow was proposed by Lacey on the basis of stable canal data from northern India. The equation for mean velocity in SI units is

$$V = 10.8\, R^{2/3} S^{1/3} \tag{15}$$

where ***R*** is the hydraulic radius, ***S*** is the friction slope; ***V*** is the average velocity. This equation, however, is not applicable at all stages of the river and hence, it cannot be used reliably for all types of alluvial rivers and channels.

Another relation obtained by Indian researchers is that by Garde and Ranga Raju and is expected to yield results with accuracy $\pm$30 percent (Ranga Raju, 1993). The method can be applied by following the procedural steps mentioned below. Remember that the average velocity ***V*** to be obtained for a given friction slope S_f. Another parameter that is related to the roughness of the bed material is d_{50}, or the mean diameter of bed grains.

a) For a particular water level, find out the hydraulic radius ***R*** and the area of cross section ***A***.

b) From Figures 4 and 5, determine factors k_1 and k_2 corresponding to d_{50}.

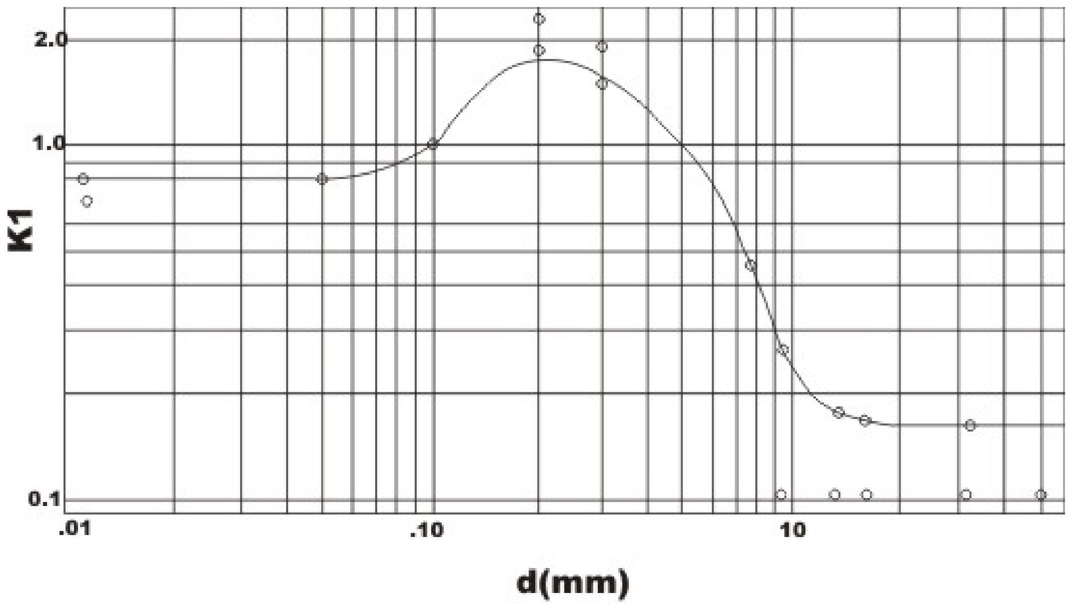

FIGURE 4. Variation of K1 with sediment size

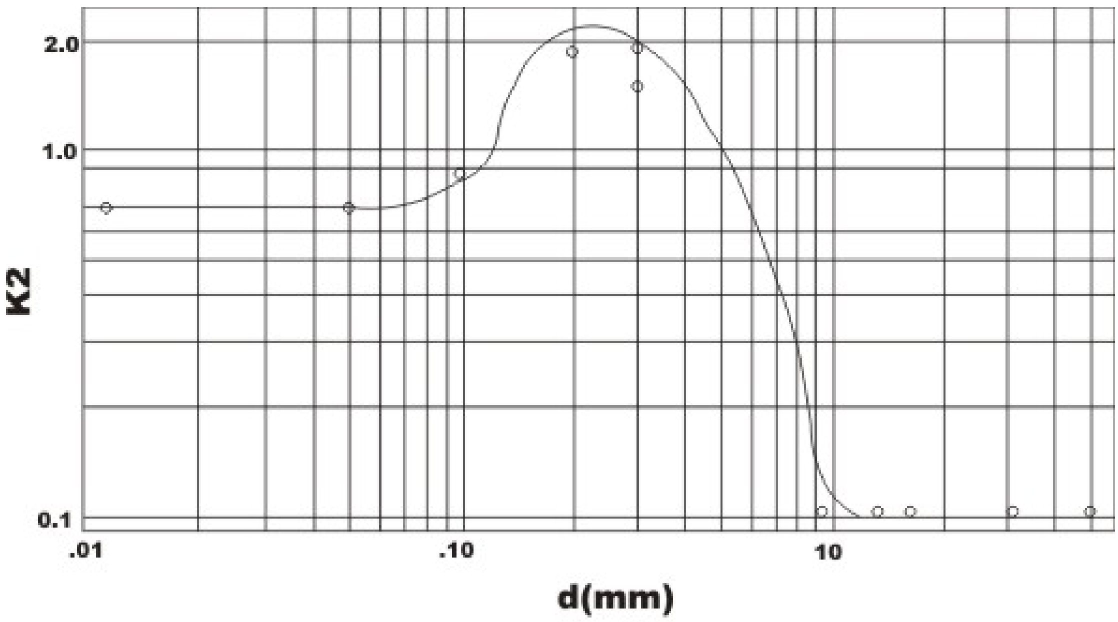

FIGURE 5 Variation of K2 with sediment size

c) Compute $f_1 = K_2 \left(\frac{R}{D}\right)^{1/3} \frac{S_f}{\left(\Delta\gamma_s / \gamma\right)}$

Where

- ***D*** is the water depth
- S_f is the friction slope
- $\Delta\gamma_s$ is equal to $\gamma_s - \gamma$ in which
- γ_s is the specific weight of sediment and
- γ is the specific weight of water

d) From Figure 6, read the value of ***f***$f_2 = K_1 \frac{V}{\sqrt{\left(\frac{\Delta\gamma_S}{\gamma}\right).g.R}}$

Corresponding to f_1 computed in step (c).

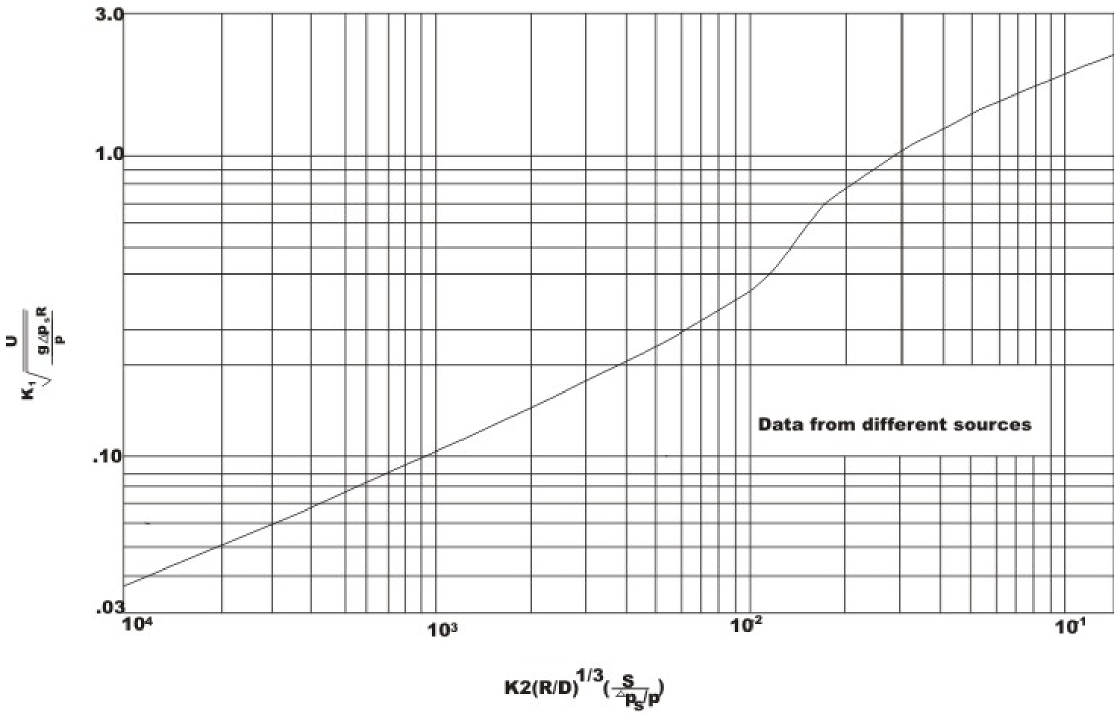

FIGURE 6 Roughness predictor for alluvial channels

e) Knowing f_2, compute the value of ***V***

There are several other methods available to find the total resistance for an alluvial stream and the interested reader may refer to Garde and Ranga Raju (2000).

2.10.7 Formula for separate resistance due to grain and form

Here too, there are several methods and the important ones are explained in Garde and Ranga Raju (2000). One of the formulae is quoted here, due to van Rijn (1984), states the following:

$$\frac{V}{\sqrt{\tau_0/\rho}} = 5.75\log\left(\frac{12R}{K_S}\right)$$

(16)

Where

- V is the average velocity
- τ_0 is the bed shear stress
- R is the hydraulic radius

K_s is the sum of the roughness corresponding to grain and form resistance, that is

$$K_s = K_{s1} + K_{s2}$$

in which $K_{s1} = 3\, d_{90}$ and

K_{s2} is related to the height of undulation (h) and the length of the dunes (L) as given by the formula

$$K_{s2} = 1.1\, h\, (1\text{-}e^{-2gh/l})$$

2.10.8 Bed level changes in alluvial channels

In Lesson 2.9, qualitative description of alluvial stream bed changes due to construction of a dam was discussed (Figure 7).

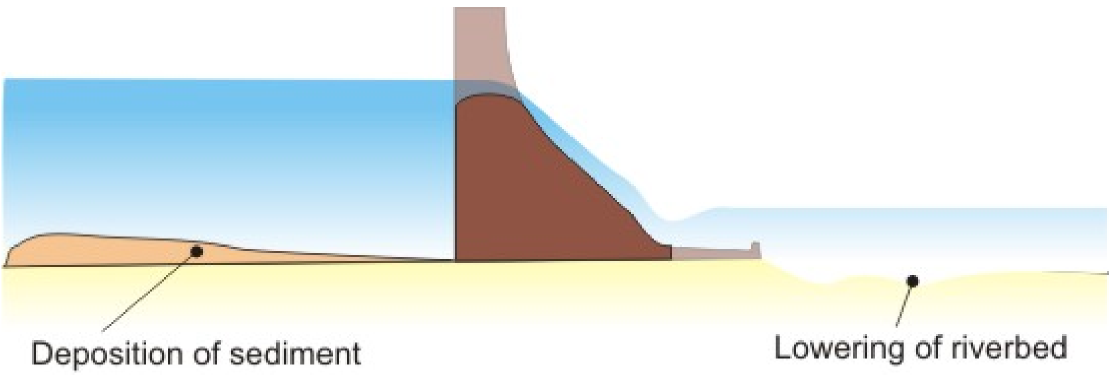

FIGURE 7. Alluvial riverbed level changes due to a Daim constructed across a river

As water resource engineers, one is interested to find a quantitative assessment to the amount of sediment deposition in the reservoir on the dam upstream or the extent of riverbed scour in the reach downstream. In the following sections we discuss the means by which it may be done. Other situations in which alluvial riverbed levels get changed due to the presence of a structure in the river are given in the following examples.

Scour around bridge piers

Bridges, crossing alluvial rivers and channels have their piers resting on foundations within the rivers. As may be seen from the figure, the foundation well extends within the river bed and determination of its depth depends to what extent the riverbed would scour during floods (Figure 8).

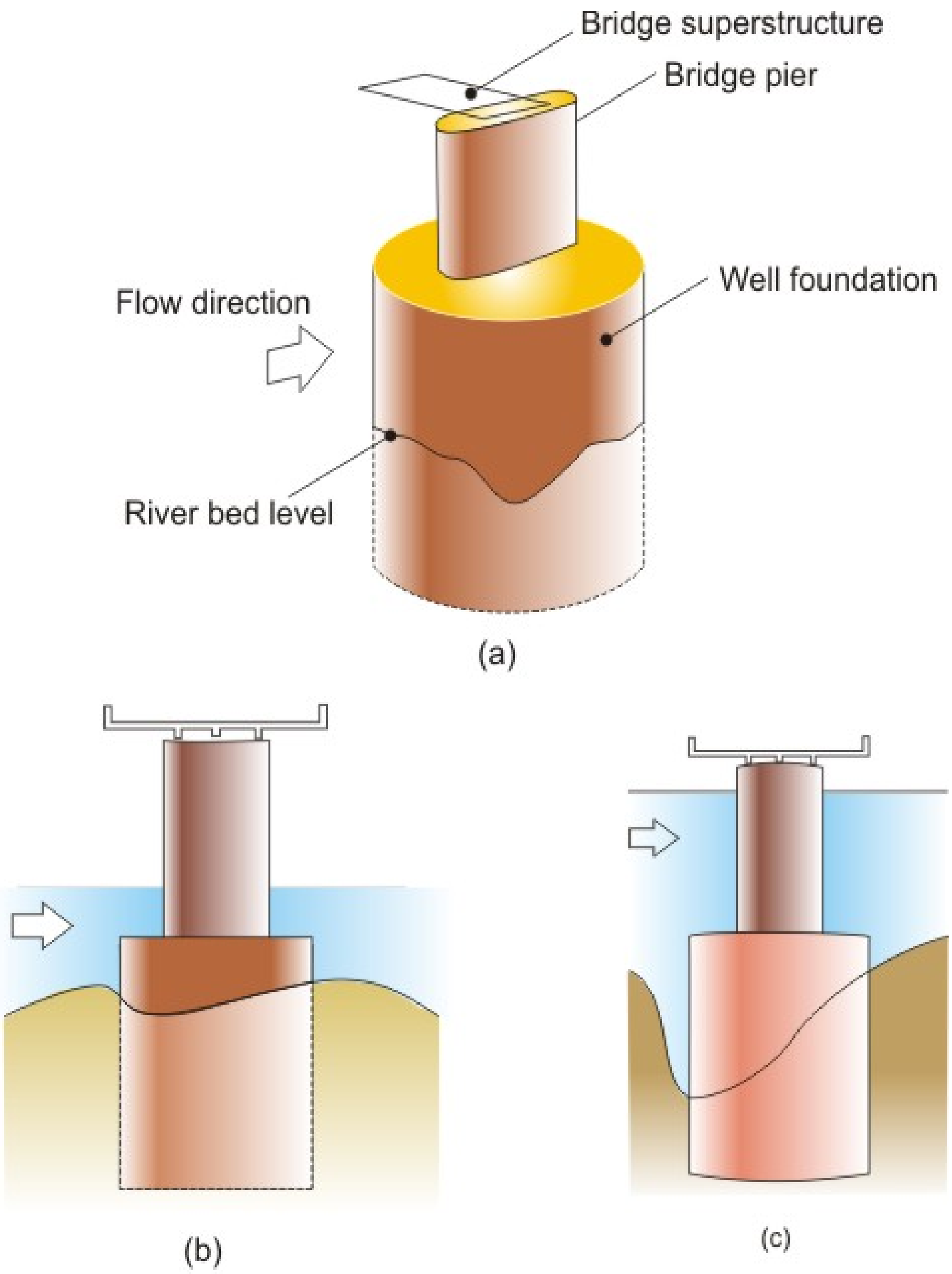

FIGURE 8 . Alluvial riverbed level changes near bridge pier
a) General view of bridge and pier
b) Bed level changes not much during low flows
c) Scour or lowering of riverbed levels during floods

Some bridges are constructed on piles, instead of wells but there too the length of the piles depends on the extent of scour that is expected during floods.

It may be mentioned that the deepening of riverbed around bridge foundations occurs only during the passage of a high flood. Once the flood peak passes and the flood starts receding, the scoured riverbeds start getting filled up with sediment carried by the river.

Sediment movement near intakes

Water intakes for irrigation or water supply are often faced with the problem of excess sediment removal or deposition near its vicinity (Figure 9). Sometimes, the gates of the intake and that of the barrage are not properly coordinated which results at undesirable sediment erosion and deposition.

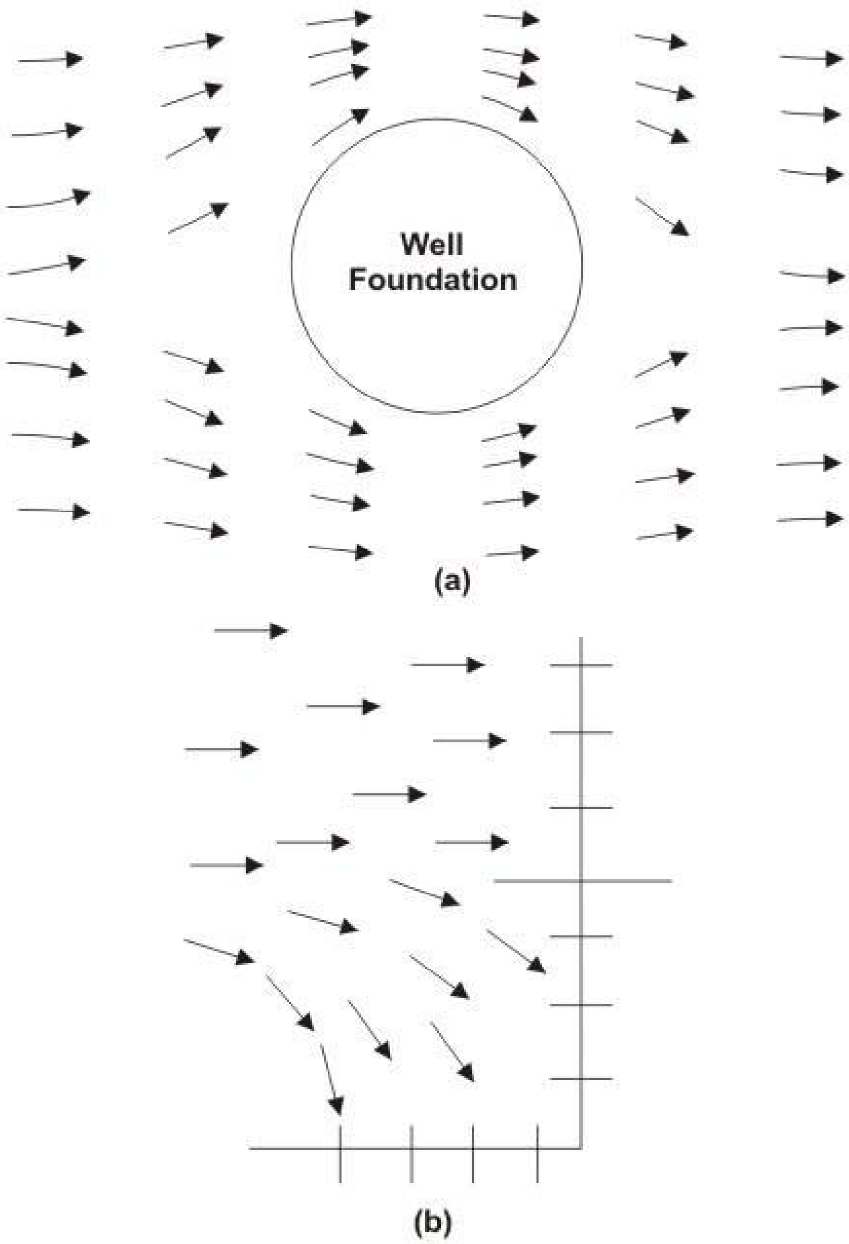

FIGURE 9 . Examples of two dimensional flow in plan
a)Flow around bridge pier well foundation
b) Flow near barrage and canal head regulator

The example of sediment deposition behind dam and erosion on its downstream may be treated as that of one dimensional flow (Figure 7). The other two examples that of scour around bridge piers and sediment movement near water intakes are examples of two dimensional flow (Figure 10).

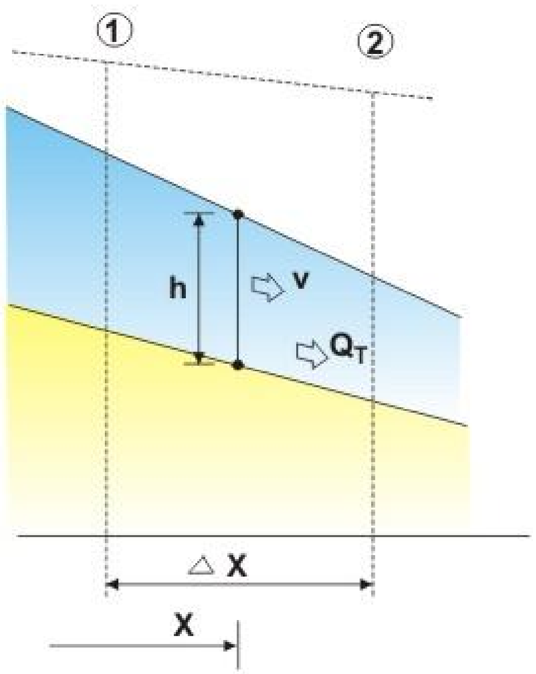

FIGURE 10 Definition sketch for derivation of bed level change due to a given sediments transport rate Q_T at a location x

In order to quantitatively evaluate the amount of sediment movement, it is necessary to solve the relevant governing equations. An introduction to these is given in the following sections.

2.10.9 Mathematical models for unsteady sediment movement

Consider a length Δ**x** of a channel of width ***B*** transporting sediment at a weigh rate of Q_T (Figure 11) at a location ***x*** in the channel. The volume rate of sediment transport through the section is Q_T/γ_s, where γ_s is the specific weight of the sediment particles.

If Q_T is the weight rate of sediment transport at ***x***, then that at section ***1***, it is $Q_t - \frac{\partial Q_t}{\partial x}\frac{\Delta x}{2}$ and at section **2** is $Q_t + \frac{\partial Q_t}{\partial x}\frac{\Delta x}{2}$.

Correspondingly, the volume of sediment entering through section ***1*** is $\frac{1}{\gamma_S}\left[Q_t - \frac{\partial Q_t}{\partial x}\frac{\Delta x}{2}\right]$ and that leaving through section ***2*** is $\frac{1}{\gamma_S}\left[Q_t + \frac{\partial Q_t}{\partial x}\frac{\Delta x}{2}\right]$. It follows that the net amount of sediment causes a change in the bed level of the channel between sections ***1*** and ***2***, which is given by $\frac{\partial}{\partial t}\left[Z\, B\, \Delta\, x(1-\lambda)\right]$ where ***Z*** is the elevation of the bed above a datum and ***λ*** is the porosity of the bed. It has been assumed that the amount of sediment carried in suspension does not change appreciably with time.

Combining the above derivations, it may be shown that the unsteady continuity equation of sediment conservation in a channel is given as

$$\frac{\partial Z}{\partial t} + \frac{1}{B\gamma_S(1-\lambda)}\frac{\partial Q_T}{\partial x} = 0 \qquad (17)$$

This equation states that the bed is lowered if the transport increases along the length and vice versa. It can be seen that when the flow is steady, the bed level cannot change with respect to time.

In equation (17), an estimate for $\boldsymbol{Q_T}$ may be obtained using equations (5) or (8), which however, contain the flow variables ***h*** (depth of flow) and ***V*** (average velocity). Hence, equation (17) cannot be solved independently, but has to be considered together with the equations of continuity and of motion for water, as given below:

Equation of flow continuity

$$B\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} = q_l \qquad (18)$$

Where

- ***B*** is the channel width
- ***H*** is the water depth
- ***Q*** is the discharge = *A* ·• *V*, where A is the cross sectional area and **V** is the average velocity at a section
- $\boldsymbol{q_l}$ is any discharge that is entering the channel from its sides
- ***t*** and ***x*** are the dimensions in time and space

Equation of flow motion:

$$\frac{\partial V}{\partial t} + g\frac{\partial}{\partial x}\left(\frac{V^2}{2g} + h\right) = g\,(S_0 - S_f) \qquad (19)$$

Where

g is the acceleration due to gravity

S_0 is the riverbed slope

S_f is the friction slope

It may be noted that the friction slope, S_f, in equation (19) may be evaluated using the Manning's equation ($S_f = \frac{V^2 n^2}{R^{4/3}}$) or one of the formulae from which Section 2.10.5 which gives specific resistance formulae for movable bed rivers and channels.

Solution of equations (17), (18) and (19) together with appropriate boundary conditions like the given discharge on the upstream of the channel (which could be a time dependent variable) and the water depth at the downstream end would provide a solution for the variables ***Z*** (the riverbed elevation), ***h*** (water depth) and ***v*** (average velocity) at each point of the channel. It may be noted that analytical solution of these simultaneous partial differential equations is possible only under very simplified and ideal conditions. In practice, however, a numerical solution has to be adopted which includes methods like that of ***finite difference***, ***finite element***, or ***finite volume***. Interested readers may refer to Chaudhry (1993) for extensive treatment on numerical methods in open channel hydraulics.

It may be mentioned that around the world, many research workers have tried to develop computer codes for solving the equations and a comprehensive list of such mathematical models may be found in Garde and Ranga Raju (2000). However, only a few of these are public domain model, which means they are freely accessible to the general public. One of these public domain software is the HEC-6 model produced by the United States Army Corps of Engineers (USACE) and may be downloaded from the following website.

www.hec.usace.army.mil/software/legacysoftware/hec6/hec6-download.htm

Equations (17), (18) and (19) when solved together for appropriate boundary conditions may be used to simulate one dimensional flow and sediment transport problems like that of sedimentation behind reservoirs and bed level lowering in the reaches downstream of a dam. Generally, for two dimensional flows and sediment movement, like that encountered due to scour near bridge piers or sediment movement upstream of barrages and water headworks, a two dimensional flow model has to be adopted. Since flow fields are, strictly speaking, three dimensional, the most appropriate model for simulation of such phenomenon would be a three dimensional model. Prof. N.R.B Olsen – of the Norwegian Technical University has prepared such software which is free for public use and may be downloaded from the following website.

http://folk.ntnu.no/nilsol/

2.10.10 Bed level changes during floods in alluvial rivers

Water resources engineers need to know the behaviour of alluvial rivers during floods for planning of some of their structures in natural rivers. It is true that their effect on riverbed may not be obvious immediately. In fact, it is not only the water discharge in the river that causes the bed level to change, but also the amount of sediment conveyed by the river which is generally increased many times during floods compared to the normal.

In many alluvial streams, the stream bed has been observed to rise during floods, while the bed is lowered after the flood recedes. On the other hand, there are other streams where the bed level has been found to be lowered during rising floods and aggraded (that is, raised) during the receding flood. It has been observed that where a river width is narrower than usual, a rise in flood usually causes a lowering of the river bed and conversely, for wider sections of rivers, there is mostly riverbed rising during floods.

It is obvious that the variation of the river bed during floods is dependent on the difference between sediment supply into the reach and the sediment transporting capacity of the reach.

2.10.11 References

1. Einstein, H A (1942) "Formolas for transportation of bed load", Trans. ASCE, Volume 107.
2. Garde, R J and Ranga Raju, K G (2000) Mechanics of Sediment Transport, New age International Publishers.
3. Yang, C T (1973) "Incpient motion and sediment transport", JHD, Proc. ASCE, Volume 99.
4. Ackers, P and White, W R (1973) "Sediment transport: New approach and analysis", J Hydraulic Divn., ASCE, Volume 99.
5. Engelund, F and Hansen, E (1972) A Monograph for Sediment Transport and Alluvial Streams, Teknisk Forlag, Copenhagen.
6. Brownlie, W R (1981) Prediction of Flow Depth and Sediment Discharge in Open Channels, Report number KH-R-43A, W.M. Keck Laboratory, Caltech, USA.
7. Karim, M F and Kennedy, J F (1990) "Menu of coupled velocity and sediment –discharge relations for rivers", J Hydraulic Engineering, ASCE, Volume 116.
8. Keulegan, G H (1938) "Laws of turbulent flows in open channels", US Department of Commerce.
9. Yang, C T (1996) Sediment Transport: Theory and Practice, McGraw Hill International Edition.
10. van-Rijn, L C (1984) "Sediment transport, Part II: Suspended load transport", J Hydraulic Engineering, ASCE, Volume 110.
11. Chaudhry, M H (1993) Open channel hydraulics, Prentice Hall of India.
12. Ranga Raju (1993) Flow through Open Channels, Second Edition, Tata McGraw Hill.