4. SEDIMENT

4.1. GENERAL

4.1.1. SEDIMENTS IN LOW HEAD HYDROPOWER

Sediment data is needed for low head hydropower development for following analysis:

- estimation of the useful life of seasonal reservoirs
- investigation of sedimentation processes upstream/downstream the weir
- design of intake structures

For seasonal reservoirs, the total sediment load constitutes the main parameter to determine dead storage requirements and also to estimate the useful life of the project. At preliminary level, the trapping efficiency of the reservoir can only be roughly estimated. In the field, suspended sediment can be sampled more easily than bed load. Therefore, it is common that bed load is estimated on basis of available information on suspended sediment. For example, as a rule of thumb it has been a common practice to assume for alluvial rivers that the bed load amounts about 20% of the suspended load.

For the design of the intake structure, grain size distribution and mineralogical characteristics of the sediment are required. However, when data is not available estimates based on regional analysis, comparison with similar catchments, and experience from similar sites and conditions may be applied to adopt a suitable value at identification and preliminary level. More detailed planning works invariably require data from the site.

The impact of the low head hydropower station with the construction of a dam upon the sediment transport has to be investigated in detail. Since the dam interrupts the natural movement of sediments downstream, sedimentation is expected upstream the barrier and erosion downstream the planned hydropower station. These phenomena have to be considered during layout and design, appropriate countermeasures should be developed.

The main problem faced with sediment data is the scarcity of the records and the difficulties faced with the application of regional analysis to estimate values. The sediment regime in a river is affected by the morphology of catchment, geological conditions, etc. which may make regional analysis and modeling techniques from different catchment not always suitable.

Another main problem is the fact, that sediment transport measurements in the field are complicated and that there are several different measurement devices in use today. The use of different instruments is due to different hydraulic conditions in the rivers. For better comparison of field measurement results, it is recommended to use the same instrumentation at one river. Experiments have shown, that different measuring techniques have different results in consequence. A more detailed discussion on this topic can be found in the following paragraphs.

The sediment loads are distinguished according to the type of transportation into

- suspended load
- bed load

4.1.2. SEDIMENT DATA

Similar to discharges and water the following sketch illustrates the type, source, processing and purpose of sediment data collection in case of canals. By division of the load into these two groups, loads can be calculated according to their transportation mechanism with physically based and empirical relationships.

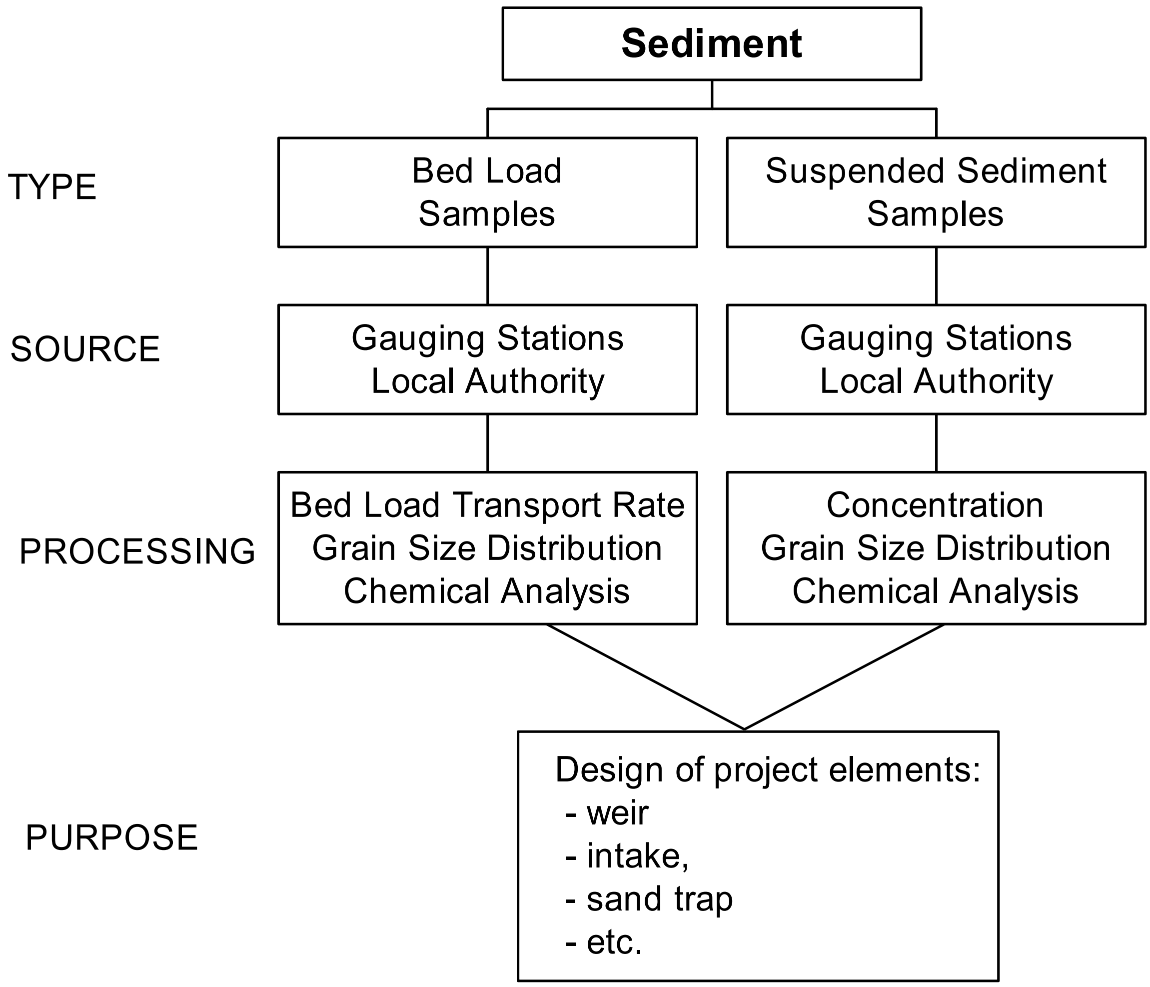

Fig. 4.1: Type, source, processing, and purpose of sediment data in case of canals

The sediment transport is more complex in rivers than for canals. In canals the maximum capacity is determined by the design and thereby also the maximum acting shear stresses on the canal bed are established. If the bed material is known from the consistency and with the sieve analysis, the resistance of bed load can be determined and the expected sediment transport calculated.

On the other hand, in natural streams the flows change with the availability of water in the catchment area. The discharge is not uniform and the availability of sediments from the sources can also be considered as a process of unknown probability. The design of sediment related structures in rivers has to take this into account, therefore the type, sources, processing, and purpose of sediment data in rivers is as follows:

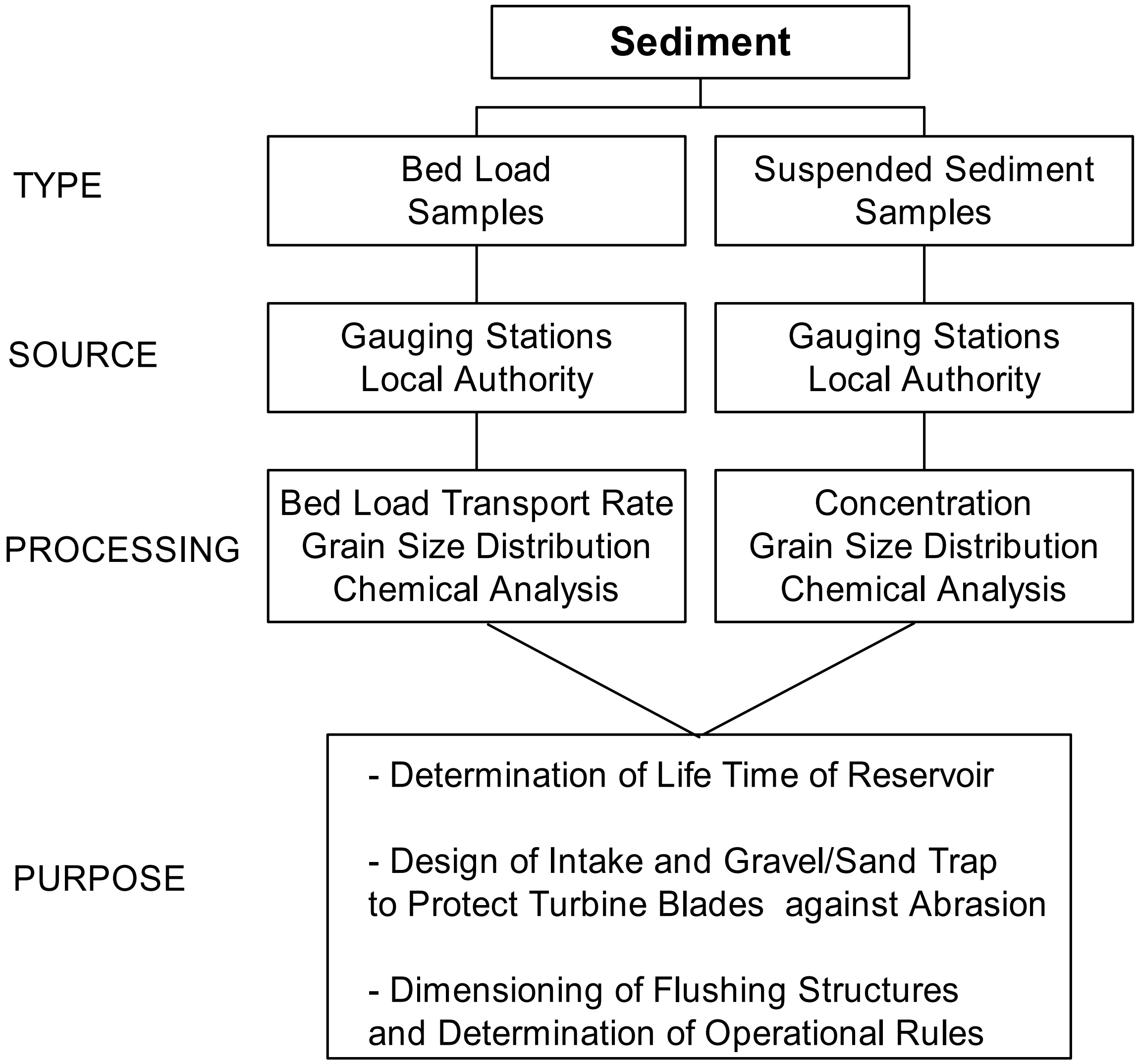

Fig. 4.2: Type, source, processing, and purpose of sediment data in rivers

4.2. DATA COLLECTION

4.2.1. CATCHMENT AREA

As already mentioned in context of high head hydropower developments, the characteristics of the catchment area have an important impact upon the sediment transport in the rivers. Depending on the development of the mountains and the climatologic conditions, different sediment sources can be distinguished, such as tectonics, glaciers, slope failures, monsoon, mass movements. All aforementioned influences act in an interdependent system. More details on the mechanisms are given in the training materials about high head hydropower as well as sediment transport.

Natural conditions at low head developments are similar, but not that extreme. For this reason the catchment area of the river should be investigated, since it gives an idea about possible sediment sources and might help to understand the geomorphologic processes in the region. A dominant factor plays the climate and the consistence of soils for erosion processes in the catchment. But also extraordinary events, such as monsoon rains and earthquakes should be taken into account for the evaluation of sediment transport processes in the catchment area. Today modern survey methods such as satellite images and processing with help of

Geographical Information Systems (GIS) might help to investigate the impact of the catchment area upon the expected sediment transport. The GIS is also a good tool to investigate geomorphologic structures and changes in river reaches.

4.2.2. FIELD INVESTIGATIONS

4.2.2.1. BED LOAD

The rate of bed load is generally difficult to measure. There are many factors that influence the success of bed load measurements, such as:

- mean velocity of current
- availability of suitable measurement locations (bridge, boat)
- mean grain size of bed load
- availability of suitable measurement instruments

In case of high velocities of the flow, as given i.e. at floods, bed load measurements will be difficult to carry out. The drag force to the sampler might be so strong, that the sampler cannot be dropped to the bed of the river. Therefore no bed load, moving along the bed can be caught. Another problem might be the fact that the measuring boat cannot be kept at one position, which makes the measurement impossible.

Depending on the mean grain size of the bed material, an appropriate bed load sampler has to be taken to ensure proper results, which represent the natural conditions on the bed. Therefore the mouth of the sampler should be great enough to catch a grain distribution that is actually moved along the bed.

In general there are two basic types of sampling:

- moveable samplers
- trap samplers

The latter one is only applicable for small mountain torrents, where less sediment is moved and can be dredged from time to time. In low head developments, usually rivers in the plains are of interest, therefore discussion will focus on moveable samplers in this paragraph.

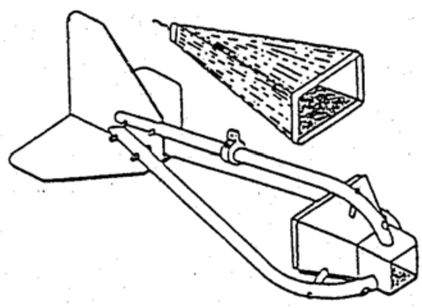

Fig. 4.3: **Moveable bedload sampler Helley-Smith [2]**

Many bed load samplers have been developed throughout the years, such as Muehlhofer, Arnhem, and Helley-Smith. Compared to the other models the sampler Mühlhofer has a solid bottom. The Dutch model Arnhem as well as the American Helley-Smith-bedload sampler is very useful for sandy channel grounds. If the sampler is not heavy enough it will be dragged by the current or it might even not be possible to drop the sampler to the riverbed.
The bed load measurement in the field is similar to the discharge measurement. The total width where the bed load is moved should be measured at different locations in the cross section of the channel. It is important that the sampler lies flat on the riverbed, without disturbing the

streambed and the movement of the sediment. The sampler should also not be moved during the measurement, it should be held in position by a rod or a wire. It is useful to have the velocity distribution as well as the suspended load measured at the same time. For a first approach the number of verticals should be chosen close together. The more dense the measurements are the more accurate the results.

At least three up to seven measurements should be taken at each vertical. The average of these samples can be considered as the instantaneous sampling at this location and the given discharge. It should be considered after measurement whether the distance between is sufficient to achieve the desired degree of accuracy. When insufficient, the density of the measurements may be increased. Alternatively samples may be taken every second vertical.

It must be ensured after every measurement that all the collected material is removed from the sampler and properly stored for transportation to the laboratory. Each sample should be dully identified, with indication of sampling site, vertical number and date.

In low head hydropower development at rivers and canals in the plains, usually the Arnhem and Helley-Smith type samplers are used. These samplers are appropriate for bed load with fine and medium sand. The mouth of the samplers has a maximum width of 20 cm. The weight of the samplers is approximately 80 kg, the steel pipes of the sampler are filled with lead to increase the weight. This is to ensure, that the sampler drops at the bottom of the riverbed and to reach stability of the sampler in the current.

Based on the design of the Helley-Smith sampler the German Institute of Water Resources has adapted the design according to the special requirements of German rivers in the plains, such as Rhine, Wesel, Elbe, Danube, etc. A sketch can be seen in the following figure.

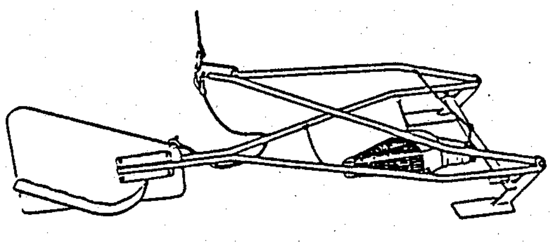

Fig. 4.4: BFG - bed load sampler

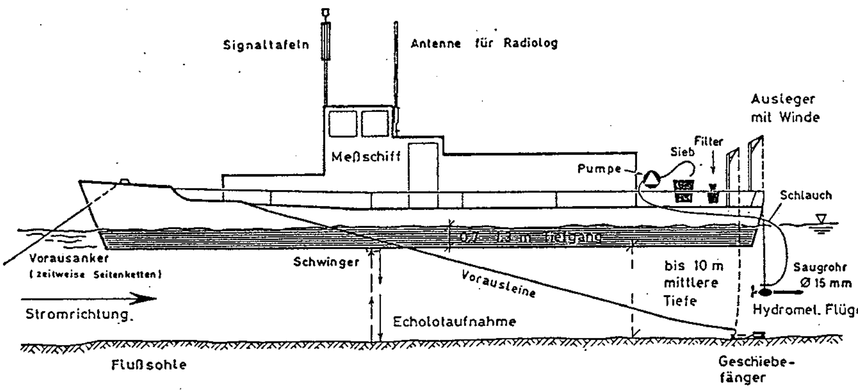

Fig. 4.5: Boat during bed load and suspended load measurements

The measurements have to be analyzed in a laboratory. With the help of a sieve analysis, the grain size distribution can be determined. This procedure is essential for the calculation of the sediment transport rates. These formulas sometimes use the mean grain diameter to characterize the sediment material. Mostly d_{50} is used, which stands for the particle size for which 50% by weight of the sediment is finer. The second important parameter for the determination of the transport rate is the density of the material ρ_s which is also analyzed in the laboratory. Usually a density of 2650 kg/m^3 can be taken for river sediments.

4.2.2.2. SUSPENDED LOAD

Suspended sediment sampling considers the determination of sediment concentrations. The measurements are mostly made at sites where gauging stations are operated. The reason is that besides having the possibility of using existing facilities, discharge data is needed to quantify the transported quantities.

The samplers used for the measurement of suspended load can be classified into three general types:

- Integrating samplers
- Instantaneous samplers
- Pumping samplers

Integrating samplers accumulate a water-sediment mixture over a period of time by withdrawing it from the ambient flow through a relatively small nozzle. Integrating samplers can be distinguished in depth- and point-integrating samplers.

Instantaneous samplers trap a volume of the suspension by instantaneously closing off the ends of a flow-through chamber.

Pumping samplers withdraw a mixture of the suspension through an intake by a pumping action. Their application in Mountain Rivers is limited.

Usually integrating samplers are preferred because they obtain a water-sediment mixture from a long filament of flow. These samplers can be traversed through the flow and thereby take sample at more than one point. One of the widely used measurement instruments for suspended load is the American depth-integrating sampler D-49 and the point-integrating sampler P-61. An example of an integrating sampler is given in the next figure.

The samplers are designed to sample isokinetically to ensure that the water-sediment mixture moves with no acceleration as it leaves the ambient flow and enters into the sampler intake. Inside the instrument a bottle with the volume of one pint is fixed where the mixture is continuously sampled. In the nozzle there are three openings which can be used with different diameters. The choice of the diameter influences the filling time of the bottle.

The number and distribution of measuring stations for suspended sediments depends upon the conditions in the catchment area, as aforementioned. Gauging stations are advisable to use for suspended sediments, they should be combined with discharge measurements. If no gauge is installed, suspension bridges near the identified hydropower site should be used due to load of equipment, such as crane etc. Suspended load measurements should be combined with bed load and discharge measurements.

It is advisable to measure the suspended load daily when suspended sediment concentrations have large fluctuations. The main reason is that normally there is no proven relationship between water discharge and suspended sediment. If daily sampling is not possible, samples should be taken at least two up to five times a week. The frequency of the measurements depends upon the experiences regarding variability of suspended load data at the site.

In case of high variability due to snow and ice melt, seismic activity and heavy rains large amounts of sediment can be transported within a couple of days. For this reason, during critical times whenever possible several times a day should be measured to record extreme loads. Depending on the variability of the concentrations, 250 up to 300 measurements a year provide a good basis to estimate the annual sediment load and especially extreme conditions.

Fig. 4.6: Examples of integrating sampler D-49 during field

The distribution of suspended sediments in a river is not uniform. Typically in a river cross-section more sediments are transported where water velocities are higher. Samples might not be representative for a site when only one measurement is taken in the center of the cross-section. To decrease the uncertainty of the measurements it is recommended to carry out suspended sediment measurements in several verticals of the rivers and to take at least three samples in each vertical to have an average representative sample in a vertical. If data processing shows, that the number of verticals can be reduced without loosing information, only a few, or even one vertical can be used as mean value. However, due to irregular changes in the regime of rivers, this procedure has to be controlled regularly by multi vertical measurements.

4.2.2.3. BED MATERIAL

Parallel to the samples of bed load and suspended load a sampling of the bed material of the river should also be carried out. The grain distribution of the riverbed gives information about armoring effects and helps to calculate the sediment transport rate. Especially in comparison to the bed load grain distribution information about the regime of the river can be gained. In general there are three different types of sampling techniques:

- Dredge/scraper with measuring boat
- Sample pits
- Line-by-number procedure

4.2.2.3.1. DREDGING AND SCRAPING

The measuring equipment consists of a dredge or scraper and other auxiliary equipment such as cranes and boats. Bed material sampling can also be considered as complicated due to the enormous need and use of equipment. Usually in rivers in the plains for low head development flow currents are not so high during low flow season. Therefore it might be possible to use the aforementioned measuring technique. In case of floods, measuring procedures will face some difficulties.

4.2.2.3.2. PITS

If no bed material samples can be taken with the technique described above, samples can be taken from the banks of the rivers to get the grain distribution of the transported material, which has been transported during floods. If this procedure is carried out during low flow season, there is the chance to take samples from the exposed riverbed, which can be considered as representative for the riverbed. Subsurface pit samples can also be taken during low flow season at locations, where the riverbed is exposed.

Fig. 4.7: Subsurface pit sampling

4.2.2.3.3. LINE BY NUMBER

In case the bed material consists of such coarse material, that it cannot be analyzed with the standard sieving procedures in the laboratory, the so called Line-by-number procedure is applied. The procedure for determination the grain distribution with a wide variability and armoring effects is developed by ETH Zuerich, which is widely used in the world today. It is developed for Mountain Rivers, but may also be applied in case of wide variability of relatively coarse bed material of rivers in the plains. Firstly a string is laid next to the river / on the exposed bed in the direction of flow. The concept is to measure the middle axis of stones, which are touched by the string. Thereby a representative sample of the bed material is gained in short time without complicated and time-consuming laboratory tests.

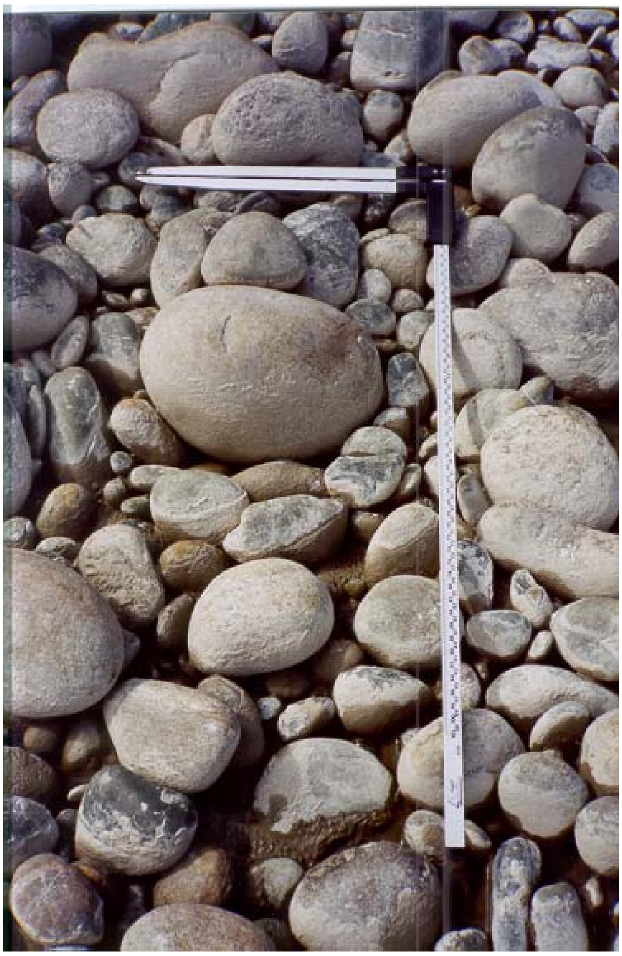

Fig. 4.8: LBN measurement of armour layer

4.3. DATA PROCESSING

4.3.1. BED LOAD

4.3.1.1. LABORATORY TESTS

The bed load samples of the field are analyzed in several respects:

- Weight
- Particle size analysis
- Specific gravity

With help of the weight of the samples at each vertical, the bed load can be transformed into the standard unit of transported bed load per unit width and unit time [kg/ms]. For this reason the width of the sampler and the measured time duration of each sample has to be recorded in the field. By application of this procedure for each vertical, the total transported bed load can be determined by interpolation in the cross-section at a certain discharge.

With help of a mechanical particle size analysis, also called sieve analysis, the grain size distribution can be determined for each sample. The particle size analysis should determine the relative proportions of the different grain sizes, which are transported by the flow. There are different international sieve sizes according to the different standard specifications used in each country. The US sieve openings range from 0.038 mm to 100 mm, German specifications range from 0.04 mm to 63 mm. Those parts of sediments, which are smaller than the smallest sieve have to be analyzed by the hydrometer method, which will be discussed in the paragraph of suspended sediments. Stones remarkably bigger than the greatest sieve, the middle axis has to be measured by hand, the sieve analysis as well as the grain size distribution plot has to be extended. If the grain size distribution is known, the sample can be described with characteristical coefficients, such as the sorting coefficient, the skewness, the standard deviation, and characteristic diameters, such as d_{50}, d_{30}, d_{90} etc.

The specific gravity test is a well-known and simple laboratory test. In most cases the specific density of sediment transported as bed load can be assumed as 2650 kg/m^3. Seldom it is needed to carry out this test.

4.3.1.2. PUBLISHING

Until today only experimental bed load sampling tests have been carried out by GTZ in Mountain Rivers. Therefore there is no systematic data collection available for processing and publishing purposes. However, the mean load transported in the cross-section should be published together with the discharge at that date and the result of the mechanical sieving in form of a tabular grain size distribution.

Table 4.1: Form of a table to be published for bed load

Date	Discharge	Bed Load	d_{10}	d_{20}	d_{30}	d_{40}	d_{50}	d_{60}	d_{70}	d_{80}	d_{90}	d_{100}
	[m^3/s]	[kg/ms]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]

4.3.1.3. DATA RELIABILITY

Following elements should be considered as far as the source of error in the sediment computation concerns.

- field sampling procedure
- field equipment
- field operator technique
- laboratory equipment
- laboratory technique
- laboratory operator
- computation method
- computation equipment
- computation operation
- local spatial variation

Different aspects of data reliability during measurement have already been discussed above. The work with data shows the quality of measurements and in some cases it might be necessary to repeat measurements. There should always be an interaction between data collection and processing to find possible errors. Every single measurement should be critically analyzed, especially those which largely deviate form the general pattern or from measurements for similar conditions made at the same site or even other sites.

4.3.2. SUSPENDED LOAD

4.3.2.1. LABORATORY TESTS

The first step in data processing is the laboratory analysis of data. Suspended sediments consist of a mixture of fine material like sand, clay. There are a number of laboratory tests, which should be carried out for further data processing, such as:

- Concentration of samples
- Specific gravity test
- Particle-size analysis

With help of the concentration, which is measured in parts per million [ppm], the load of suspended sediment material can be calculated. The test is carried as follows: Firstly, the weight of the water-sediment mixture is determined. Afterwards the sample is dried in an oven and weighted again. Thereby the concentration of the sample can be determined.

Since the specific gravity of the mixture of sediments has an impact upon the sediment yield calculations, this laboratory test should also be carried out. Some detailed information on the used laboratory equipment and the detailed procedure of the test can be found in the literature.

Furthermore the grain size distribution of the suspended sediments is also of interest. Since the material is so fine, that standard sieves cannot be applied, a special particle-size analysis, the hydrometer test, has to be used. Particles, which pass the sieve No.200 (0.2 mm) have to be analyzed by the procedure mentioned above. The method is used to obtain an estimate of the distribution of soil particle sizes between 0.075 mm and 0.001 mm. Similar to the mechanical method for coarse material, result data are also plotted on a semi-log plot of percent finer vs. particle diameter and may be combined with the data of the mechanical analysis. A hydrometer is needed, such as the one shown below.

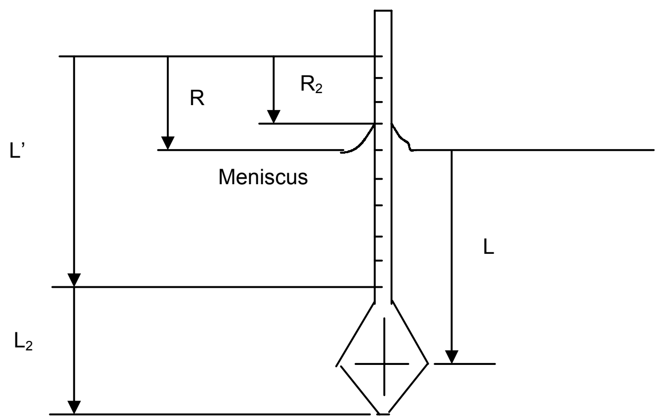

Fig. 4.9: Hydrometer dimensions and terms

The principle of the hydrometer is based upon the physics, that by mixing an amount of soil with water to a 1000 ml suspension, the mixture will have a specific gravity larger than 1.000. The hydrometer displays the specific gravity of the suspension at the center of the bulb. Any soil particles larger than those still in suspension in the shown figure and marked with L (distance between water surface and center of the bulb) have fallen below the center of volume.
This will constantly decrease the specific gravity of the suspension. Since the hydrometer is a constant mass, the less the specific gravity of the suspension, the deeper the hydrometer will sink into the suspension and the larger the distance L will become. Of course larger particles with a greater specific gravity will settle first, after this continuously smaller particles. By reading

the distance L of the falling parameter and using Stokes' law of fall velocity, the distribution of the fine material can be determined.

4.3.2.2. PUBLISHING

After the laboratory tests have been completed, suspended sediment data are published in the hydrological yearbooks. The yearbooks give information on the date of measurement, the measured discharge, the temperature of the water, the measured value of suspended sediments and the result of laboratory analysis, splitted in percentage of sand, silt and clay. It looks as follows:

Table 4.2: Form of a table to be published for suspended load

Date	Discharge	Temp.	Suspended Load	Sand	Silt	Clay
	[m^3/s]	[C]	[ppm]	[%]	[%]	[%]

4.3.2.3. DATA RELIABILITY

After the data collection in the fieldwork has been finished and the samples have been analyzed in the laboratory, the data processing is continued. By using the data for calculation it is always necessary and important to check the data regarding their reliability. Because the data have been passed a long way to be published in the yearbooks or any other report and some mistakes might have happened, for example:

- Improper measurement procedures
- Incorrect reading of the measurement
- Improper identification of the field samples
- Deficient analysis
- Incorrect reading of the equipment
- Mistaken calculation of the analysis
- Incorrect transcription of the data (typing mistakes)

Different aspects of data reliability during measurement have already been discussed above. The processed data should reflect the reliability of the measurements. In some cases it might be necessary to reject data and repeat measurements. There should always be an interaction between data collection and processing to find possible errors in data collection and /or processing.

4.3.3. BED MATERIAL

For the processing of bed material data the same laboratory test should be carried out as for bed load. Independently of whether a sample pit has been taken from the exposed riverbed during low flow or from the riverbank, processing is the same. The samples should always be large enough to allow the determination of its grain distribution by mechanical methods.

However, if a 'line-by-number-procedure" has been applied, the specific gravity is automatically assumed to be 2650 kg/m^3. In this case, it is usually not foreseen to carry a sample to the laboratory. The table from the data collection from the field is analyzed and transformed with help of regression analysis into a cumulative grain size distribution curve. Since sediment material smaller than 1 cm is not taken into account during measurement, fine material data from concrete engineering is artificially added to the sample to develop a grain size distribution similar to bed load procedures.

4.4. APPLICATION

4.4.1. BED LOAD

There are mainly two issues which are of special interest concerning bed load:

- Incipient motion criteria for the beginning of bed load transport
- The amount of transported bed load

Once, the bed load has been started to move, the bed load transported in a river can be assessed basically by two methods:

- Bed load transport formula derived from field measurements
- Use of empirical formulae

4.4.1.1. INCIPIENT MOTION CRITERIA

The critical water depths for incipient motion can be determined and compared with classical approaches after Shields and Meyer-Peter/Mueller etc.. However the applicability should be confirmed with field measurements. Incipient motion criteria have been mostly developed in the laboratory with special boundary conditions. These boundary conditions might not always be fulfilled in the nature.

In rivers with a wide grain size distribution of relatively coarse material armouring effects yield higher resistance of the bed and therefore movement starts at higher water depths and discharges. In case of fine bed material the phenomenon of cohesion has an impact on the incipient motion criteria. Due to acting forces between the grain particles, the critical water depth for incipient motion increases.

4.4.1.2. TRANSPORT FORMULA DERIVED FROM FIELD MEASUREMENTS

With help of the field measurements a relationship between the transported bed load and the discharge can be derived for one cross-section. Since many points have to be known of the graph, this procedure needs a lot of reliable data from the field. However several measurements at different sites of the river have to be done to gain a comprehensive view of the transport mechanisms of sediments. By this procedure the critical water depths for incipient motion can be achieved and be compared with classical approaches after Shields and Meyer-Peter/Mueller and van Rijn.

With help of the derived bed load transport formula the expected sediment loads for other discharges can be calculated. The mean annual bed load can be computed on basis of the flow duration curve. The mean annual bed load can be applied to several years, which gives the mass of transported material for a given duration. Provided that the density of the sediments is known, the sediment volume can be calculated.

The derived bed load transport formula can be compared with other different empirical formulae and show the range of application. With the background information about the database for the empirical formulae, the self developed equation can be checked. The variability of results might be more than 100%, which is not unusual for the use of different sediment transport functions. In such a case, the self-developed equation is more reliable, since it is based on boundary conditions of the concerned river in nature.

Moreover the grain distribution of the transported sediment material in nature can be compared with the bed material or the material on the banks and conclusions about possible armouring processes of the river might be established.

4.4.1.3. EMPIRICAL TRANSPORT FORMULAE

There are various methods and formulae used to estimate bed load. Their applicability depends on the conditions under which the formulae were developed compared with the conditions of the river under study. For rivers in the plains there are several suitable equations, such as Einstein, Ashida and Michiue, Engelund and Fredsoe, Van Rijn, and Parker. Special literature on the prerequisites for applying these formulas can be seen in hydraulic publications on sediment transport and in journals.

For the application of both formulae the grain size distribution is needed. For this reason, empirical formulae have to be combined with results of bed material sampling by means of above mentioned methods.

In the following the bed load of the Chashma-Jhelum-Link Canal (C-J Link) was estimated using the bed load formula by Einstein and the total load formula by Einstein-Brown and Garde/Ranga-Raju. To estimate the bed load the following procedure was adopted: The calculations can be carried out automatically, i.e. with the hydrological data bank DBHYDRO. However, by hand calculations have the same procedure:

- Surveying of cross section and water level slope of the river.

The cross section of the C-J Link is given with a bed width of 116m, a side slope of 2.5.

- A pit sample from the riverbed was taken to obtain the grain size distribution of the material.

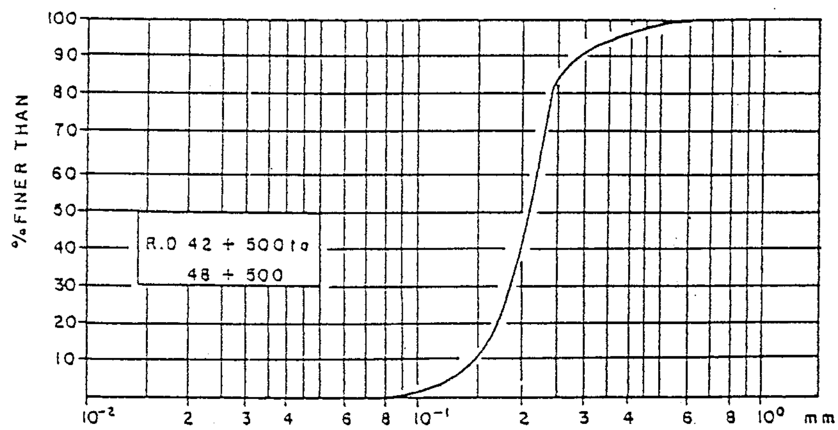

Fig. 4.10: Grain size distribution curve, C-J Link Canal

- Bed load was estimated for four discharge stages using the above mentioned formulae
- Bed load rating equation was developed from the bed load and the respective water discharge for various stages.
- Bed load was estimated applying the rating equation to the series of daily flows.
- Bed load was totalized to obtain monthly and annual totals.
- A mean annual value of bed load was estimated.

This procedure is illustrated in the following graph. For the determination of the yearly sediment discharge, the procedure starts with the flow duration curve in the top left square. Via the discharge rating curve top right and the sediments rating curve bottom right, by application of above mentioned formulae, the bed load/total load duration curve can be obtained. The bed load discharge is equal to the area below the bed load duration curve.

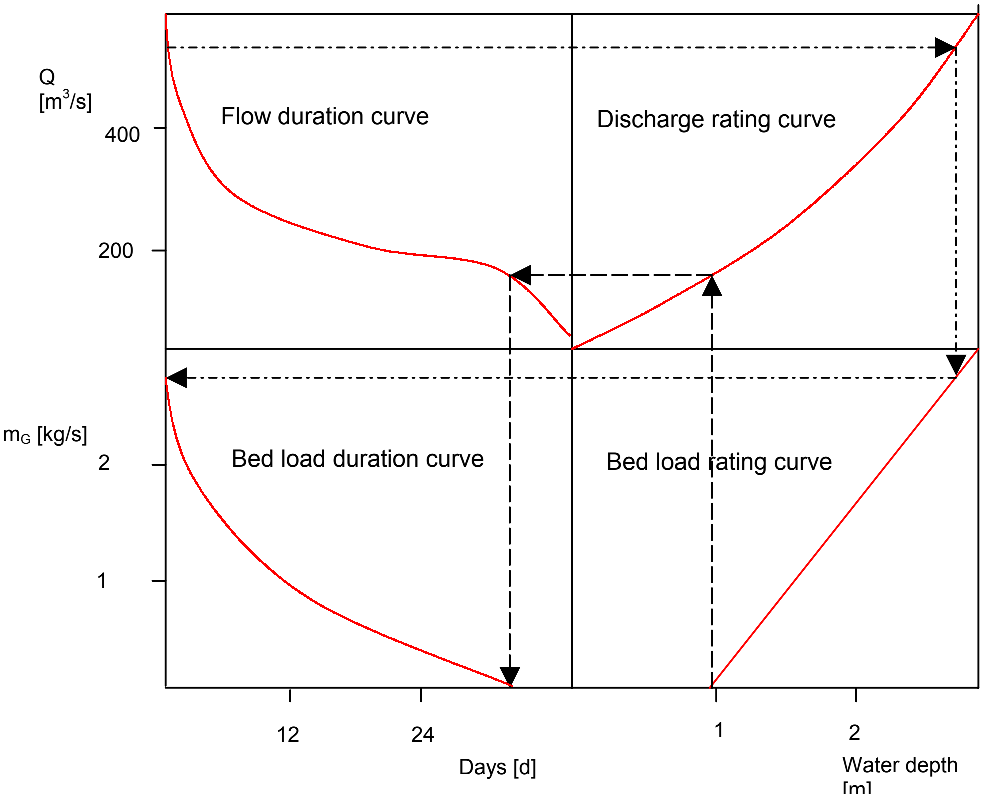

Fig. 4.11: Diagram for determination of yearly bed load rates

The following tables show the calculation of sediment loads depending on different discharges. While the function of Einstein is a pure bed load relationship, formulae of Einstein-Brown and Garde/Ranga-Raju are total load equations.

Table 4.3: Bed load at different discharges according to Einstein:

Q	F^*	u*	ψ	ϕ	G*	g_s	m_f
100	0,35	0,034	2,86	2,2	10,64	$4{,}26*10^{-2}$	4,94
200	0,61	0,043	1,64	4,3	9,09	$7{,}37*10^{-2}$	8,54
400	0,89	0,054	1,12	8,0	9,52	0,153	17,73
600	1,04	0,058	0,961	9,0	8,33	0,166	19,22

Table 4.4: Total load at different discharges according to Einstein-Brown:

Q	u*	F^*	G*	g_s	m_f
100	0,034	0,35	8,28	0,0033	3,85
200	0,043	0,61	19,06	0,154	17,91
400	0,054	0,89	33,58	0,539	62,52
600	0,058	1,04	42,42	0,844	97,88

Table 4.5: Total load at different discharges according to Garde and Ranga-Raju:

Q	u*	F^*	g^*	g_s	m_f
100	0,034	0,35	0,24	0,0043	0,5
200	0,043	0,61	2,21	0,005	5,86
400	0,054	0,89	10,04	0,287	33,32

600	0,058	1,04	18,72	0,575	66,74

Based on the daily water discharges, the bed load/total load discharges can be calculated. This is the basis for the monthly and annual distribution of expected sediments.

4.4.2. SUSPENDED LOAD

4.4.2.1. RATING CURVE

As already discussed, suspended load can be estimated from the suspended sediment samples. A commonly used method for estimation of suspended sediment is the development of a suspended sediment rating curve relating the discharge of suspended sediment to the water discharge. The suspended sediment discharge is then calculated applying the rating curve to the daily discharges.

An example for this methodology is given with the Indus River in Pakistan. At Sukkur Barrage for instance, an approximately linear relationship between the total suspended solids concentration and discharge was developed. The total concentration (C) is related to the flow (Q) with the equation:

$$C = 0.25Q \qquad \textbf{(4.1)}$$

where C = concentration [mg/l]
Q = discharge [m^3/s]

If suspended sediment measurements confirm a relationship between concentration of suspended sediments and water discharge near the proposed site, and the rating curve shows only small scatter of data, a self developed rating curve can be applied. This methodology might be more suitable for rivers in plains, it has to be evaluated through measurements.

However if the scatter of correlating data is great, this approach leads to an underestimation of expected suspended sediments. The underestimation of suspended load is due to the fact that the rating curve represents the mean condition of the river and does not represent the extreme conditions when the river carries the larger part of the sediment load. Large suspended sediment loads might be transported during heavy monsoon rains, or during floods. Therefore the suitability of application of rating curves has to be checked carefully before processing of data.

4.4.2.2. INTERPOLATION (SHIFTING) METHOD

Alternatively to the rating curve method, the interpolation method can be used, if scatter of data is extreme. The method comprises the calculation of the suspended load from the concentration of the samples. For the days when no sediment sample is available, interpolated values between the concentration of the previous and consecutive samples and the respective discharges are calculated.

- Shift is the correction applied to the discharge of a concentration measurement to bring the measurement to the standard curve.

- Shifts vary with time and fluctuations of concentrations

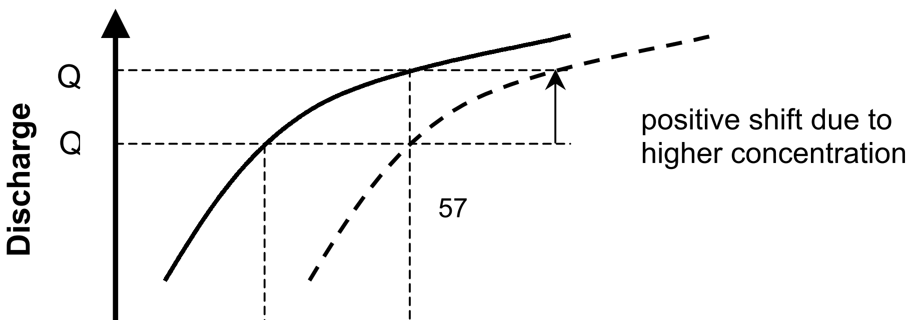

Fig. 4.12: Shifting of discharge-concentration

With:
Q_m, C_m: Discharge and concentration by measurement
Q_r, C_r: Discharge and concentration by rating curve
If:
$C_m > C_g$ => positive shift
$C_m < C_g$ => negative shift

Lower Concentration   Higher Concentration

As an example for the estimation of suspended loads in a river, the Tables 4.6 up to 4.8 of the Jinnah Barrage are enclosed in the appendix. Table 4.6 shows the existing conditions of suspended sand concentration for different flows, covering low flows but also the 100-year flood.

Table 4.6: Suspended Load Concentrations at Jinnah Barrage, existing conditions

Flow	Discharge [m^3/s]	Concentration [mg/l]
Low quartil	1700	85
Median	3380	169
Upper quartile	4970	248
Mean annual flood	14700	735
10-year flood	19250	963
100-year flood	28300	1415

It is expected, that sand concentrations at Jinnah are likely to increase as the trap efficiency of Tarbela reservoir decreases. In this context the planned construction of Kalabagh Dam upstream of Jinnah barrage should be mentioned. It is expected, as shown in Table 4.7, that the suspended load inflow is reduced by nearly 50% through the barrage of Kalabagh.

Table 4.7: Suspended Loads at Kalabagh Dam Site

	Suspended Load	Bed Load	Silt/Clay	Sand	Total [ml/annum]
Inflow	138	4	111	31	142
Trapped	65	3	52	16	68
Outflow	74	1	60	5	75

Thereby the nearly the complete bed load is trapped in the Kalabagh reservoir and a considerable amount of suspended load is reduced at Jinnah barrage. Estimations are given in Table 4.8.

Table 4.8: Suspended Load Concentrations at Jinnah Barrage, after construction of Kalabagh

Flow	Discharge [m^3/s]	Concentration [mg/l]
Low quartil	1700	42
Median	3380	84
Upper quartile	4970	124
Mean annual flood	14700	369
10-year flood	19250	482
100-year flood	28300	707