BRAZILIAN ELECTRICITY REGULATORY AGENCY

Hydrologic Studies and Information Department – SIH

SEDIMENTOMETRIC PRACTICES GUIDE

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SEDIMENTOMETRIC PRACTICES GUIDE

SUMMARY

1. *INTRODUCTION*

The herein sedimentometry referred to concerns the quantity of sediment transported by streams. There are several methods for performing measurement, regarded as direct and indirect, depending on the kind of equipment used and other procedures. Sediment load refers to clay, silt, sand and fine gravel transported. Although the granulometry classification comprises coarse gravels, stones and small stones, such material is usually not considered in this kind of study.

There are several sedimentometric methods that may be classified as direct and indirect. Sedimentometry in Brazil has been performed through sediment sampling, laboratory analysis and computations for obtaining sediment discharge. This last procedure is considered as one of the indirect methods. One reason for using such methodology is the use of North-American series equipment for sampling sediment, which is also adopted in several countries and provides relative facilities; there is also Brazilian-made equipment of that series.

In order to become acquainted with several measurement methods, one should better refer to the book *Hidrossedimentologia Prática,* edited by CPRM and ELETROBRÁS (Carvalho, 1994) or, in 2nd. Edition (Carvalho, 2008) edited by Editora Interciência. By the end of that work, there is a bibliographic list, which was not necessarily entirely used for preparing this Guide; nevertheless, it was prepared to assist the reader on its consultations.

The sediment discharge measurement – when intended to determine the suspended discharge, the bed discharge, the bed material discharge and total discharge – involves the measurement of water discharge, suspended sediment sample, bed material sample, water temperature, water line energetic gradient slope, as well as other as sediment analysis and final computations.

Sedimentometric works are always performed at fluviometric gaging stations and require the knowledge on measures such as water level, stream velocity, water discharge and others.

The target audience of this Guide are mainly field and laboratory professionals directly involved with network operation. It also aims at providing guidance on how sedimentometry may be performed, trying to standardize the working methodology. It is just a guidance based on Brazilian experience, since there are several methodologies available in other countries.

2. *THE RELEVANCE OF THE FLUVIAL SEDIMENTOLOGY STUDY*

The terms erosion and sedimentation involve the processes of erosion, transportation and deposition of solid particles, which is usually named as sediment. Those processes have been active along the geological time (see item on rocks cycle) and have assisted in modeling the current relief of our world. Nowadays, erosion, transportation and sedimentation may cause severe engineering problems, as well as environmental issues.

Human activities introduce a deep influence over erosion. Under some circumstances, erosion rates are 100 times higher in face of human interference, only in geologic terms. The erodability of natural material is strongly influenced by perturbations on soil use due to improper management, be it in agricultural practices or for engineering works. The soil protective layer (vegetation) is weakened by fire, cut, plowing, and so on. Besides harmfully producing sediments, erosion may severely damage lands that might be used for agriculture, by reducing the soil fertility and productivity. The conditions for superficial runoff and hydraulics features of natural channels are intensified by the increase on draining area and by changes on its original morphological features, such as, for example, the arising of meanders.

Severe erosion may occur during the construction of roads and highways, where protection vegetation is cut and the natural slope is changed, without the due precautions. Local erosion causes serious problems, and the “washing effects" of eroded areas may be felt dozens and even hundred kilometers downstream the problem source.

In the United States, 85% of the 571.000 bridges and viaducts were built over water streams. The phenomenon of sediment mud mass sliding resulting from land washing - due to huge floods - is mentioned by Julien (1998) as the reason for major problems occurred with bridges during critical hydrologic events.

Mines operations may also introduce great volumes of sediments into natural environment. Open cultivation areas favor erosive action of rains for years, even after the mine exploitation ceases. They cause instability problems in natural channels, thus raising difficulties for navigation in some cases, besides introducing factors that make the responses of the fluvial system even more complex.

The control work performed by natural fluvial rivers and channels greatly influences the erosion process. The narrowing of channels, thus increasing water line slope and slow velocity, favor the starting of water channel erosion. Sometimes, that erosion may be benefic, by restructuring the channel morphology and also increasing its flow capacity. Reworking eroded material in downstream stream reaches may also be a factor for starting another erosion cycle in a basin. An example is the case of sediment sources for Rivers Purus and Juruá, in Amazonas State. The eroded sediments from the Andes, settled in a region with a relief still relatively high, are the main sediment sources for those rivers.

The sediments transportation affects water quality and the possibility for human consumption, or its use for other purposes as well. Several industrial processes do not tolerate even small portions of suspended sediments in water. This fact sometimes involves high public expenses for solving the problem.

Damming influences the stability of natural channel, mainly in two ways:

1) Holding the inflowing sediment; and

2) Modifying the natural flow and sediments transportation towards downstream.

As a dispersed result, degradation occurs downstream, and retention may favor the risk of floods. There are no computations for Brazil, but in the United States the reduction on reservoirs capacity – caused by the accumulation of sediments – generates losses of about US$100 million (Julien, 1998). Issues such as turbines abrasion, material dredging, and likely mechanical faults may be associated to reservoirs and damming. Other problems, such as diminishing sediments for maintaining fluvial and even coastal beaches are part of literature, and dams are regarded as being the cause for such effects.

Sediments are not just one of the major water pollutants, but also serve as catalyzer, transporters and fixing agents for other pollutants. The sediment, by itself, degrades water quality for human consumption, leisure, industrial consumption, hydroelectric infrastructures and aquatic life. Additionally, chemical products and waste are assimilated on and in sediment particles. Ionic exchanges may happen between the solute and the sediment. Therefore, sediment particles also intensify the power of those problems caused by pesticides, chemical agents resulting from waste, toxic wastes, nutrient, pathogenic bacteria, viruses, and so on.

There are several resulting from sediments disposal. However, sediment is vital for conservation, development and management of soil and water resources. In face of the quick population expansion, and resulting demand for infrastructure, food and products derived from soil and water, the simple exploitation must be reviewed. The integrated management of the system soil + water shall be emphasized. For Brazil, and specifically for the electric power generation sector - where almost 90% of electric power is hydraulic - it is necessary to have the problem planned and worked in partnership with other users of the basin tributary to the hydroelectric stations' reservoirs.

3. *FLUVIAL SEDIMENTOLOGY AND THE "ROCKS CYCLE"*

Suspended sediments are part of a process that cannot be fully monitored during a human being life. Such process is named the rocks cycle and may be exemplified as follows (Figure 3.1):

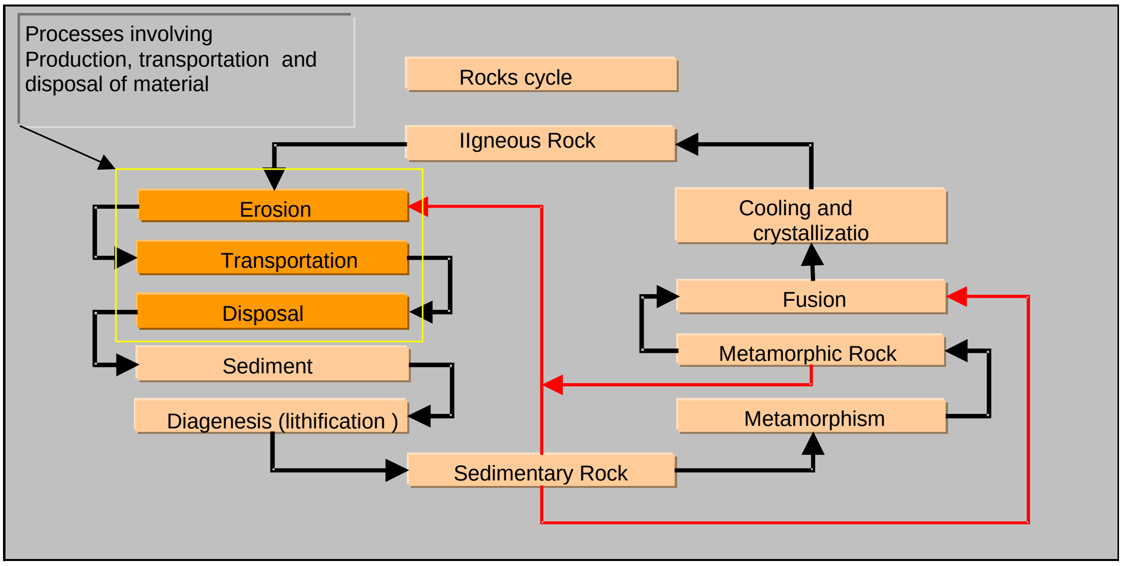


Figure 3.1 – Rocks cycle. Black arrows mean the longest way of the cycle and the red arrows mean other likely ways. Source: www.mineriobr.com.br

Let us suppose that about 15 or 20 km beneath the Earth surface, there is a "magma chamber"[1] and that it comprises, for example, a granitic magma, i.e., a magma made up by all ingredients, such as silicium, oxygen, sodium, aluminum, etc., for building, upon cooling, minerals that will make up a granite (an IGNEOUS ROCK).

Upon the gradual loss of heat of the *magma chamber* material, crystals are formed, aggregate themselves and give rise to a granite. For that granite to become exposed on ground surface, it is necessary to happen EROSION along many kilometers of rocks that are over it and, for that, some million years will be required. When the granite reaches the surface, it meets an environment very different from that where it was built. It meets free oxygen, carbonic gas, water, etc., and pressure and temperature much lower than the existing ones where the granite was formed. When rocks are uncovered and exposed to atmosphere and hydrosphere, they need to adjust themselves for the new environment. Such adjustments (chemical and physical) are named INTEMPERISM.

Water temperature and dilatation variations, when water freezes on the rocks fissures, are examples of a physical intemperism process (in this case, physical phenomena are acting). On physical intemperism, there is the break of great rocks into smaller blocks that are more and more exposed to the action of water and air. Those agents slowly decompose the rock through the chemical attack of their minerals. This is the chemical

[1] Closed and restrict accumulation, on lithosphere, of magma – material under fusion state that, by consolidation, originates igneous rocks.

intemperism. For chemical intemperisms, some minerals are more easily <<attackable>> than others.

The destruction of materials that may undergo intemperism leave holes and fissures on the rock, and may liberate fragments of the rock, as well as minerals like quartz, for example, which is more resistant to the intemperism attack. The product of rocks decomposition results in materials with low consistency, which are the SOILS.

Let us consider that part of particles coming from rock decomposition, as well as from the dissolved part, are carried by rain and river waters to the oceans[2]. In that case, sediments may become gradually deposited for a given time in water basins, and for a longer time in ocean basins, nearby the coast. The continuous sedimentation may lead to the sinking of such basins. A plain oceanic basin that is undergoing constant sinking and continuous sedimentation is called GEOSYNCLINE.

As the geosyncline sinks, the environment containing sediments becomes modified. Pressure increases, due to the continuous sediments load, and temperature gets higher due to the GEOTHERMAL GRADIENT (depth, in Earth crust, in meters, required to have a 1ºC increase in temperature). Sediments, sand and mud, therefore, loose water; they are compacted, cemented and changed into sedimentary rock, as arenite for example.

The sum of sediments transformation processes in sedimentary rock is the DIAGENESIS (set of physical and chemical modifications undergone by sediments, from its deposition up to its transformation into SEDIMENTARY ROCK). As geosyncline continues to gradually sink, mainly due to actions of factors such as pressure and temperature, the METAMORPHIC process starts.

By increasing pressure and temperature, the sedimentary rock may become a METAMORPHIC ROCK. If sinking remains, the rock may finally reach a FUSION environment (dissolution due to high temperatures and pressures) and change into magma again. That magma may start the process of ascending to surface and, due to the temperature decrease, solidify itself (COOLING AND CRYSTALLIZATION), thus making up a new igneous rock. This new rock may reach surface, undergo intemperism and restart the whole cycle.

3.1 *Sediment load and sediment discharge*

Sediment present at water stream is originated by erosion on the basin and on bed and banks. During rainy occasions, torrents carry several particles for the river, where that sediment moves either suspended or on the bed, by sliding or jumping. Depending on the stream velocity and the turbulence effect, bed particles may enter the liquid means and remain suspended there, until moving again on bed, due to the reduction of acting forces. Particles also move on bed because of stream action, but each one is subject to friction resistance, thus resulting that their movement velocity is lower than for the suspended particles.

[2] This is the part of the process subject to sedimentometric-fluvial analysis. This process is dealt with in this Guide.

The term *sediment load* refers to the qualitative phenomenon of the movement, and may be suspended, entrainment, contact or jumping. The term *sediment discharge* refers to the quantity in movement.

Suspended discharge and bed discharge are separately measured, because the movement of bed discharge particles is subject to resistance forces, while saltation bed particles are free in liquid means.

There are finer particles suspended in liquid means, such as clays and silts, and small quantity of coarse, such as sands. Under high velocities and turbulence regimes, the quantity of suspended sand may increase. The movement of suspended particles is considered as equal to the stream velocity.

The coarse – such as sands and gravel – is in the bed sediment load. Under slow velocities regime, the thicker particles, such as gravel, stop moving, thus increasing the amount of sandy materials in movement. The bed coarse incorporated to the fine suspended load is considered as the *bed material load.*

4. *SEDIMENTOMETRY*

Brazil has one of the major fluvial networks in the world, which is highly relevant to Brazilian development concerning water supply, hydraulic power generation, navigation, irrigation etc. The management of those water resources requires knowledge about the fluvial regime, which is achieved through fluviometric network and further studies.

The management and maintenance of that network includes to obtain data on water levels, water discharge, sediment discharge and parameters on water quality. This is continuously monitored by local observers and, periodically, by hydrometry teams, through recorders or daily operation. Such operation is critical for water resources management, since several studies derive from it. Each datum obtained will be used several times by several entities (either public or private), be it for planning and operating the system for its own network, be it for studies aiming at electric power generation, water supply, irrigation, navigation, flood control or any other water resource project.

Therefore, accurate data are essential. The simple reading of a ruler, measurement of water discharge and all additional data shall be obtained in an accurate, honest way, by using the best technique and knowledge available. The measurement moment is highly relevant, since a mistake made is hard or even impossible to be corrected, thus voiding all efforts and bringing losses.

The basic or primary Brazilian fluviometric network, under ANA responsibility, counted with more than 2000 fluviometric gaging stations on this year of 2013, out of which more than 400 measure suspended sediment discharge. Other entities have operated the secondary network, and some gaging stations were incorporated to the basic network.

Due to operational and financial constraints concerning the primary sedimentometric network, operation is limited to obtaining suspended discharge in a number of gaging stations lower than it would be desirable. The frequency of measurements is also lower than what would be desirable for reaching good knowledge on natural environment. It is expected that, on future, the network may be expanded determination of granulometry of the material,l bed discharge be included and operation frequency be increased. There are efforts towards advancing in this sense, as well as for the use of modern and proper equipment, both in field and in laboratory.

It is necessary to know sediment discharge for analyzing the basin degradation, verifying water quality for supply, studying rivers and reservoirs sedimentation, surveying sedimentation at fluvial works sites, as well as for several additional environmental and engineering works. It is usual for entities services to focus only measurements of suspended discharge, since it is easier and cheaper, and also because it is more abundant in water streams. Therefore, the survey on bed discharge not always corresponds to the desirable approach.

In small hydroelectric reservoirs, for example, there are stream velocities enough for the easy flow of suspended sediment and, therefore, to avoid its deposition. However, the coarse, such as sands and gravel, is transported on the bed, and does not flow through ducts and weir, thus directly contributing for the deposit in the lake. Therefore, it is essential that bed discharge and material granulometry are also known. In fact, it is necessary to measure both suspended and bed discharge, in order to have knowledge enough about the river sediment load regime.

Sedimentometry in Brazil has been performed by sampling networks, collections of water and sediment samples, analysis in laboratories and computations for obtaining sediment discharge; this process is considered as one of the indirect methods (see Figure 4.1). One of the reasons why this methodology has been used is the use of North-American series equipment for sediment sampling, diffused in Brazil through several hydrologic studies of USGS. Such equipment is relatively easy to manage, and Brazil already produces some equipment like that.

Sedimentometric works are always performed at the fluviometric gaging station, and it is necessary to know other measures, such as water level, stream velocity, water discharge and others. When intended to determine the suspended discharge, bed discharge (or entrainment), bed material discharge and total discharge, the measurement of sediment discharge involves measurement of water discharge, suspended sediment sampling, bed material sampling, water temperature, water line energetic gradient slope, as well as other measurements.

As previously stated, sedimentometric works are a process. When analyzing the process as a whole, and following the new organizational methodology, it is possible to deal with the topic as indicated in the macro-diagram below. In that diagram, several stages of the sedimentometric measurement are highlighted, from basic and/or reference information providers, up to final clients, passing by products and sub-products, besides, of course, sub-processes, which will be the major stages of the work.

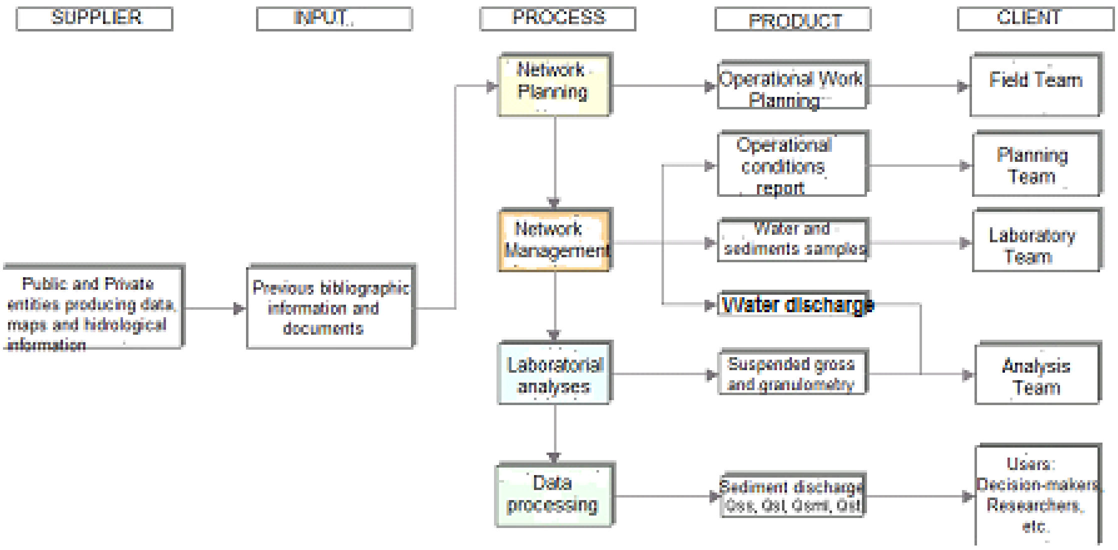


Figure 4.1. Macro-diagram of the process for obtaining sedimentometric data.

Therefore, the works for obtaining final values on sediment discharge involve 4 stages, which can be described as follows:

4.1 *Sedimentometric Network Planning*

In this stage, the network purposes will be defined; contact will be made with entities that may be operating in the region being studied; and survey on data and additional information that may exist will be performed. Here, the kind of network intended (long-term monitoring or for a short-term specific study) is also defined, as well as the gaging station operation frequency (number of samplings to be performed each year, as well as the dynamics concerning water cycle) and methodologies to be adopted concerning sampling performance and equipment to be used. Besides the laboratorial sampling processing to be adopted along the process, how many and which gaging stations shall be operated by whom, i.e., script and operation teams shall also be established. Based on the output for this stage, the planning team shall outline a working plan documenting all process stages or activities, in such a way as to provide the teams with guidance for further stages (see Figure 4.2).

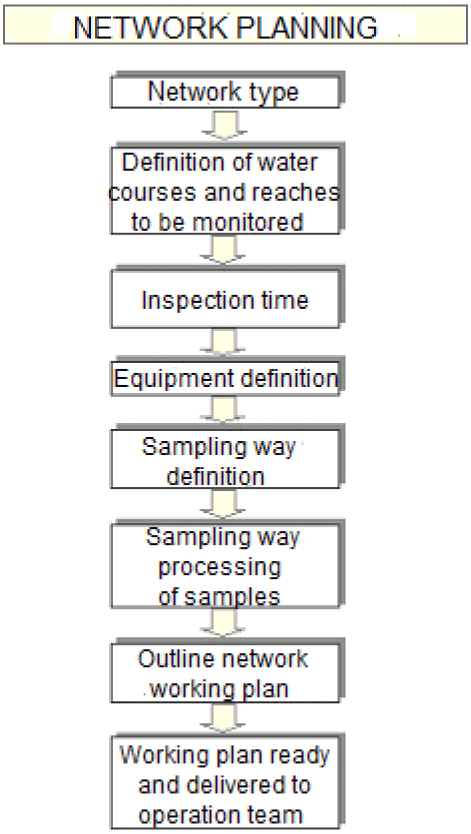


Figure 4.2. Planning stages

4.1.1 *Definition of network type and sites to be monitored*

The planning concerning the number of sedimentometric stations, duly distributed in a water basin and their respective operation shall depend on the network purposes. Usually, gaging stations may be installed in order to build either a main or a secondary network.

The **primary network**, or **basic**, is made up by a minimum number of gaging stations that will be operated by an entity in charge of the National and/or State hydrometric network, whose operation is addressed to several long-term water resources management purposes.

The **secondary network** is addressed to specific purposes and is restrained to a hydrographic basin or draining area. This is the case for stations addressed to studying reservoir sedimentation.

Sedimentometric gaging stations may be planned to measure the total sediment discharge for the ocean, or for measuring the sediment transportation in stream, resulting in values that may allow for surveys on erosion and sediment deposit in rivers and reservoirs. An optimum network must have gaging stations nearby the river mouth for each important river flowing to ocean (WMO, 1994). For a given basin, stations shall be installed along the stream presenting the greatest sediment transportation. A large river will surely have gaging stations properly distributed along its stream. If just one gaging station is to be installed in a given river, then such installation may be at the starting point for the medium stream.

Gaging stations shall be installed specially in basins or regions susceptible to severe erosions or even intensive precipitations. When there is a great interest in managing the water resources of a specific basin, it may be contemplated by more stations. It is intended to install new gaging stations at existing operational fluviometric gaging stations; this would also allow the use of historical hydrometric data existing there.

The density of stations in the main sedimentometric network desirable for a water basin or region is presented in Table 4.1 (WMO, 1994). One should bear in mind that obtaining sedimentometric data is an expressive task and, therefore, planning shall emphasize gaging stations in areas where erosion is severe. As an example, one may use the Chinese criterion that performs regular measurements of sediment discharge in all fluviometric stations reporting concentration higher than 500mg/*l* (Yuqian, 1989).

Table 4.1 – Minimum density recommended for establishing a sedimentometric gaging stations network (WMO, 1994).

Physiographic Unit	**Minimum Density by station (area in km^2 by post)**
Coastal region	18.300
Mountainous region	6.700
Interior plains	12.500
Hilly / undulating	12.500
Small islands (<500km^2)	2.000
Polar or arid	200.000

The network suggested by WMO intends to obtain data on total sediment discharge. However, due to high costs involved, and also because suspended discharge prevails, the entities services usually contemplate only the suspended sediment measurement. The lack of knowledge about bed discharge jeopardizes many sedimentological studies.

An alternative would be to contemplate special fixed-term programs for some troublesome basins, performing measurement on total sediment discharge and including the due knowledge on concentrations, sediments features, suspended and bed discharge. Another alternative would be to choose a part of the network where bed sediment would also be monitored.

The bathymetric survey may contemplate data on sediment transportation for lakes and reservoirs, although information obtained not fully replace the gaging stations measurements at the stream (WMO, 1994).

The **secondary sedimentometric network** shall meet a specific purpose. The gaging stations for that network may also belong to the basic network, or become incorporated to it later on. Usually, they are operated for measuring total sediment discharge, contemplating accurate measures on concentration, characteristics of both suspended and bed sediment, such as granulometry, suspended discharge and bed discharge.

For important river reaches or reservoirs, at least 80% of the drainage area must be monitored for total sediment discharge (Yuqian, 1989). For surveys on operational reservoirs, it is necessary to install, besides the one upstream the backwater of reservoir, a gaging station right downstream the dam for measuring the effluent sediment. Important tributaries representing more than 10% of total discharge shall also have sedimentometric stations, monitoring at least 60% of the draining area of each one. Streams with significant discharge, and whose tributary is nearby the dam or the intake, must also have a gaging station.

For studies on reservoir sedimentation, it is very important to determine total sediment discharge, defining the sediment characteristics. For establishing the specific weight of deposits, it is necessary to know the average affluent percentages of granulometry for suspended and bed sediments.

4.1.2 *Gaging Stations Installations and Sampling Frequency*

This installation is for a fluviometric gaging station, that may be called as “fluvial-sedimentometric”, and it shall have staff gages (rulers) and limnigraph (optional), level references, measurement and control sections. Sediment measurement is performed at the cross-section of the discharge measurement. It can be said that a gaging station is composed of the staff gages, level references, a cross-section for measurement and a control, this one downstream.

Using maps it is possible to select a better straight reach before to go to the field. A straight reach of the river is later selected, presenting high banks and moderate slopes, firm and uniform bed, where threads are parallel to banks, and the flume shall contain all flow variations, with no flooding. If there is uniformity for runoff and distribution of velocities at the cross-section, conditions will be good enough for sediment samplings (Carter & Davidian, 1968).

The access to the gaging station shall be permanent, in order to avoid interruptions in operation. It is very important to have people living nearby the gaging station, in order to keep them as observers and watchmen.

The station shall not be installed very close to water mouth or ocean, in areas susceptible to backwater or tidal influence. Sedimentometric stations shall neither be installed downstream an affluent with significant discharge, because sediment load shall influence the distribution of sediments along the section.

The staff gages and limnigraph sites shall be upstream the control section, in still waters, as closer as possible to the measurement section, and there should be no affluent or water derivation among them.

The measurement section should be as close as possible to the staff gages, with no significant discharge contribution. That section should have vertical distribution of velocities, in such a way that its variation be logarithmic and that vertical distribution of sediment concentrations be exponential.

The control section is a site along water stream where there is a change on the river regimen, passing by critical regimen. It happens in waterfalls and riffles, which are excellent controls, granting the bi-univocal relation $Q = f(h)$. If there are no such accidents, one should look for river narrowing or bridge that strangles a little the runoff. Sometimes is necessary to install an artificial control.

The frequency for sediment sampling or measurement depends on the basin runoff characteristics. For many water streams, the quantity of sediment load during rainy period represents an average from 70 to 90% of the whole hydrological year. Then, the suspended sediment shall be measured more frequently during such wet periods, rather than during dry periods. During floods, for some water streams, it may be required hourly measurement of suspended load, or even a higher number of samples to accurately define the sediment concentration. For the remaining year, samplings may be daily or even weekly performed. For hydrographic basins with great variety of soils and geological conditions, as well as an irregular distribution of rains, sediments concentration along the water stream depends not only on occurrence of floods along the year, but also on the basin runoff sources. Under such conditions, no consistent program may be performed if samples or measures on sediments concentration are not properly distributed along such periods for verifying that transitory variation (Yuqian, 1989).

Consequently, the frequency of sediment measurements depends on the required accuracy of data to be obtained for the studies to be performed. As more accurate and more complex the runoff system and basin conditions, as more frequently should measures take place (Yuqian, 1989).

Therefore, one may conclude that for a given station or for sedimentometric networks, the frequency of measurements may range from continuous or almost continuous, to hourly, daily, weekly, monthly or eventual.

As previously discussed, even eventual measures shall contemplate the rainy period, mainly the first three months of that period, because the basin shall undergo great erosion upon the first rains, since soil lacks vegetal coverage. Nevertheless, it is useful that measurements are more focused on the river flow increase, when a greater sediment transportation can be observed.

Currently, continuous measurements may be performed by using recorders, while the almost continuous or hourly ones are performed by using pumping equipment in rotating trays. The observer may perform daily or weekly samples, while hydrometry teams may perform eventual ones.

4.1.3 *Measurement methods*

The different methods for suspended, bed or total discharge measurement are classified as *direct* (or *in situ*) and *indirect*. Table 4.2 shows, in a simplified way, those methods.

Surely, other kinds of equipment for measuring sediment transportation have been successfully used in many countries. Technological development has allowed for projecting new equipment, both for direct and indirect measures. Equipment mentioned in the table was developed for meeting several fieldwork conditions, and both concentration and granulometric variations for the material.

Table 4.2 – Methods for measuring sediment load (see Carvalho, 1994 and 2008).

Sediment discharge	Measurement	Description	Measurement equipment or methodology
Suspended sediment discharge	Direct	Uses equipment that measures concentration or any other value - such as turbidity or ultrasound - directly in the stream	Nuclear measurer (portable or fixed), Optical ultrasonic flow meter, Doppler Ultrasonic Flow meter, Turbidimeter (portable or fixed), ADCP (Doppler), laser Lisst (Sequoia)
		Through sediment accumulation in a measurer (graduated test tube)	Delft Bottle (punctual measure and high concentration)
	Indirect	Sediment collection by sample of the water-sediment mixture, concentration and granulometry analysis and further computation on sediment discharge	Several kinds of equipment: - pumping, equipment using bottles or bags, being punctual instantaneous, punctual through integration and vertical integrators (in Brazil, the North-American series– U-59, DH-48, DH-59, D-49, P-61 and bag sampler are the mainly ones that are used)
		Use of satellite pictures and comparison with simultaneous field measures for calibration in large rivers.	Equations are established in order to correlate the values of picture observation and measured concentrations
Bed load entrainmen	Direct	Samplers or portable measurers of three main kinds (the sample is collected in several points of the cross-section, determining its dry weight, the granulometry and calculating the entrainment discharge); the measurer is fixed on the bed from 2 minutes to 2 hours, in such a way as to receive in its receiver from 30 to 50% of its capacity	1) Basket or box - Muhlhofer, Ehrenberger, Switzerland Authority and other measurers 2) Tray or tank, as pan-type measurers - Losiebsky, Polyakov, SRIH and others 3) Pressure difference –Helley-Smith, Arnhem, Sphinx, USCE, Károlyi, PRI, Yangtze, Yangtze-78 VUV measurers and others

t discharge		Door or slot structures – the bed slots are opened for a few minutes and the sediment is collected	Mulhofer measurer (USA)
	Indirect	Bed load collection, granulometric analysis, slope gauge, temperature hydraulic parameters and computation on entrainment discharge and bed load through formulas (Ackers and White, Colby, Einstein, Engelund and Hansen, Kalinske, Laursen, Meyer-Peter and Muller, Rottner, Schoklitsch, Toffaleti, Yang and others)	Kinds of equipment for sampling bed material: 1) horizontal penetration, like dredge and shell bucket 2) vertical penetration, like vertical tube, scraper bucket, excavation bucket and gravel excavation 3) piston-core, which holds the sample though partial vacuum 4) USBMH-60 and USBM-54
		Dunes displacement – by measuring the volume of the displacing dune, using high-resolution echobathymeter	1) successive bathymetric surveys along the cross-section 2) successive bathymetric surveys along longitudinal sections
		1) Radioactive trackers 2) Dilution trackers, being both methods by setting the tracker on the sediment and monitoring it by using the suitable equipment (the tracker shall be chosen in such a way as to avoid polluting environment)	Methods: 1) by settling the tracker directly on the bed sediment 2) by collecting sediment, settling the tracker on the sediment and returning it to the bed.
		Lithologic properties – use of sediments' mineralogical features	Collection of tributaries and main bed sediment, determination of sediments' mineralogical features and comparison by using suitable equations based on the quantity of components existing in the sample
		Acoustic method – used for stones striking against the measure	(Unsatisfactory)
		Sample photograph method – used for stones. A scale is settled and also photographed	1) Photos of underwater stones 2) Photos of dry beds stones
Sediment discharge total	Direct	Use of block-type structures, on the bed, to cause turbulence and all sediments become suspended. Also use turbulence flume or special weir	A turbulence flume consists of a series of baffles and sills arranged to create artificial turbulence USGS on the Middle Loup river at Dunning, Nebr. Sediment sample is performed and calculated as suspended discharge
		Topo-bathymetric survey for the reservoir, determination of deposits volume and trap efficiency in the lake	1) For small reservoirs, it allows for the computation of bed sediment 2) For large reservoirs, it allows for the computation of total sediment
	Indirect	Collection of suspended and bed material, concentration analysis, granulometric analysis, temperature measurement, hydraulic parameters and computation of total discharge – Einstein's method modified and Colby's method simplified	Several kinds of equipment – pumping, equipment using bottles and bags, being instantaneous point, points by integration and vertical integrators (in Brazil is mainly used the North-American series U-59, DH-48, DH-59, D-49, P-61 and bag sampler) for suspended material. Those for bed material – BMH-53, BMH-60, BM-54 and others

Several measurement or suspended sampling equipment may be classified in different kinds, such as:

- *Instantaneous* or *integrators*, where *instantaneous* quickly gets the sample or performs readings, while *integrators* admit sample for few seconds through a beak or a nozzle, storing it in a recipient;
- *Portable* or *fixed*, where portable ones are hand-operated, by pole or shrill, or even fixed to a boat, while the *fixed* ones are installed in a proper structure, either on a bridge or on the bed;
- *Beak* or with *nozzle*, where the *beak* ones are of pumping or other, and those using *nozzles* are the portable ones furnished with bottles, plastic recipient or plastic bag;
- *Punctual instantaneous, punctual by integration* and *by vertical integration*, where *punctual instantaneous* are cylinder-like with a device for capturing the sample, sending a messenger/weight that closes the valves. The *punctual by integration* collects sample in a few seconds at a vertical point. The *vertical integrators* or *in deep waters* collect sample by moving the equipment along vertical section in a steady movement that may be in a single way or back and forward from surface to bottom.
- *Horizontal tube sampler, of bottle, collapsible bag, pumping, integration, photoelectrical, nuclear, optical ultrasonic flow meter, dispersion ultrasonic, Doppler Ultrasonic Flow meter, laser Lisst* – the horizontal sampler is a punctual instantaneous one. The bottle sampler is hydrodinamically built and has a cavity for inserting a collection bottle; the sample is performed through a nozzle that may be of several diameters (1/4", 3/16" e 1/8"), while air is expelled through a tube. The collapsible bag sampler is also hydrodinamically built and has an aluminum-made recipient for holding the plastic bag, which is collapsed in order to expel the air; its capacity is greater than the bottle's capacity and it also uses exchangeable nozzles. The pumping device may be settled on a boat or installed at the bed; normally, it is used a hose furnished with a beak or a nozzle adjusted for allowing in the sample; the pumping is monitored according to the stream velocity, and there are several kinds of such equipment. The equipment working through integration is a bottle or bag collapsible one. The photoelectrical and the nuclear ones operate through light and rays, respectively, through a constant intensity source. The optical and the dispersion ultrasonic work with sources that produce ultrasonic rays that are received by the suitable equipment. The Doppler Ultrasonic Flow meter uses Doppler effect to measure the intensity of acoustic energy reflected by the particles suspended in water, thus providing a correlation between the amount of decibels (dB) received by the equipment (for example, ADCP) and the distribution of suspended sediments along the gauging section. There are also the equipment using laser, a new ones.
- The equipment may also be classified according to its nozzles or beaks orientation, such as on the *stream direction* or *at 90º with the stream.*

Note – The North-American collection equipment for suspended material have denominations indicating their origin: US, for *United States*; kind of usage: D, for *depth*, for vertical integration or in deep waters; and, P, *punctual*, for punctual sample; light equipment, hand-operated, are represented by H, of *hand*; the number corresponding to the project, 48, for *1948*.

4.1.4 *Sampling techniques and types of equipment*

Despite being topics detailed during the operation stage, the working plan should determine some standardization concerning the procedures, as annexes and roll of material to be preferentially used, in order to allow further control over the operation for each station. Generally speaking, it is necessary to inform during this stage:

i) If samplings will be performed by vertical integration or by point;

ii) If by integration, so how many verticals shall be adopted at least, and which kind of technique is the most recommendable the method of Equal Width Increment, EWI, or Equal Discharge Increment, EDI;

iii) Kind of reel to be used, as well as the method for measuring net discharge and other computation procedures, and so on.

iv) It is useful to have a checklist.

4.2 *Sedimentometric Network Operation*

During this stage, the operational conditions for each station is analyzed during each visit to a sedimentometric station. The hydrometry technician shall select field materials and equipment based on river conditions and works to be performed. It means to decide on how the working plan may be better executed. The procedure adopted in field must be reported to both planning and analysis teams (see Figure 4.3).

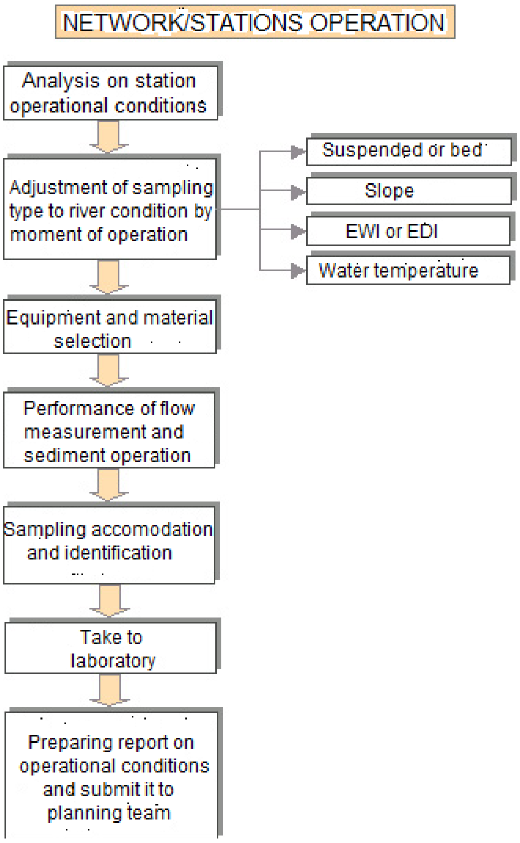


Figure 4.3 – Network operation stages.

It is expected, as a result from this stage:

i) A report on the field operational conditions, where must be informed:

- If water discharge was determined;
- If sampling for suspended and/or bed material was performed;
- If water line slope was determined;
- Which was the method used for suspended material sampling (EWI or EDI),
- How many verticals were used;
- The total volume of samples collected,
- If any "in situ" procedure was performed,
- How samples were stored,
- If temperature was determined,
- List of all values obtained in field, and justification for any bias from what was required in the operational working plan.

ii) Samples collected and spreadsheets for water discharge computations.

4.2.1 *Sampling techniques*

a) S*uspended material sampling*

Sampling methods or techniques are: instantaneous punctual, punctual by integration and vertical or depth integration.

Punctual samples are used only for specific or scientific works. The commonest one is integration on vertical, because it allows for obtaining average concentration and granulometry on vertical. For sampling through integration, the sample is collected in a given time, usually more than 10s, thus allowing the establishment of the average concentration in a more representative way than the punctual sample.

Sampling is performed along several verticals, in order to allow for obtaining average values for the whole section, since sediments distribution varies along the river width and depth. (Figure 4.4).

Samplings shall not be performed in still water sites; it shall take into consideration only the moving waters width. One should avoid samplings behind sand banks and bridge pillars.

During the sampling process it is necessary to measure water temperature, in order to obtain kinematics viscosity, which is a value used for several sediment transport formulas. The thermometer shall be totally submerged into water, until water temperature becomes regular; reading is performed almost on surface, horizontally, not taking the thermometer out of water.

Besides the need of performing vertical samplings along the whole cross-section, both in width and depth, one should be careful in order to collect samples enough for performing analysis as accurate as desired.

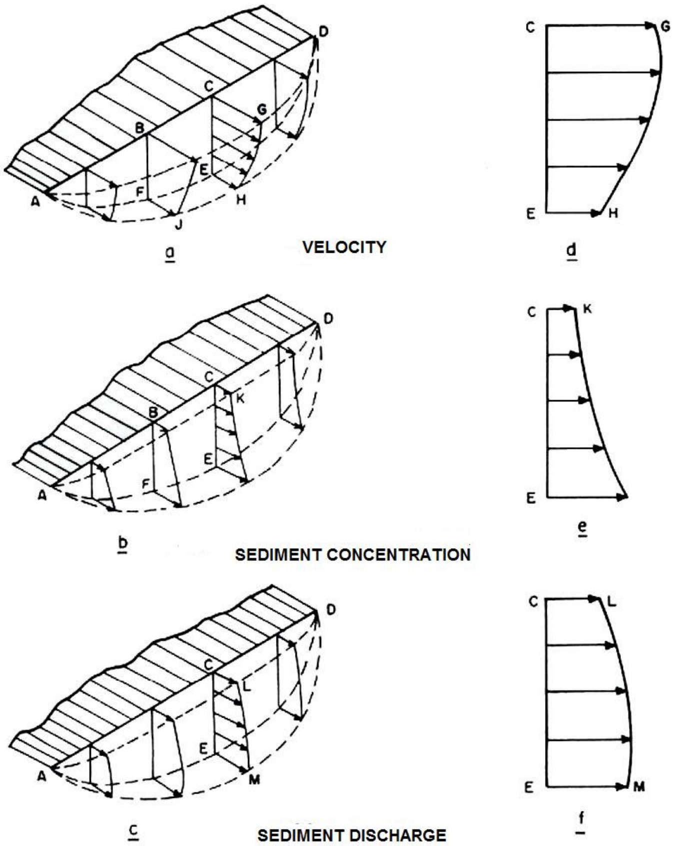


Figure 4.4 – Distribution of stream velocity, sediments concentration and sediment discharge in the cross-section. (Guy and others, 1970)

For suspended sediment, concentration analysis is performed and, whenever required, the granulometric analysis is also performed. Sediments quantity and characteristics, as well as chemical quality of components present in water may influence sample processing. Samples with few sediments may not provide conditions for a successful analyses with the desired accuracy, because they lead to weighting errors. Rather, huge amounts require bi-partition of the sample or may cause weighting problems; both lead to undesired errors.

Therefore, a permanent understanding must exist among hydrometry experts, laboratory experts and processing team, in order to ensure that works be performed following the rules.

a. i) ***Sample by vertical integration***

Sample by vertical integration may be performed either in one- or two-ways, ascending and descending. One-way is adopted when controlling the entry of sample by opening and closing the valve, as is for sampler P-61. Equipment DH-48, DH-59, D-49, bag samplers and others, allow just for two-way samplings (the US denomination will be retired from now to simplify).

For vertical integration sampling, the mixture water-sediment is continuously accumulated in the recipient and the sampler moves vertically in a constant transit rate, between surface and a point a few centimeters above the bed. The mixture enters in a velocity similar to the stream instantaneous velocity at each vertical point. This procedure is known as *ETR - Equal Transit Rate*. Usually, the sampler should not touch the bed, in order to avoid collecting entrainment sediment. Because the sampler nozzle is a little above the floor, there is a non-sampled zone, few centimeters deep, right above the riverbed.

For the sample entry velocity to be equal, or almost equal, to the stream instantaneous velocity, it is necessary that the nozzle remains in horizontal position, i.e., the sampler must move with no slope. It occurs when transit rate, or route velocity, is proportional to average velocity. According to laboratorial studies, nozzles present different proportionality constants, as follows:

1/8” nozzle: $$v_{t.\max} = 0{,}2.v_m \qquad (4.1)$$

3/16” and 1/4" nozzles: $$v_{t.\max} = 0{,}4.v_m \qquad (4.2)$$

Where

$v_{t.max}$ - Sampler’s maximum transit or route rate.

v_m – Average velocity of stream in the sample vertical

For field practice, sampling time is calculated and, since it is inversely proportional to velocity, it shall correspond to a minimum time:

1/8” nozzle: $$t_{\min} = \frac{2.p}{v_{t.\max}} = \frac{2.p}{0{,}2.v_m} \qquad (4.3)$$

3/16” and ¼” nozzles: $$t_{\min} = \frac{2.p}{v_{t.\max}} = \frac{2.p}{0{,}4.v_m} \qquad (4.4)$$

Where 2.*p* is the distance run back and forward by the sampler at the depth *p* from surface to bed.

In a vertical integration collection, it is always useful to collect a representative sample. Therefore, one should always try to optimize such sample by filling in the 0,5*l* bottle as much as possible. Since the bottle is inclined at the equipment bulge, the maximum volume would be 400ml, or as indicated in Figure 4.5. Then, the collection time may be longer than that calculated by equations 4.3 and 4.4. The minimum collection time for 400ml, calculated according to the above formulas, may be obtained from the diagram presented in Figures 4.6, 4.7 and 4.8, presented by Edwards & Glysson (1999). To use the diagrams of Edward & Glysson (1999) in the field it is necessary to have the depth to get the transit rate divided by the velocity in the position of optimum range.

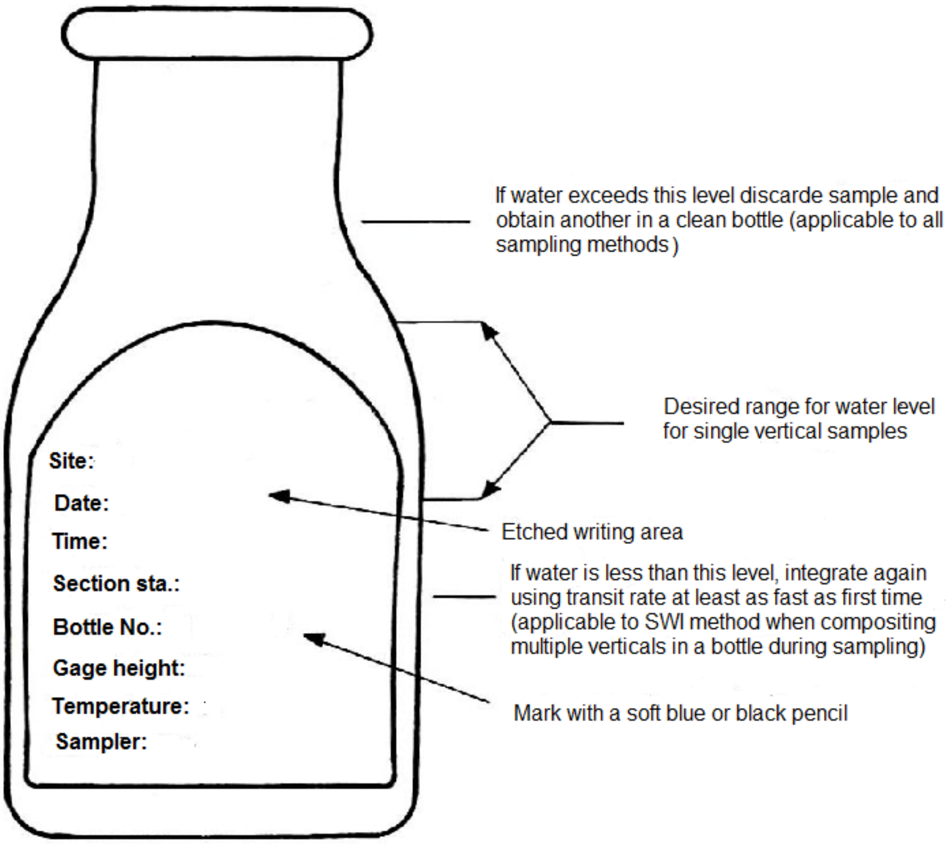


Figure 4.5 – Sample bottle indicating levels to be obeyed (Edwards & Glysson, 1988)

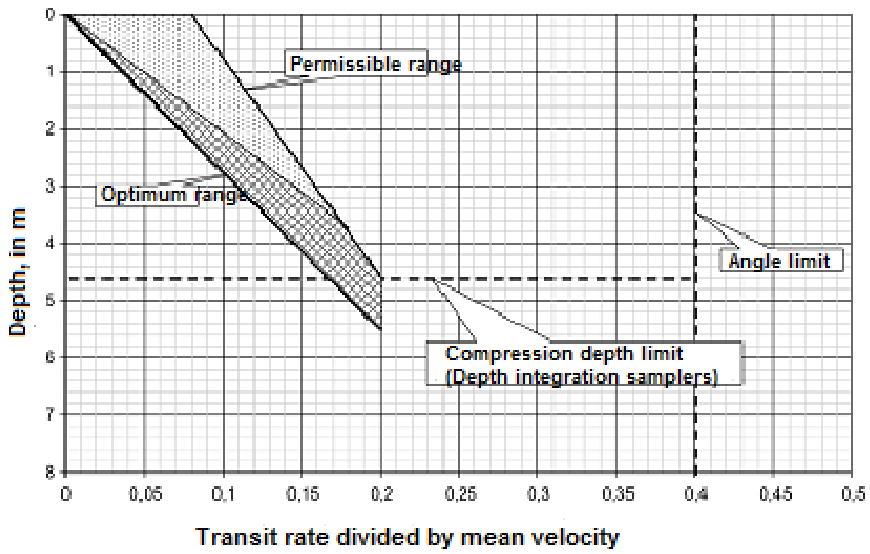


Figure 4.6 – Variation of range of transit rate to mean velocity ratio versus depth relative to nozzle size of 1/8" for 0,5 l sample container (Edwards & Glysson, 1999 – modified for metric system)

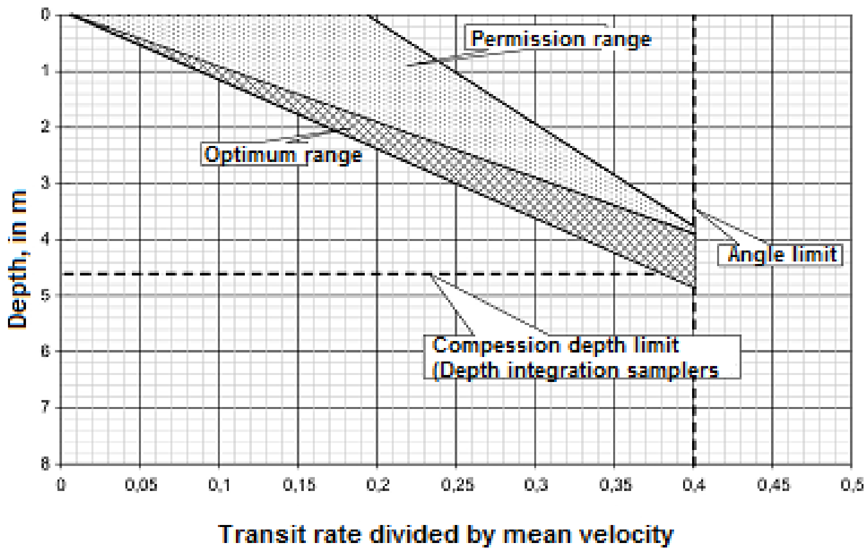


Figure 4.7 – Variation of range of transit rate to mean velocity ratio versus depth relative to nozzle size of 3/16" for 0,5 l sample container (Edwards & Glysson, 1999 – modified for metric system)

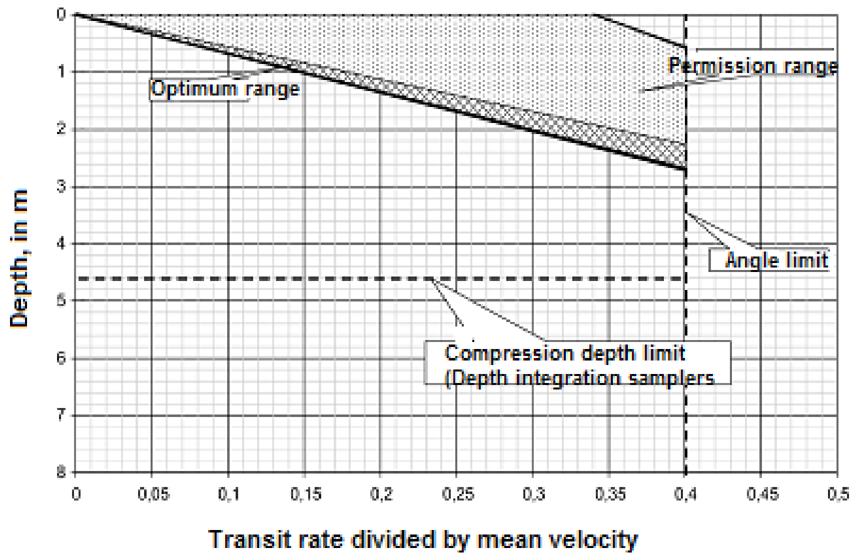


Figure 4.8 – Variation of range of transit rate to mean velocity ratio versus depth relative to nozzle size of 1/4" for 0,5 l sample container (Edwards & Glysson, 1999 – modified for metric system)

If there is no proper sampling criterion, then it will be necessary to analyze the sample from each bottle. However, that procedure is not right, because small quantity of water not always allows an analysis as accurate as necessary. On the other hand, a number of analysis in samples with no criteria and without the required computations turns the procedure into an inadequate one. Therefore, sample by excellence is performed by equal width increment, EWI, or equal discharge increment, EDI, thus simplifying both analysis and computation procedures, and making the result more accurate.

a. ii) ***Sample through equal width increment, EWI***

Due to its simplicity, this is the most used method for water-sediment sample. In EWI method, the cross-section area is divided into several verticals with equal space between them. The vertical integration sample is used for each vertical, but using the same transit rate for all verticals. For this case, the same sampler, with the same nozzle, shall always be used. Since average velocities for each vertical are different, usually decreasing from the thalweg to banks, the quantities sampled by bottle become reduced from thalweg.

For field operation, and for properly obtaining several samples, the first step is to measure water discharge at all selected verticals, equally spaced, in order to have stream average velocities for calculating sampling times. For EWI method, it is necessary from 10 to 20 sub-samples; therefore, water discharge measurement is performed by using twice the quantity of sub-samples desired, since that flow usually reports a minimum of 20 verticals. It is necessary to take care to provide to laboratory a volume of sample enough to make the analysis. Following, the verticals selected for sampling are programmed, and one searches among them the one presenting the highest average velocity – for regular section, or the greatest product between average velocity and depth – for irregular section. On that vertical, the first sample is obtained, by adopting procedures with computation of the minimum sampling time (equations 4.3 and 4.4). The nozzle is chosen according to velocity: in slow velocities, the 1/4” nozzle is used; for moderate velocities, the 3/16” nozzle is used and for higher velocities, the 1/8” one. It is necessary that the first sub-sample be optimized, i.e., that a volume up to the limit allowed for the bottle, or a volume close to it, be collected. The remaining sub-samples will be obtained with proportional times, by applying a rule of three to standard time and depths. The collection time for other sub-samples may be also obtained by calculating the new transit rate used, that shall be held along the whole sampling (Figure 4.9).

Sub-samples obtained may be combined in one single composite sampling, for determining the average concentration and, whenever required, the average granulometry, thus allowing for analysis with the desired accuracy.

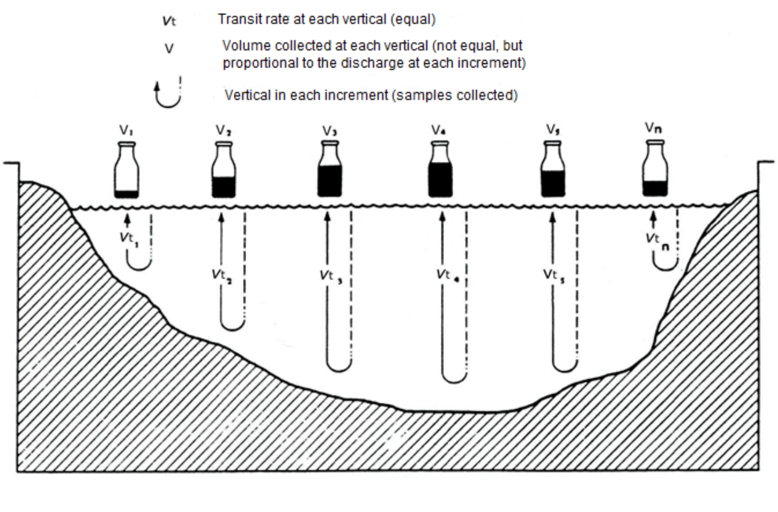


Figure 4.9 – Example of sampling made by using the method of equal width increment (Edwards/Glysson, 1999)

a. iii) Sample by equal discharge increment, EDI

For EDI method, the cross-section is laterally divided into segments, representing similar discharge increments for collecting sub-samples in each of them and dividing each increment into two equal shares. The first step for such procedure is to measure the water discharge and calculate it; after that, a graph is made using the discharge accumulated percentages, in ordinates, in function of distances in relation to the measurement initial point, in abscissas. The cross-section are also traced out in the graph bottom side, as well as the average velocities in the section. In the ordinates, the percentages obtained are equal to the desired number of samples. The next step is to obtain, in the abscissas graph, the desired depth for collection sites. For each sub-sample, the nozzle may be chosen according to stream velocity, and the maximum transit rate (equations 4.1 e 4.2) and the shorter sampling time (equations 4.3 e 4.4) are calculated. The next rule is that all sub-samples must report the same volume, which should be 400ml or close to it. In this method, 5 to 15 sub-samples may be collected and combined into one single composite sample for the required analyses. As mentioned before it is necessary to provide enough sample to laboratory analysis Figure 4.10) (Edward & Glysson, 1999).

An example is presented on Figure 4.11 (Carvalho, 2008).

In field, that method may be practically performed through the water discharge measure, with a large number of verticals, for example, 35. Following, partial discharges, accumulated and total discharges are calculated, and the result is divided by the number of sub-samples desired. The first sample will be obtained at the abscissa, or close to it, of half the discharge increment (Figure 4.11). Then, increments are added and sub-samples are obtained on the corresponding abscissa, or very close to such positions. For example: the collection of 10 sub-samples for total discharge of $100m^3/s$ will result in a $10m^3/s$ increment; the 1st sub-sample will be collected at the accumulated abscissa of $5m^3/s$, the 2nd on the abscissa of $15m^3/s$ and so on; the last one will be on the abscissa of $95m^3/s$.

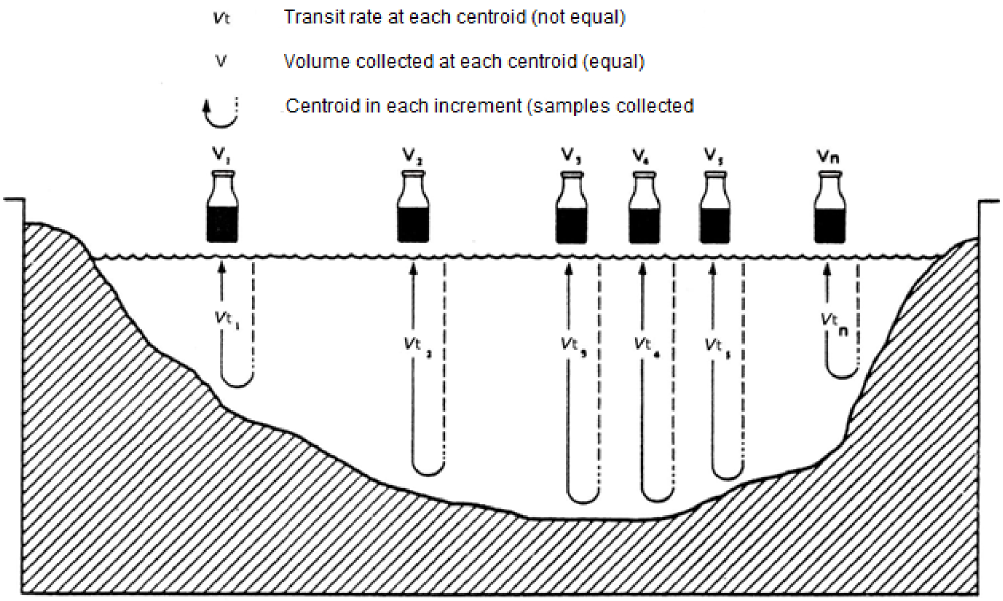
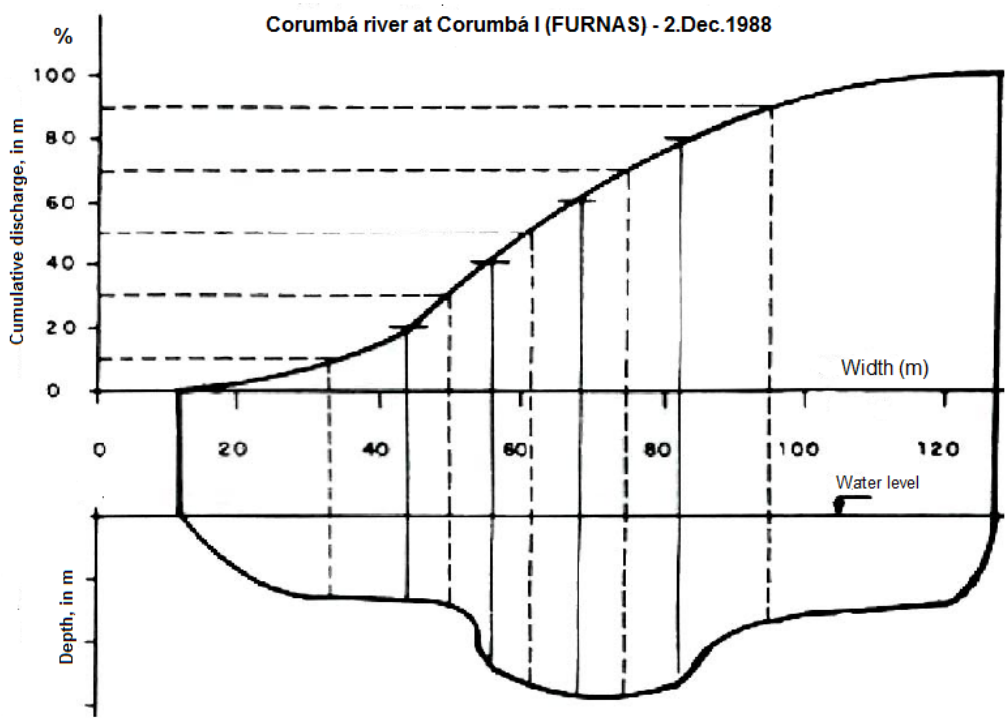


Figure 4.10 – Example of sampling using the method of equal discharge increment (Edwards/Glysson, 1988).



Width (m) Abscissa	Partial flow *q* ($m^3.s^{-1}$)	q/Q (%)	∑ q/Q (%)
12,30	-	-	-
20,60	6,106	1,37	1,37
30,60	27,620	6,22	7,59
40,60	37,555	8,45	16,04
50,60	47,627	10,72	26,76
60,60	80,688	18,16	44,92
70,60	79,148	17,82	62,74
80,60	68,736	15,47	78,21
90,60	36,124	8,13	86,34
100,60	27,833	6,22	92,56
110,60	18,568	4,18	96,74
120,60	14,472	3,26	100,00
126,90	-	-	-
Total Q	**444,277**		

Incre-ments	% of flow	Width for q (m)	Width for sample	Depth for sample	Average velocity	Máx. Vel. For transit	Min. time (s)
1	20	43,5	35,0	2,6	1,34	0,54	10
2	20	58,0	53,0	2,9	1,57	0,63	9
3	20	69,2	64,0	5,6	1,44	0,58	19
4	20	82,0	76,0	5,6	1,31	0,52	22
5	20	126,9	95,0	3,4	0,95	0,38	18

Figure 4.11 – Example of the graph tracing and respective computations for sediment sampling by equal discharge increments (Carvalho, 2008)

a. iv) Required notes

There are two sample labeling or identification processes: the first is to label each bottle with all required data (Figure 4.5); the second is to simplify the bottle labeling by creating a parallel list.

In any process, it is necessary to identify both station and river, date, collection hour, equipment used, number of the bottle, sample abscissa and depth, water level, water temperature, sampler used and name of the hydrometry expert; all information are required. Additional useful information may be included in the hydrometry expert's report.

For samples addressed to granulometry determination, the field should be provided with aluminum or cupper solution, in order to avoid flocculation; it is to be used 2 drops for each liter of sample. That solution must be prepared in the laboratory, at 10% in relation to the amount of distilled water.

The recipients containing samples must be well closed, in order to avoid pouring while being transported to the laboratory. If possible, put an adhesive tape indicating the bottle's water level.

b) *Bed material sampling*

For bed material, collection is performed in about five or more verticals, duly distributed along the section; they may be the same verticals used for suspended sampling in alternate positions, if required. One should try to collect few material, so that the sum does not exceed 2 kg or so of material. The sediment collected of each vertical in the bucket shall be placed each one in a plastic bag, taking care for not loosing the fine ones.

The horizontal scraping equipment is operated in shallow waters, using the sampler fastened to a long string. The sampler must be thrown downstream, and it is expected to lay on bed. Then, it is dragged to collect the material that can be transported by entrainment. It shall be slowly lifted in order to avoid disturbing the collected material. The removal of material from the bucket shall be made only when particles rest, and the water excess is slowly removed.

Vertical penetration equipment, Peterson-type, is also operated with the sampler fastened to a string, and the sample is obtained at the intended vertical of the section. The sampler is pushed down by its own weight, dully armed, unfastening its handle and collecting sample when touching the bed and; then, it slowly lifts it. The sample is placed in a plastic bag, and one should try to use also fine sediments, carefully eliminating water excesses.

BM-54 and similar are shrill-operated. The bucket is equipped with a proper snap and the sampler is suspended between water surface and the shrill pulley. Then, the sampler is laid down at the collection position, and the bucket snaps shut, taking a sample. The sample is rescued by opening the bucket, using the lever; the lever shall set both spring and the bucket into action. The sample is collected by dragging the material with a steel cable or using a plastic bag involving the most part of the sampler. Under no circumstances, it shall be dragged by using hands and fingers in the bucket, due to the risk of accident.

Samples are labeled stating the same data as previously mentioned.

c) ***Direct measurement of bed discharge***

This measurement requires special technique (see Edwards & Glysson, 1999)

Using portable samplers, usually operated on a boat with central hole, the measurement is performed along about 20 verticals, equally spaced. The equipment is supported on bed for at least 2 minutes, in such a way as to trap sediments in about 30% to 50% of the measurer capacity. Slowly lifted, all sediments are taken from the bucket, so that dry weight and granulometry can be obtained.

d) ***Large rivers sampling of suspended sediment***

Measurements in large rivers are hard and time consuming. The discharge measurement with reel, using boat positioning with sextant, telemeter or teodolite (maybe even GPS), may consume major part of daylight hours. On the other hand, it is difficult to settle the boat on previous positions in order to perform sediment samplings. Therefore, it would be useful if such collections could take place simultaneously to the discharge measurement.

The bag sampler is to be used for deep water rivers. For calculating the sampler maximum transit rate at the thalweg position, previous measures for the section are used and the velocity value is used for calculating $v_{t.max}$; depths for each point are used for calculating sampling time. The discharge measurement shall be performed by using approximately equidistant positions for the boat.

4.2.2 *Definition of proper material*

Since, in general, there are few sampler equipment in use for management, and there are many stations to be visited and operated, the hydrometry expert must carry such equipment to almost all stations, in order to perform work under several different conditions. A checklist must be made and attached to the working plan.

The reel and its accessories, extremely important, shall not be forgotten. It is useful to have available two full reels to take to the field. It is indispensable to talk about auxiliary equipment, such as boat, reel (Figure 4.12), several weights ballasts, marked steel cables, topographic level, sight, telemeter, sextant, GPS, tools, etc., that shall be foreseen and listed.

If the hydrometry expert has to go to one single station, where he knows the stream velocity and depth, so he can take less equipment for sediment sampling. For example, if it is a station where section depths are up to 2,5m and slow velocities, the hydrometry expert shall choose light suspended sampler, such as DH-48 for wading or boat measurement, or the DH-59, for use with reel. For collecting bed material, it is useful to take a scraping cylinder-type sampler.

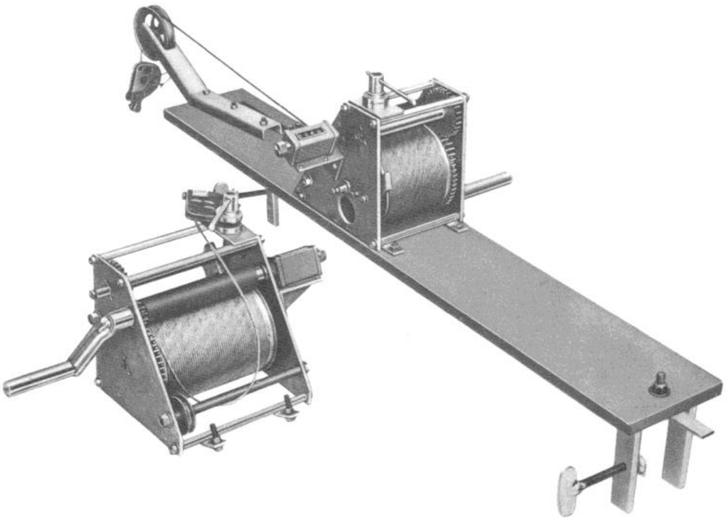


Figure 4.12 – Hydrometric reel, equipment auxiliary to measurement.

If measurement section is up to 4,5m-deep, with moderate velocity, he can take the DH-59 sampler for suspended sediment. If velocity is high, then it will be necessary to take a heavier sampler, such as the D-49, which is not easily dragged by stream. For collecting bed material, it is useful to take the scraper and the BMH-60 or, if there is none of this type available, the BM-54.

If the section waters are deeper than 4,5m, or if a flood is expected so that the water level will increase, it is necessary to take the bag sampler or the punctual P-61. For collecting bed material, it will be necessary to take the BMH-60 or the BM-54.

If there is any other equipment, not specified in this Guide, it is useful to consult on the possibilities of using such equipment, as stated in the manufacturer manual.

4.2.3 *Definition of equipment during sampling*

Equipment available for sediment sampling in the Brazilian hydrometric services are, in general, those of the North-American series. Despite other methods were used for measuring sediment discharge in Brazilian rivers, the values of measurements are usually obtained through indirect method through water-sediment mixture and bed sediment at cross-section. This is the traditional method for sedimentometric services in most of the countries. In that indirect method, samplings are forwarded to the laboratory for concentration and granulometry analysis; sediment discharge computations are further performed.

Technological advance has allowed for the development of more accurate and functional equipment. To mention just one, there is the ADCP case, which is used for measuring the rivers instantaneous water discharge and, currently, there are many of them in Brazil. This equipment may also allow for full acquaintance about the suspended sediment discharge. However, it requires a good historical data series for calibration and there are major technical implications, due to ultra-sound dispersions offered by thicker irregular particles. Those particles are not fully detected by sensors, and thus demand calibration by highly specialized experts, as well as the implementation of a proper model in a computational system.

Other kinds of surrogate equipment, such as the turbidimeter that continuously records the turbidity measurement for a fixed site, shall be calibrated with equipment traditionally used for measurements along the section, so that average concentration values may be obtained.

Brazil also has French and Dutch equipment, operated by several entities, such as Neyrpic sampler and Delft bottle for suspended sediment, as well as Arnhem measurer for bed sediment. Most recently, pumping equipment, rotary-tray have been used in Brazil for suspended sediment in a given fixed point; they perform automatic samplings in pre-established times (see item 4.1.3). Very few equipment designed using laser procedure have been used.

a) ***Equipment for suspended sampling***

Equipment used for suspended sediment sampling, in general, hydrodynamic-shaped , for vertical integration sampling, is made of aluminum, bronze or steel. Due to its physical size, the existing samplers are capable of performing collection just up to a given bed limit; therefore, there is a zone that remains non-sampled (Table 4.3).

Usually, equipment is built to be easily operated, using hydrometric auxiliary material, and allow for collections all along the river width. They are portable and allow for easy collect of sample, which must be kept in the sampling bottle. Under special conditions, the transference of several samples to a sole recipient may be considered. The bed material is usually transferred to plastic bags.

North-American series samplers usually have exchangeable nozzles (or mouthpieces), with diameters of 1/4”, 3/16” and 1/8”, for sampling in low, medium and high velocities, which is also a function of local depth. The samplers’ nozzles and nozzles for suspended material allow the sample entry to be equal to the stream velocity, provided that operated by using the right technique. The nozzles are produced in different lengths for each sampler, and shall not be exchanged among different equipment.

Equipment for suspended sediment sampling is vertical integrators-type, accumulating the water-sediment mixture obtained through a constant movement, ascending and/or descending, from surface to the bed, or nearby it. The north-american series was designed to use 1 pint bottle. In Brazil the samplers were adapted to be used for 0,5*l* bottle.

Samplers produced for 0,5*l*-bottle, for vertical integration collection, are capable of collecting mixture in depths up to 4,5m, or close to that, and those 1,0*l*-bottle in depths up to 7,0m. This shall be verified for each case, using the proper sampling procedures (see Table 4.3). In Brazil, samplers DH-48, DH-59, D-49 and P-61 are produced; it is not very significant in relation to the several conditions found in Brazilian rivers. The equipment may also be built to carry 1,0 liter bottle, thus allowing for increasing the sampling depth.

The bag sampler may perform collections in any depth by using a bag for 4,0*l* bag, or more. The bottle sampler requires a vent for expelling the air, while bag sampler collects with collapsed bag, with no air. It is also produced in the country, but shall be improved in order to become more operational from a boat and reducing the non-sampled distance.

Table 4.3 – Most used suspended sediments samplers in Brazil

Sampler	Nozzle diameter (pol)	Max. Volume of bottle (*l*)	Max. Sampling depth (m)	Min. velocity for sampling (m/s)	Max. velocity for sampling (m/s)	Non-sampled zone (m)	Sampler weight (lg)
US DH-48	1/4	0,47	2,7	0,46	2,7	0,09	1,8
US DH-59	3/16	0,47	4,6	0,46	1,5	0,11	10,0
US DH-59	1/4	0,47	2,7	0,46	1,5	0,11	10,0
US D-49	3/16	0,47	4,6	0,46	1,5	0,12	28,0
US D-49	1/4	0,47	2,7	0,46	1,5	0,12	28,0
Collapsible bag	1/8, 3/16 and 1/4	Bag capacity	100	-	1,5	Variable	Variable
US P-61	1/8, 3/16 and 1/4	0,47	~15	0,46	1,5	0,12	49,0

Note: Brazilian denomination for these samplers are: for USDH-48=AMS-1; for USDH-59=AMS-3; for USD-49=AMS-2; USP-61=AMS-4, and collapsible bag sample=AMS-8. In the table and also in descriptions it will be used the US origin.

USDH-48, or **AMS-1** samplers, domestically produced, are made of aluminum and their body is hydrodynamic-shaped, holding a handle for wading or boat operation, in shallow water - up to 2,7m in depth - for use in both-ways vertical integration collection. It uses 1/4” nozzle and 0,5*l*-bottle, being the distance between the nozzle and the sampler floor equivalent to 0,091m. It may be adapted with a device for use in suspension, and the nozzle may be changed for diameters smaller - 3/16” and 1/8”, for deeper samplings up to 4,5m. Since it is light, it can only be used under slow velocities conditions, and in the both-way vertical integration process (Figure 4.13). That sampler can be easily produced in order to use 1,0*l* bottle, thus allowing for samplings up to 6,0 to 7,0m, according to stream velocity and bill to be used.

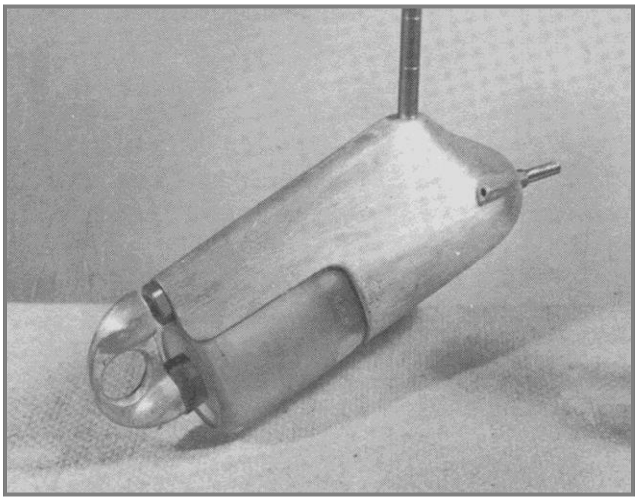


Figure 4.13 – Suspended sediment sampler USDH-48 (AMS-1) (Subcommittee on Sedimentation, 1963).

The **USDH-59**, or **AMS-3**, is light, bronze-made, hydrodynamic-shaped sampler, for use in suspension with reel, installed on boat. Three standard nozzle are used and a 0,5*l* bottle, where the distance from the nozzle to the sampler floor is equal to 0,102m. Since it is light, it can only be used under slow velocities conditions, by the two-way vertical integration process and up to 4,5m in depth (Figure 4.14). Adapted to 1,0*l* bottle, it may perform collections up to 6,0 or 7,0m in depth.

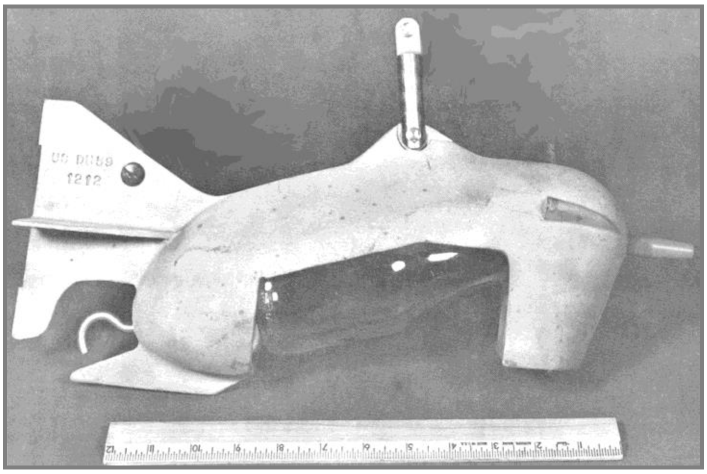


Figure 4.14 – Suspended sediment sampler USDH-59 (AMS-3) (Edwards & Glysson, 1999).

USD-49, or **AMS-2**, is a sampler hydrodynamic-shaped, for use in higher stream velocities, and is almost 30kg in weight. It uses three standard nozzle and the 0,5*l* bottle, being capable of sampling only in depths up to 4,5m, or a little lower, in two-ways vertical integration process. The distance from the nozzle to the sampler floor is 0,122m (Figure 4.15). Adjusted for 1,0*l* bottle, it may perform samplings in depths up to 6,0 - 7,0m.

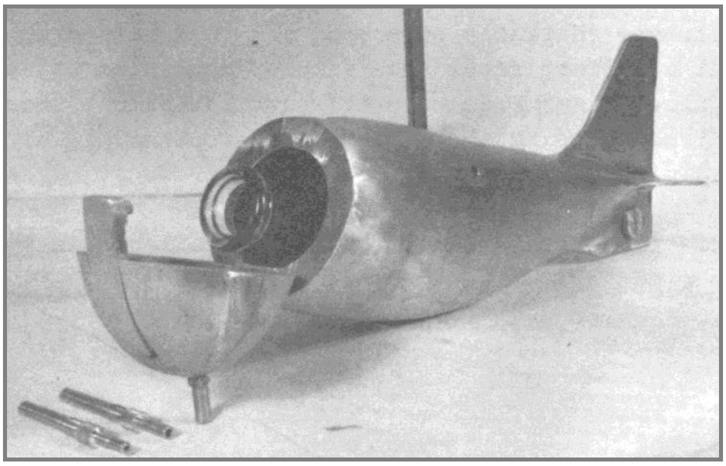


Figure 4.15 – Suspended sediment sampler USD-49 (AMS-2) (Subcommittee on Sedimentation, 1963).

USP-61, or **AMS-4**, is a punctual integrator sampler, hydrodynamic-shaped, and has a valve that may be electrically activated for admitting the sample. It uses a 0,5*l* bottle and exchangeable nozzles, weighting 48kg (Figure 4.16). If it is built for 1,0*l* bottle, the sampler may perform collections in depths of up to 36,0m, according to existing tables for equipment use (USDA et al., 1978). This sampler may also be used as integrator in one or two ways, by parts, until reaching the full depth. if it is to be used in deeper waters, it requires working with an air pressure regulator (Carvalho, 1994 and 2008).

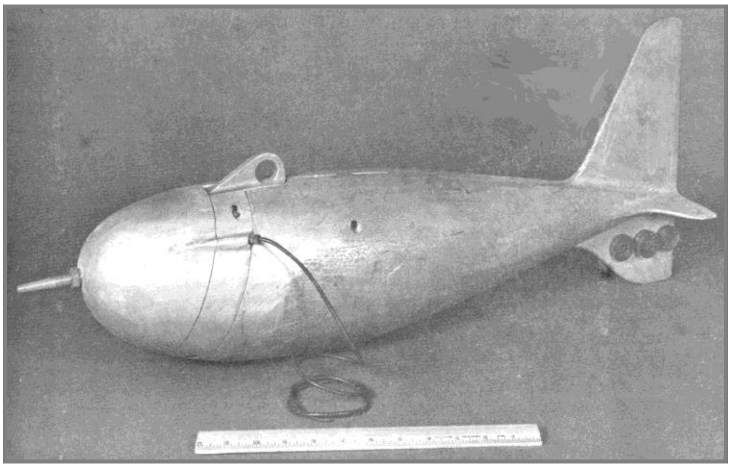


Figure 4.16 – Suspended sediment sampler USP-61 (AMS-4) (Edwards & Glysson, 1999).

The **collapsible bag sampler**, or **AMS-8**, uses an aluminum cylinder with nozzle for the proper adaptation of the bag; it has a helm for adjusting the sampler and the stream. It is used with exchangeable nozzles and needs ballast (sounding weights) , because of its size and lightweight; due to it, the non-sampled zone, or distance from the nozzle to the lowest position, which is the ballast floor, is above 50cm and shall be measured and registered in the measurement card. The operation of this sampler with common boat is troublesome, and the proper device must be adopted (Figure 4.17).

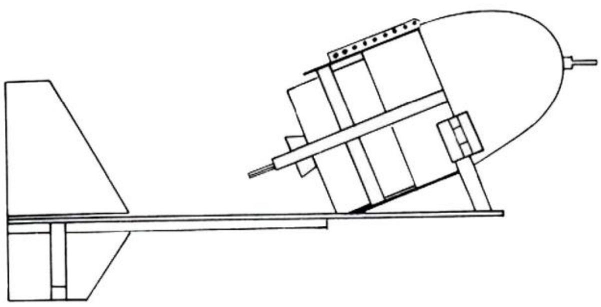
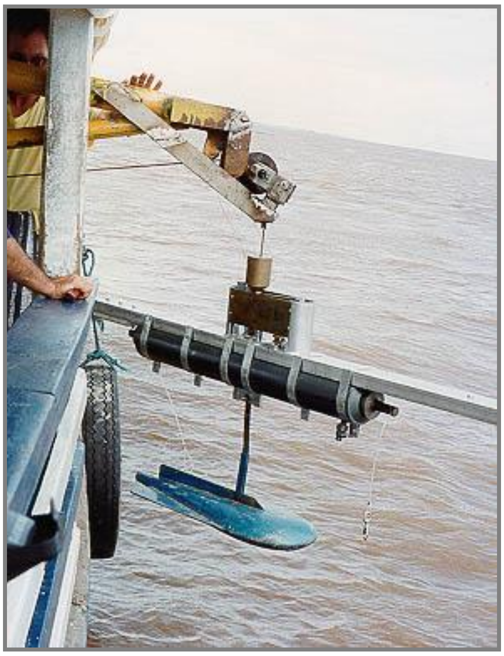


Figure 4.17 – Collapsible bag sampler for suspended sediment (Carvalho, 2008).

The horizontal cylinder-type **water sample collector**, for instantaneous punctual sampling is addressed to quality and sedimentometric analysis or instantaneous mixture water-sediment sample. It works with a messenger that shoots two special rubber-made valves, which close the extremities when the trigger is shot (Figure 4.18). Another kind of sampler which use the cylinder is showed in the Figure 4.19.

A series of new kind of equipment for sediment measurement is using devices of laser, all them produced by Sequoia Scientific, Inc. Figure 4.20 present one, the LISST-SL, which is a iso-kinetic sediment grain-size analyser. As written in the manual, it provides all the data necessary to compute sediment transport in a river. The measured parameters are: river velocity, sediment concentration and size distribution as a function of depth, depth of the instrument at any time, and water temperature. Some others equipment of the series are LISST-25X, LISST-ST and LISST-100X, each one for determined use.



Photos showing equipment using cylinder-types

Figure 4.18 – Water sample collector (Hibam Project)

Figure 4.19 – Water sample collector for instantaneous of mixture water-sediment sample, used in Madeira River (Glenber equipment).

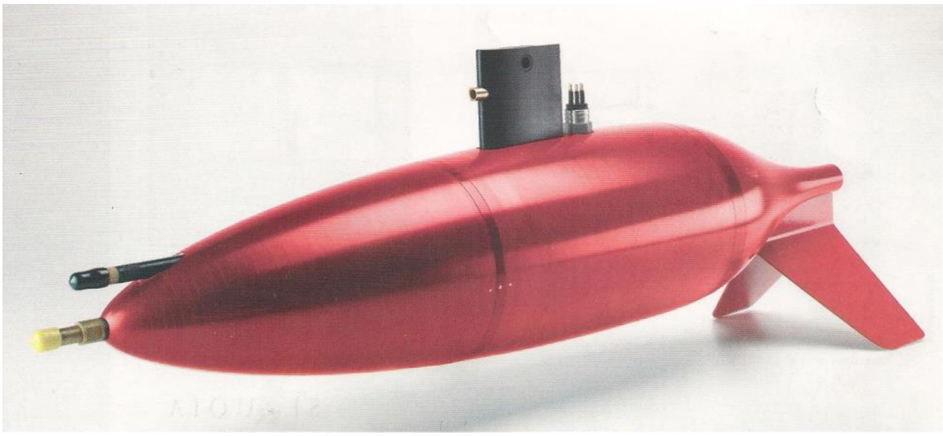


Figure 4.20 – The LISST-SL, a new equipment for sediment measurement using device of laser (Sequoia Scientific, Inc.)

b) *Equipment for bed material sampling*

Rock-Island, or **AMF-2**, is a scraping-type sampler, weighting 7,5kg, and has a suspension device in it that alters the sample when lifted, leaving the fine sediments. Because of that, it shall not be used (Figure 4.21). Here, registration is made because there are many pieces of equipment like that working in Brazil. It would be better to build a similar sampler from a steel or cast iron cylinder, 30 cm long and 10cm in diameter, with lateral suspension in on or two ears externally welded. It is used for shallow waters (Figure 4.22). The sac is a hard one, made by jeans or another alike texture, can keep the sediments.

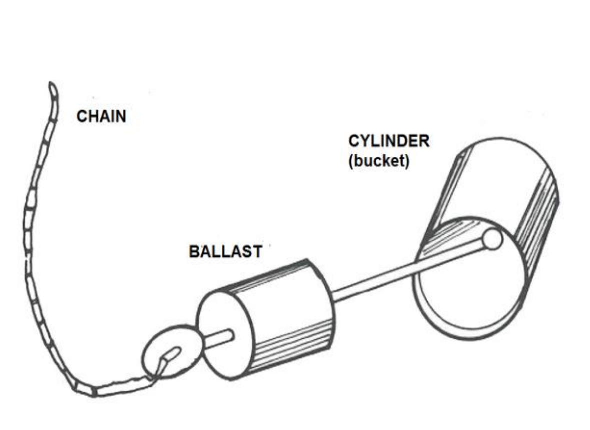


Figure 4.21 – Rock-Island sampler for bed sediment (inadequate equipment).

Figure 4.22 – A bed sampler for use in shallow waters

The **Peterson sampler -** is of vertical penetration type, and has two parts in buckets like dredger, with lever, movable arm, that shoots when reaching the bed. One shall always seek for a model of such equipment that does not allow for loosing fine sediments when being lifted to the boat (Figure 4.23). It is used for shallow waters.

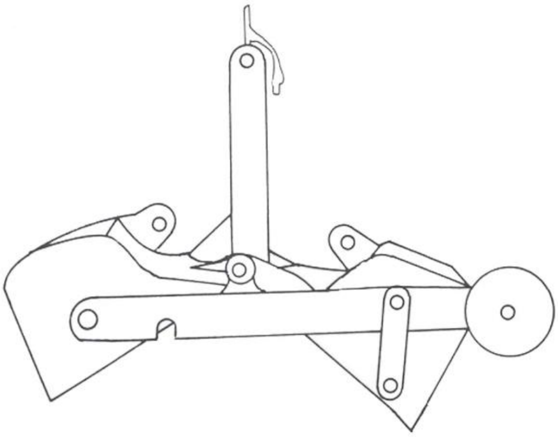
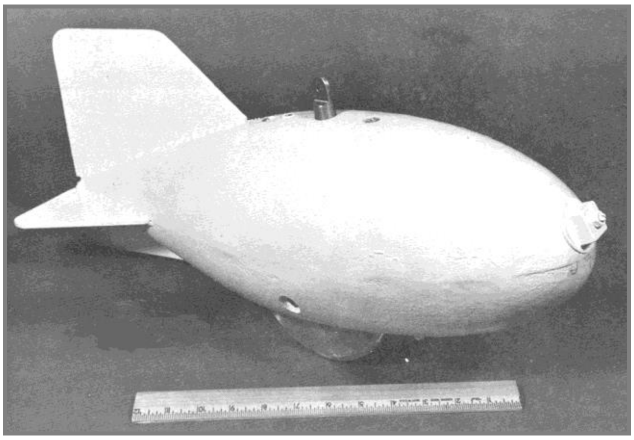


Figure 4.23 – Peterson sampler for bed sediment.

USBM-54, or **AMF-1**, is a vertical penetration sampler, hydrodynamic-shaped. It uses a bucket that is provided with spring and housed in its bulge. It is efficient for sampling, but requires care when used, due the strong pressure of the spring, that is easily activated. It weights almost 50kg, and is operated by reel up to very deep waters, used under higher velocities conditions. The bucket collects a small bed layer (Figure 4.24).



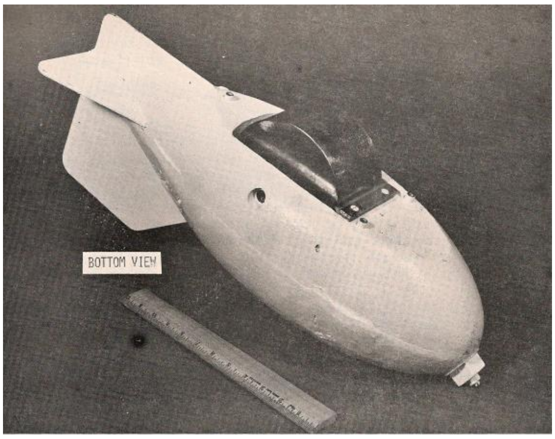


Figure 4.24 – Sampler USBM-54 for bed sediment front and bottom views (Federal inter-Agency Sedimentation Project, 1986)

USBMH-60 is similar to USBM-54 but lighter – it weights a little more than 20kg, and is more easily operated, for use under moderate velocities. It uses the same bucket and spring, and also requires care when being operated. It is already produced in Brazil, but there is still some imported equipment.

USBMH-53 is a hand-operated piston-core equipment, for shallow waters. It consists of a piece containing a piston inside a cylinder 2" in diameter and 8" long, which is pressed on the bed river in order to collect sample through the pressure of a handle on its upper end (Figure 4.25). The full sampler is 46" long. When the cylinder is pressed into the bed, the piston retracts and holds the sample through partial vacuum. The piston is also used for ejecting the sample (Agriculture, 1978).

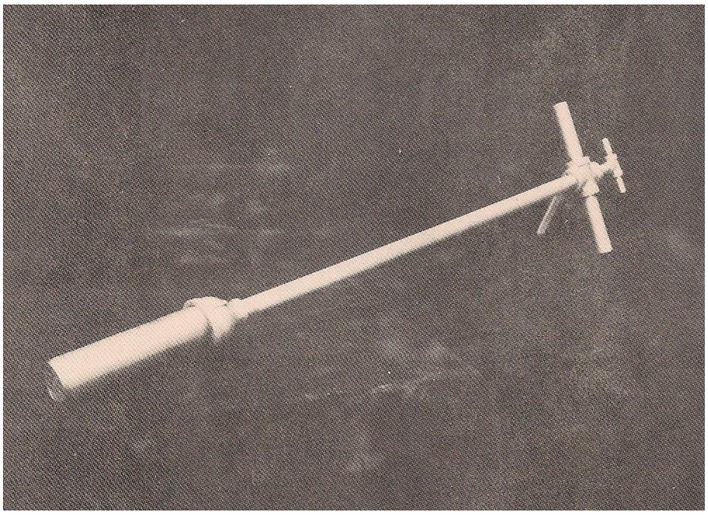


Figure 4.25 – USBMH-53- Piston-type bed-material hand sampler (Committee on Water Resources, 1963)

4.2.4 *Equipment calibration*

Usually, this procedure is to be oriented by the producer. The equipment to be calibrated is a suspended material sampler, whose nozzles have been damaged and recovered. The calibration may consist of the review of hydraulics efficiency.

For calibration purposes, one must have a reel, a chronometer, a 1,000ml graduated test tube and values for the nozzles areas (Nordin, 1981 and Carvalho, 1994). The first step is to measure the stream velocity v in such a point that must be very close to surface if the sampler is an integration use one,. Then, to collect the sample on the same point, measuring sampling time t. The velocity in the nozzle v_n is:

$$v_n = \frac{V}{a_b . t} \tag{4.5}$$

where,

v_n - velocity in the nozzle, in cm/s
V - sample volume, in cm^3
a_b - nozzle area, in cm^2
t - sampling time, in s

Nozzle areas are as follows:

Diameter		**Area**
(inches)	**(mm)**	**(cm^2)**
1/8	3,1750	0,079173
3/16	4,7625	0,178139
¼	6,3500	0,316692

Hydraulic efficiency is provided by the following expression:

$$Ef.hid. = \frac{v_n}{v} \tag{4.6}$$

where v is the velocity for the point in cm/s.

This amount must be around 0,95 in order to present a good performance for the sampler. Errors will be greater as granulometry increases. If hydraulic efficiency is lower than 0,90, it will be necessary to verify if the nozzle presents faults in its entry, or any internal roughness. If so, it must be replaced.

A nozzle must have hydrodynamics shape, and its cavity must be perfectly plain. Even a small irregularity in its entry may reduce the efficiency in 10 to 15%, thus not allowing a successful sampling. The reduction in efficiency may also be resulting from fault in the sampler. For bag sampler, it may result from a flat bag or even a rough one, on the recipient mouth, may cause the nozzle sinking during sampling.

4.2.5 *Equipment maintenance*

Before going to field, it is always necessary to review equipment conditions. It is important for the hydrometry expert to have a checklist for equipment and materials required for traveling. Table 4.4 shows a checklist that may serve as guidance.

Table 4.4 – Checklist for equipment and materials to be used in hydrometry, and that shall be taken to the field (this check-list may be complemented or changed by the hydrometry expert, at his discretion).

Current meter and counter (completed set)
Rotation counter (or velocity counter)
Chronometer
DH-48 Sampler
DH-59 Sampler
D-49 Sampler
Bag sampler
Bucket bed sampler
BM-54 Sampler
BMH-60 Sampler
Hydrometric reel with 15m-cable
Hydrometric reel with 25m-cable
25 or 30kg sounding weight
Telemeter for up to 1.000m measurement (or sextant)
Teodolite, buoy and sight
Hand GPS
Topographic level and sight
Fluviometric scales (staff gages)
25m tape measure
Boat
Small anchor
Outboard motor
1/8” steel cable, 100m long, graduated at every 2m (for use in small rivers)
3/16” steel cable, 300m long, graduated at every 5m (for medium size rivers)
Tool box
Proper vehicle, like pick-up
Other materials such as string, pair of blocks, hoes, land drill, machete, wood drill and boring machine, scythe, 1,5 kg and 6 kg hammer, small ax, hammer, sewer, brushes, ink, nails, electric wires, so on.

Samplers using bottles require the review of its working conditions. The most important is trial for spilling, by blowing the nozzle while closing the air exit with the finger. If the air is leaving between the bottle mouth and the pressure rubber, so it is necessary to have that rubber or spring replaced.

Collapsible bag sampler requires the verification of spilling by inflating air in the bag. If the bag reports this problem, or if there is not enough bags, so a strong plastic bag, like those used for 5kg-rice packages, may be used.

Another permanent care concerns samplers’ nozzles, which may become crushed when managed; if that is so, they must be repaired or replaced. When repaired (uncrushed or polished), each one must be calibrated.

The bed sampler BM-54 shall have its spring working well. The spring may be adjusted through a screw on its lower part.

There are several additional cares that equipment may require; the producer may specifically point them out, or the hydrometry expert, being experienced and conscious, may deduce them.

4.2.6 *New equipment for suspended sediments*

The need for knowing the quantity of sediment transported along water stream is increasing, both due to the increase on water resources management works, as due to land management and the erosion resulting from it. Equipment that may continuously measure the sediment discharge are designed and installed in such a way as to grant data collection under critical sediment transportation conditions, as may be strong precipitation occasions, whose torrents take great amounts of sediment for water stream. The peak measures then become valuable, as well as total amount of sediments transported during floods.

The increase on land management includes the use of pesticides and other pollutant agents that are transported, together with the sediment, to the river. Therefore, it turns the measurement of sediment load jointly with stranger substances into a very important issue for environmental surveys.

Therefore, the existing equipment is improved in efficiency, in possibility of continuous use, as well as for measurements under adverse conditions.

The Subcommittee on Sedimentation (USA), now by FISP, continues on designing and building equipment and auxiliary devices, improving the old ones or searching for new versions. Earliest equipment was projected in order to adapt 1 pint bottle, which allowed for purchasing the milk glass anywhere in the country. Later on, due to the restriction to the use in waters deeper than 4,5m, samplers were adapted in order to contain the 1 quart bottle.

DH-75-P and DH-75-Q are new samplers for vertical integration using plastic bottles (Figure 4.26).

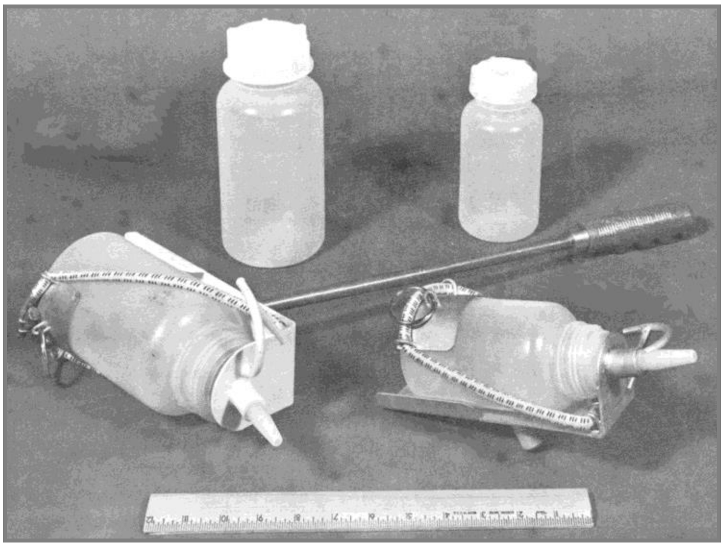


Figure 4.26 –DH-75 samplers and their accessories for 1 pint and 1 quart capacities (Edwards & Glysson, 1999).

DH-81 is a sampler for vertical integration use, and has a plastic nozzle to be adjusted to a bottle that may be purchased in any bakery in the country (Figure 4.27).

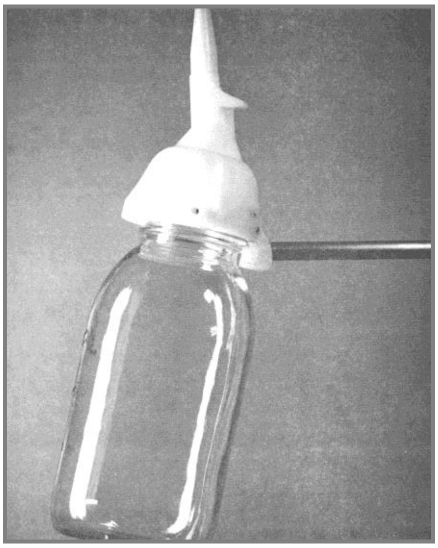


Figure 4.27 – USD-81 sampler for 1 quart bottle (Edwards & Glysson, 1999).

D-77 is a sampler that may perform collection in very deep waters, by vertical integration, having a 3-liter plastic recipient. It may be adjusted for punctual sampling (Figure 4.28).

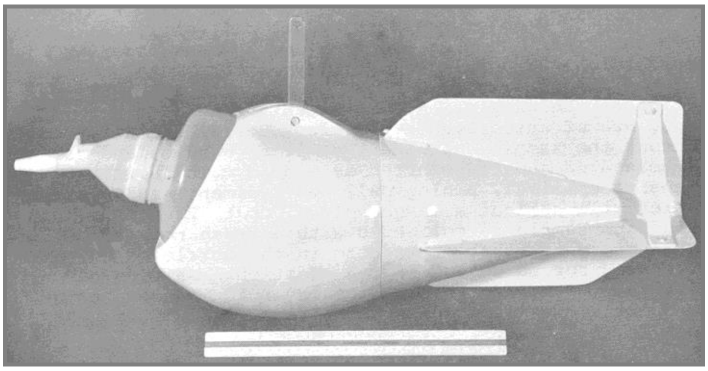


Figure 4.28 – USD-77 sampler of the North-American series for use in deep rivers (Rickly, 1997).

Nuclear equipment, both portable and fixed on bank, were developed for measuring very high concentrations, over 100g/*l*, under torrential regimen and also during short-term floods. Such equipment was built and used by the Institute of Geology and Geophysics, University of Naples, Italy. Figure 4.29 shows a schedule for one of the equipment used for several surveys (Tazioli, 1981).

Portable nuclear equipment for measuring very high punctual concentrations were built by the Institute on Hydraulics Search, in Zhengzhou, China, for measuring sediment in Yellow River (Zhu et al, 1981). In Hungary, the Research Center of Water Resources Management has also developed equipment like that for measurements from 500 to 12.000mg/*l* (Berke and Rákóczi, 1981). Such equipment may be fixed on a position for measuring sediment during short-term floods.

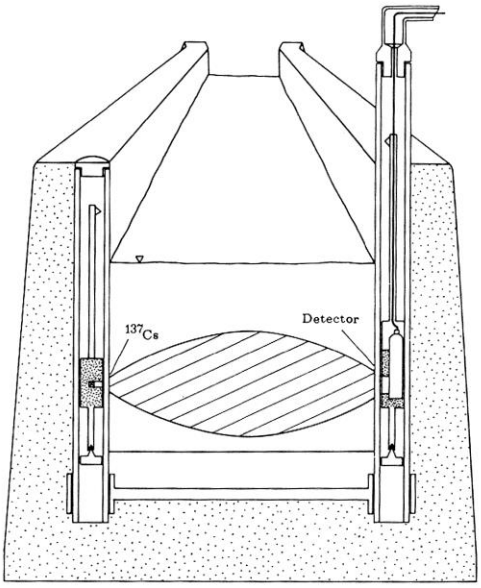


Figure 4.29 – Sedimentometric station with nuclear fixed equipment (Tazioli, 1981).

Turbidimeters for continuous measurement of suspended sediments in rivers have been built for fixed installation; they have capacity to measure punctual concentrations from 0 to 5.000mg/*l*. Several entities have performed successful surveys using that kind of equipment; among them, there is the Institute on Hydrological Search, Pretoria, South Africa (Grobler e Weaver, 1981), and the Hydraulic Survey Station, Wallingford, Oxfordshire, UK (Brabben, 1981).

PS-69 is a pumping equipment of the North-American series. It allows for the installation, in fixed position at remote sites, for automatic collection during scheduled times. Samples are stored in several bottles. The tray stands for 72 bottles (Figure 4.30). There is a more recent version, the PS-82 sampler, to hold 24 bottles only.

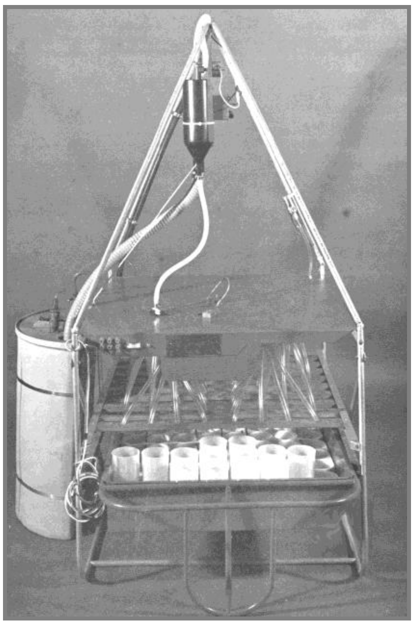


Figure 4.30 – Pumping sampler PS-69 - fixed installation (Subcommittee on Sedimentation, 1986).

Several types of equipment for direct concentration measurement in a point were built by WL Delft Hydraulics, in Delft, Netherlands which OSLIM and FOSLIM may be mentioned. They are measurers of suspended sediment concentration through optical system. OPCON also measures sediment concentration and granulometry in optical system. The UHCM measures concentration by using ultra-sonic system. The CCM/CM measures sand concentration through the variation on water conductivity (Figure 4.31). The Siltmeter 1995 measures concentration by using the turbidity principle and the 2-D USTM measures sand concentration using the ultra-sonic system.

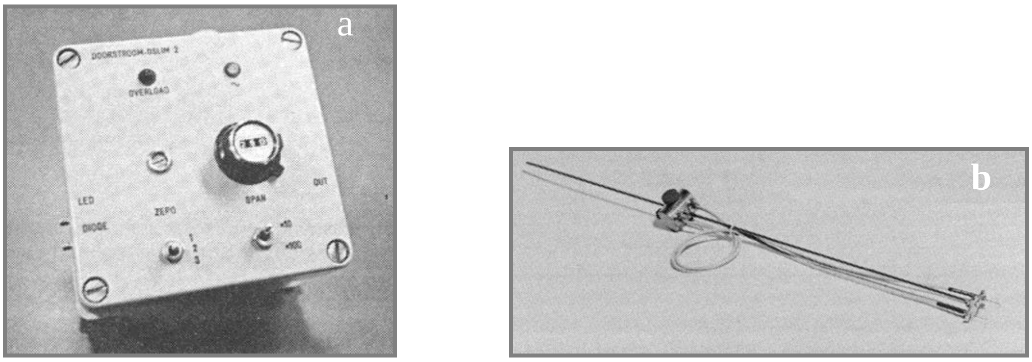


Figure 4.31 – Punctual measurers of sediment concentration named OSLIM(a) *and FOSLIM*(b) *(WL Delft Hydraulics, 1999).*

The Delft Laboratory constructed two kinds of equipment for directly measuring concentration, by using the ultrasonic system: UDS of a dimension that may be built in a supporting piece on the bed, and two dimensions UDS.

The ADCP, equipment purchased by several Brazilian entities, may measure the sediments concentration, registering the values along the section and the vertical (Figure 4.32). It needs calibration, what may be performed through punctual samplings. There are programs available for such calibration.

Figure 4.32 – ADCP (300 KHz) operating in Amazonia (Hibam Project).

The ADCP is an equipment to make water measurements using mainly the reflection sound from fine particles of sediments because the gross sediment has irregular shaping which can lost the reflection sound. Due this the sediment concentration getting from the values from ADCP can’t represent the total suspended sediment.

4.2.7 *New equipment for bed sediments*

Direct measure of bed load is performed by using equipment fixed on bed. Since the equipment is a hindrance for the regular runoff in that position, there is a change on streams direction causing a change on conditions and also on bed sediment discharge. Therefore, new equipment intends to improve sampling efficiency by reducing its volume and facilitating the runoff.

Helley-Smith is one of the most frequently used measurers nowadays. BL-84, Model 8030, of the North-American series, weighting 30kg. It was built with more adequate parts, in order to report good efficiency.

There is a version for wading measuring, of the North-American series, named BLM-84, Models 8010 and 8015, as shown in Figure 4.33. The equipment is made of conjugate pieces produced in aluminum cards, being the front one a 3” x 3” parallelepiped shaped melted to a pyramid trunk of 1,4 expansion ratio; a bag is adjusted on its back side, and has a 200 or 270 micron mesh size that holds coarse. It is operated through a handle adjusted on its top.

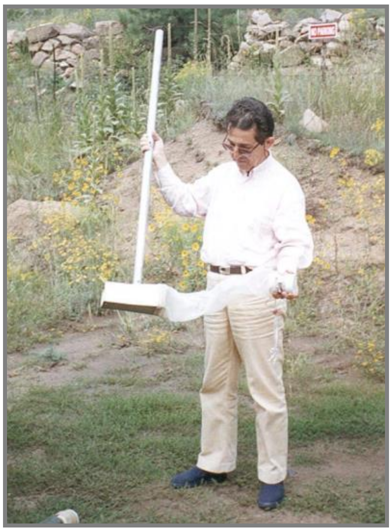


Figure 4.33 – USBLM-84 sampler for wading bed load measurement (Rickly Hydrological, 1999, photo by Carvalho).

4.2.8 *New laboratorial equipment*

Traditional laboratorial equipment for determining concentration uses both filtering and evaporation methods. For determining sand granulometry, it is used sieve and visual accumulation tube; for fine sediments, pipetting or BW tube (see item 4.3).

There are some laboratory equipment – already in use in Brazil – that use the turbidimeter for analyzing concentration, and ultrasonic equipment for granulometric analysis. Such equipment is part of the Subcommittee on Sedimentation, but are not used in Sedimentometry regular services.

Laboratorial equipment using laser allows for analysis on granulometry and concentration for small samples, containing few sediments. They are computer-operated. The Mastersizer, equipment produced by Malvern Instruments, performs granulometric analysis with particles from 0,02μm to 2.000μm (Figure 4.34). Another laser equipment for use in laboratory and on field is produced by Sequoia. It is used for determination of concentration and granulometry (Figure 4.35).

Figure 4.34 – Mastersizer that allows for granulometric analysis of the sediment, with few samples.

Figure 4.35 – Analyzer for granulometry and sediment concentration Lisst-Portable, of Sequoia (Carvalho, 2008)

4.2.9 *Special care with field sampling*

In an aquatic environment, organic and inorganic substances are found in several ways: free or complex, dissolved, suspended, adsorbed to suspended material and biomass, or even associated to bed material. In that process, suspended sediment sampling is, in general, part of a context and, therefore, the same water sample may serve to several purposes within a given context. Therefore, it is necessary to seek for a proper procedure for treating and/or filtering, in such a way as to allow the maximum extraction of collected sample. For that, one must take special cares, be it in relation to the recipient to be used, to collected material storage and, whenever required, to the delivery of the material to be analyzed. However, it is recommended that, whenever possible, filtering be performed *in situ*, i.e., whenever duly trained staff and proper equipment are available.

For *in situ* works, aimed at determining the suspended material concentration, the filter and filtering equipment should have being treated in the laboratory. Since literature understands dissolved stage as all material passing through a 0,45µm-filtering membrane (GEMS/Water, 1994); such amount has been adopted as the minimum mesh to be used in field for filtering processes addressed to obtaining the suspended material concentration (a filter with a little higher porosity may be used if sediment of a given water stream easily fills in the less porous one). It is also recommended that filter material be inert-type, as, for example, celluloses acetate. It may vary (Teflon, glass fiber, etc.) according to the type of further analysis intended for the dissolved stage. Filtering units shall go to field duly cleaned with filtered water, and demineralized. They shall also be washed with filtered water after each filtration.

Following, it is suggested a working routine to be adopted for *in situ* filtration, aiming at quantifying suspended material:

In the laboratory, before leaving to field:

1. To set apart and wash filtering units[3] (preferably PVC-made) that will be used with filtered and demineralized water;
2. To set apart the number of filters to be used for field survey, with at least 0,45µm membrane mesh;
3. To weight filters by using precision balance (at list two significant algorisms) and settle them into individual recipients, like “petri card”, preferably PVC-made;
4. To label filter recipients and register the weight obtained in previous stage; and
5. To build a kit with the filter set to be taken to field.

In field, after sampling:

1. Filtration unit must be prepared with the corresponding filter; station’s data must be duly registered on the filter label;
2. For surveys performed following the integration method, the different samples for each vertical shall be collected in individual PVC bottles and, by the end of the survey, they must be homogenized in a single recipient; at least 1 liter shall, then, be filtered for each river section surveyed;
3. Previously to filtration, the sample must be shook at least 10 times, in order to suspend again the material that may have already become deposited on the recipient bottom;
4. If any material becomes deposited at the filtration unit walls, it should be removed by using a pisset containing filtered and demineralized water;
5. When managing filtering membrane, one shall choose using a PVC tweezers for both settling the filter into the unit and for removing it after filtration;
6. By the end of each filtration, remove the filtering membrane and put it again on its respective “petri card”, not forgetting to take the required notes;
7. If water sample has suspended material in such an amount as to hinder the filtering of 1000ml - due to the membrane colmatation - the label for that filter shall display the sample volume effectively filtered;
8. After each filtration, to have the filtration unit washed with filtered and demineralized water; and,
9. Accommodating “petri cards” in a safe and proper recipient.

In the laboratory, after field survey:

1. The membranes shall be dried in stove for one hour, under a temperature of 100-105°C; after that they must be weighted on a balance similar to the one used for weighting it previously to field stage; and,
2. The weight values obtained from previous stage shall be registered, and the initial weight shall be subtracted. Then, one will get the suspended material concentration

[3] There are several models of plastic filtration units in the market. It is suggested the use of two overlapping chambers, the filter should be installed between them. Following that model, the lower chamber must have an orifice where, by using either manual or automatic pump, the air is taken out, thus assisting filtration process, with no damage to the filtering membrane.

for the respective sample volume effectively filtered, and adjustments must be made for 1000ml, in order to obtain the concentration in $mg.l^{-1}$.

When a field sample collection procedure and laboratorial homogenization and treatment (filtration or other method) are adopted, it is suggested that:

1. After field integration sampling, the samples must be kept in refrigerated environment (recipient with ice) or refrigerator (if available), taking the necessary steps to avoid freezing;
2. To forward bottles containing water samples to the laboratory, sheltering them from light. Therefore, the same sample may have other uses, not just for suspended material;
3. That no substance like conservants, algaecide and so on be inserted;
4. That samples be forwarded as soon as possible for the laboratory; and
5. To avoid intermediary procedures, between field and laboratory treatment, such as filtration a few days after the survey and forward only the filter for the laboratory for drying and weighting.

4.3 *Laboratorial analysis*

During this stage, collected samples will be received from operation team and the transportation conditions, storage and identification will be verified. For this process, samples are weighted as soon as they are received for verification purposes. During verification, they are re-weighted, since they might have been stored before being processed and have lost water due to evaporation (see Figure 4.36).

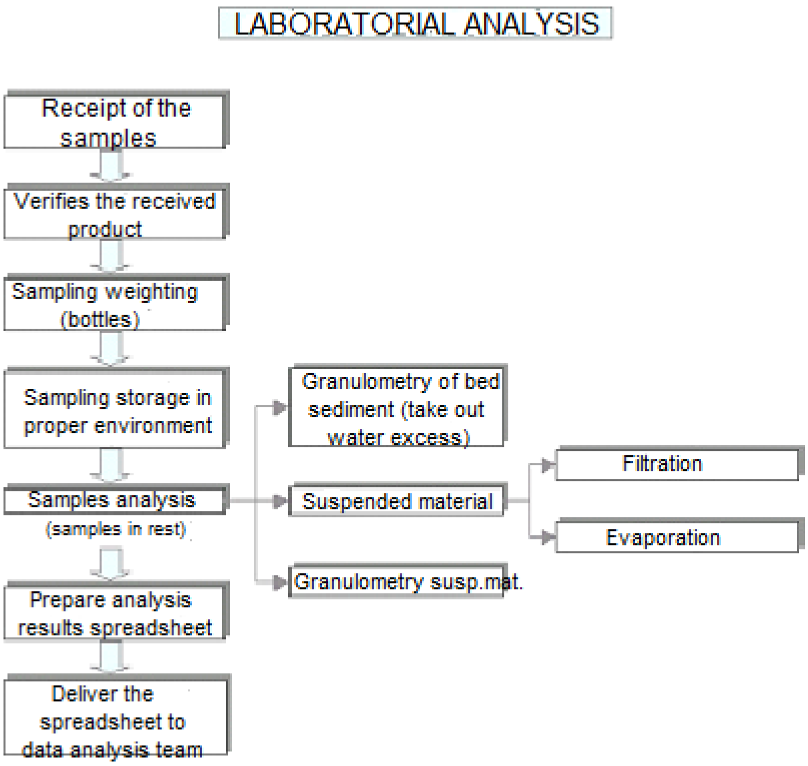


Figure 4.36 – Laboratory stages.

Further, samples are processed according to their typology:

i) Bed sediment sample – follows for having its granulometry determined; here, several procedures may be used: sieve, visual accumulation tube, bottom-whithdrawal tube, pipetting or densimeter;

ii) Suspended material sample – follows for having its concentration determined, be it through filtration or evaporation; it also follows for granulometry determination, which can be performed through bottom-withdrawal tube (BW tube), pipetting or densimeter.

There are more modern methods using X-Ray and Laser technologies, thus reducing a lot the processing time, and improving a lot granulometry results. However, such methods are not yet frequently used in Brazil, due to their high costs.

By the end of this stage, the laboratory team shall produce spreadsheets, organized by sample containing information on analysis and outputs (or gross data) both on concentration and granulometry for suspended material sample, as well as for bed material.

4.3.1 *Samples delivery and management*

The laboratory expert shall receive samples directly from the hydrometry expert in charge of measurements, conferring all material based on bottles' and recipient's labeling, or on due lists filled in the field. He must verify if all sample bottles or plastic recipient or bags, samples in general, are duly labeled and well kept, with no problems of water spilling or sediment loss, for bed sample.

The bottles containing water-sediment mixture shall be immediately weighted and the values shall be registered in proper forms. This is necessary due to the possibility that the sample looses water, due to evaporation, thus having its volume diminished.

The analyses shall be performed in the shorter time as possible, in order to avoid altering samples characteristics, and also for liberating the bottles for further measurements. Such changes may be caused by organic matter, pollutants, nutrients or even ions. Reactions may occur along time, as algae formation or even fine particles with contrary charge being gathered, thus forming flocks. In anyway, there are constant joints of particles, thus jeopardizing the granulometry analysis. In this case, the analysis process always uses a defrocking.

Suspended material samples shall be stored in a proper environment, with mild temperature, and no direct incidence of sunlight.

Bed sediment samples shall be kept wet in order to avoid clods formation. Nearby the analysis occasion, they must be dried in the sun, with the due cares, with an operator mixing particles in order to avoid their spilling and also for a better evaporation, thus decreasing stove work and facilitating the management for removing waste or putting it on the tray.

It must be said that dully-skilled laboratory experts shall perform laboratory works, since they demand care and operation of adequate equipment. The sediment analysis is different from the analysis of material diluted in water, such as soluble salts, due to the difference in size, weight and density existing among particles.

All suspended sample received by the laboratory must be analyzed; one shall not perform, for example, a sample on the total for determining concentration, due to the difficulty in homogenizing the water-sediment sample. A supposed homogenization of the sample is never complete, because heavy particles become soon deposited.

4.3.2 *Kinds and methods of analysis*

Usually, the suspended sample concentration analysis is performed for water-sediment mixture. Whenever required, the granulometry analysis for suspended sediment is also performed; this is to be determined by the work coordination team, according to the computation methods for sediment discharge to be performed. Another analysis sometimes required is for soluble materials; it is performed when establishing the concentration by using the evaporation process, or when the value shall be used for several studies.

The analysis to be performed for bed material is restricted to granulometry. For direct measurement of bed discharge, with equipment based on bed, the determination of dry weight for all material, as well as granulometry shall be specified.

Concentration data are used for all suspended sediment computations. Whenever granulometric bands require the sediment discharge, the corresponding analysis is performed. For the total sediment discharge computation using the modified Einstein method, the granulometry analysis, both for suspended and bed sediment, is indispensable.

Bed material granulometry data are used for calculating both bed and bed material discharge, by using traditional formulas; it is used for obtaining total sediment discharge as well.

The analysis methods are listed in Table 4.5.

Table 4.5 –Analysis methods more frequently used.

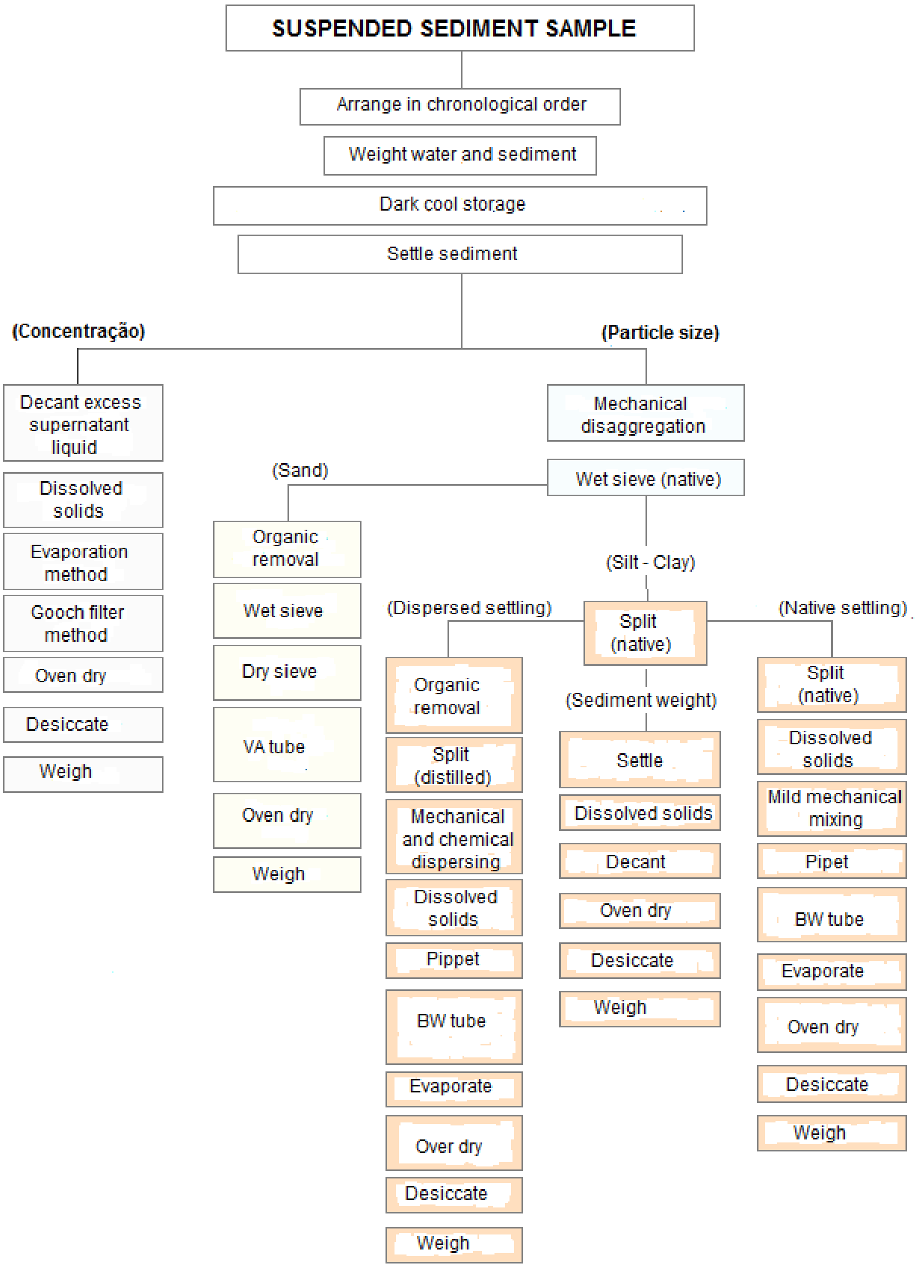
Suspended sediments	Total concentration analysis	Filtration Evaporation BW tube
	Granulometric analysis	BW tube Pipetting Densimeter
Bed Sediments	Granulometric analysis	Sieve Densimeter Pipetting Visual accumulation tube BW tube

Concentration and granulometry for both suspended and bed material are also very useful for other engineering and environmental studies. For assessing the specific weight of deposits in a reservoir, it is necessary to have the granulometry of historical data, for both suspended and bed sediments. One can conclude that it would be convenient to always have the granulometry of suspended and bed material duly determined.

According to Guy (1969), the analysis for water + sediment samples, as well as for bed material, shall always be performed according to those diagrams presented in Tables 4.6 and 4.7.

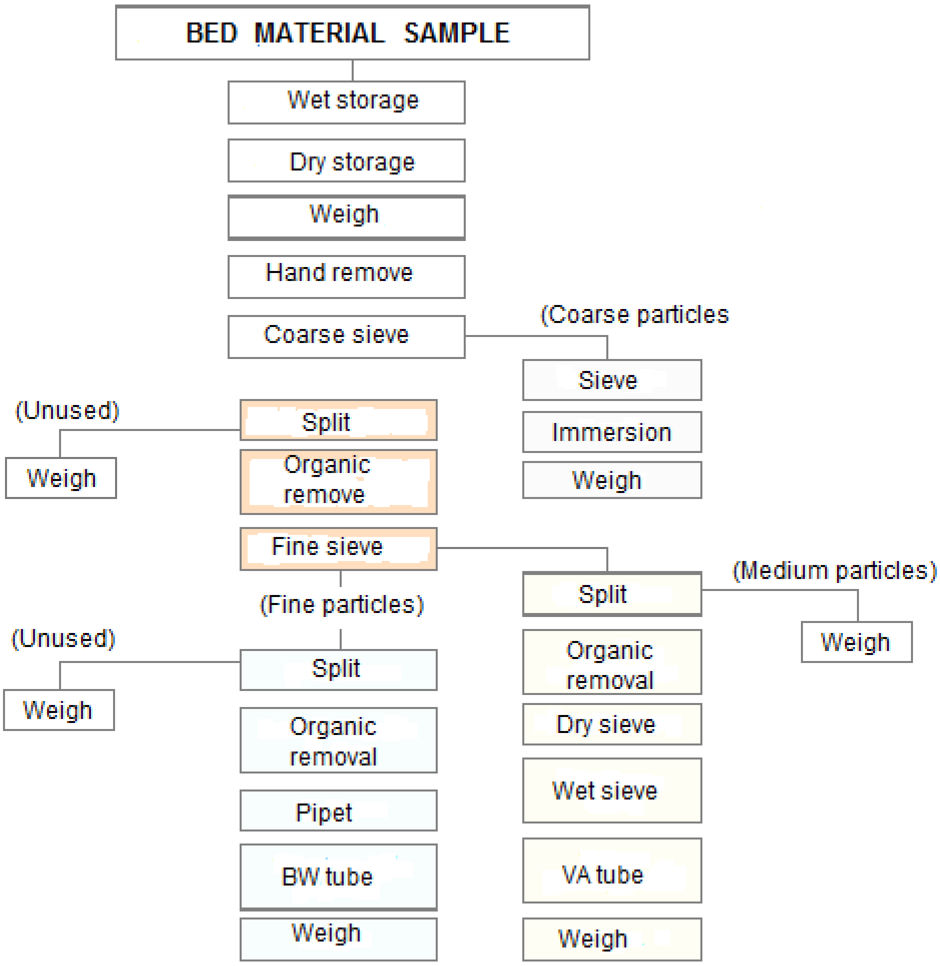
Bed material collected along the cross-section may present great granulometric diversity, from coarse such as gravel and sand, up to fine material such as silt and clay. In this case, an analysis for such material shall require different methods for completely defining it – the coarse would be analyzed through sieve, while fine material would be analyzed by using the densimeter, pipette or even the bottom-withdrawal tube (BW tube).

Table 4.6 – Diagram with the sequence of suspended material analysis operation (Guy, 1969)



***Explanation** – The flow diagram for essays on concentration and granulometry analyses for suspended sediment samples. Divisions and blocks may be replaced, or some may be added whenever required, depending on quantities, conditions and graduation of the sample granulometry, as well as on objectives of data management. If the analysis is not performed with native water, so distilled water may be used for wet sieving and separate in blocks named "Mechanical disaggregating”. The blocks divided by horizontal lines show alternative procedures.*

Table 4.7 – Diagram with the operation sequence of bed material analyses operation (Guy, 1969).



***Explanation :** Flow diagram for particle size analysis of stream bed-material samples. Blocks divided by horizontal lines show alternate procedures. Some blocks can be bypassed depending on the amount, the condition, and the size gradation of the sample and the objectives for use of the data. For example, organic material is usually not present in significant quantity to be bothersome. Also, there is little need to determine the amount of the unused split portions if the quality of the splitting operation is assumed to be good*

4.3.3 *Volume of samples required for analysis*

In previous items, the measurement methods were described, as well as equipment and sampling procedures, once informed the proper quantity of verticals. One could suppose that, once met a minimum quantity of verticals, the issue of sample volume required for the analyses to be performed would also be met. However, not always that is true, mainly when concentration is low.

Concentration and granulometry analyses for suspended sample are performed in laboratory.

In relation to concentration, according to WMO, it is necessary to collect such a volume as to allow the proper analysis; such volume should increase as concentration decreases. Table 4.8 shows the minimum volumes required for sediment concentration analysis.

Table 4.8 – Minimum sample volumes required for suspended sediments average concentration analysis (WMO, 1981)

Expected concentration of suspended sediment	**Sample volume**
(g/m^3, mg/l, ppm)	**(*l*)**
> 100	1
50 to 100	2
20 to 30	5
< 20	10

The sample volume required for the suspended sediment granulometric analysis will be in function of the methods available for the laboratory. Usually, the volume to be collected when this analysis is programmed is higher than the one required for concentration. Usual and available methods in Brazil are BW tube, pipetting, and sieving. The first two are for fine sediments (silts and clay), and the last ones are for sands. Each of them requires a minimum amount of sediment in order to have a successful analysis. Table 4.9 shows minimum values required concerning sediment weight, while Figure 4.37 presents the minimum amount of 400m*l* bottles required for the adequate analysis of sediment granulometry. Further, in the item for *analyses*, additional references shall be provided.

Table 4.9 – Desired amount of suspended sediment required for the different types of granulometric analysis (Edwards & Glysson, 1999)

Kind of analysis equipment		**Granulometry thresholds**	**Minimum sediment amount desired**
		(mm)	**(g)**
Sieve	Fine	0,062 – 0,5	0,07
	Medium	0,25 – 2,0	0,5
	Thick	1,0 – 16,0	20
Visual accumulation tube	The smallest	0,062 – 0,5	0,05
	The greatest	0,062 – 2,0	5
Pipette		0,002 – 0,062	0,8
BW tube		0,002 – 0,062	0,5

In field, it is hard for the hydrometry expert to know such quantities. A best judgment may arise from volume, as presented in Porterfield graph, Figure 4.37 (Guy/Norman, 1970 and Edwards & Glysson, 1999), which shows the number of 400m*l* bottles to be collected by pipetting analysis, obtained from the intersection of concentration lines in function to the percentage of particles finer than 0,062mm.

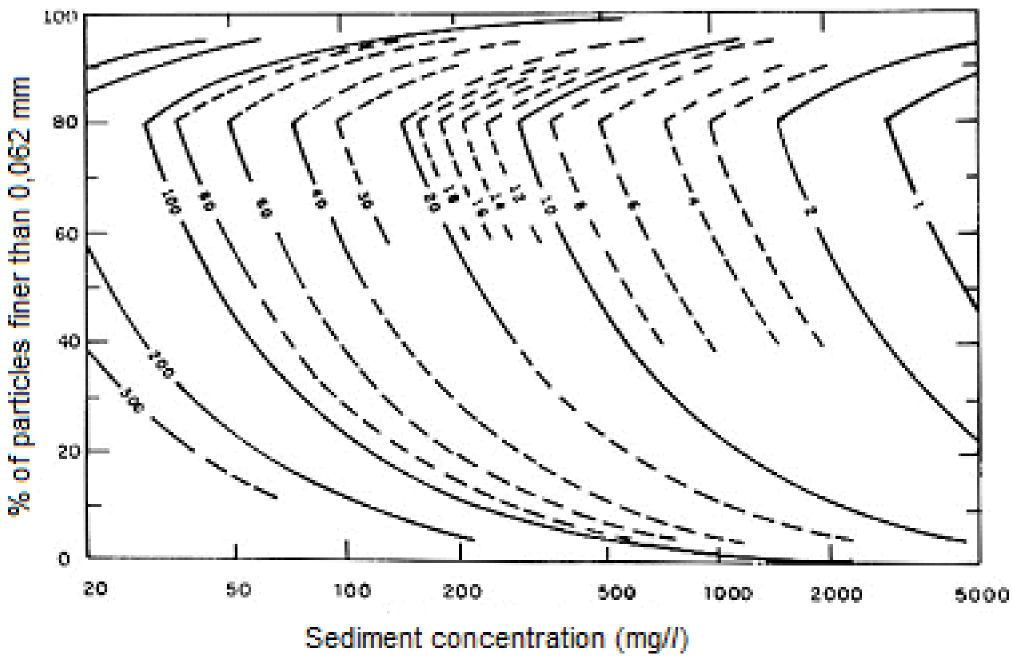


Figure 4.37 – Minimum of bottles containing optimum sample volume need do yield sufficient sediment for size analysis (from Porterfield, 1972).
Data is based on 350 g of sample per bottle; a minimum of 0,2 g of sand for sieve or visual accumulation tube analysis, and 0,8 g of silt and clay for pipet analysis in 400 ml suspension. For analysis by the BW tube method the number of bottles needed for less than 80 % finer is five-eighths of the indicated number. Instructions: Estimate sediment concentration and percentage of particles finer than 0,062 mm based on knowledge of stream and (or) examination of first bottle. The number of bottles required is the value of the line to left of the intersection of the sediment concentration and the percentage of particles finer than 0,062 mm. Interpolation of number of bottles may be made along abscissa (Guy & Norman, 1970).

According to the graph and information included therein, for example, if sample has 100ppm with 80% of sediment finer than 0,062mm, so it is necessary to collect 30 bottles containing 350 m*l*, i.e., 10,5 *l* for performing the analysis with pipette and 8,4 *l* for performing the analysis with BW tube.

It is also hard to know the granulometry in advance; it requires some field experience, as well as the knowledge of analyses outputs, due to the water color, being the table an indicative whose use will depend upon the laboratory results and good relation among teams.

According to Edwards & Glysson (1999), although it is possible to perform granulometry analysis in such a way as to also obtain concentration, it would be better to obtain separate samples through both analysis.

4.3.4 *Limitations for analyses methods*

The different analyses methods, as well as equipment for performing them, have limitations. Reliability and accuracy on the laboratory analysis are directly related to sediment discharge computation. Collected samples must arrive at the laboratory in quantities enough for allowing the proper analyses for determining both concentration and granulometry.

Samples concentration analyses with few suspended material, i.e., less than 200 mg/*l*, are performed through the filtration method. If the sampled amount is greater, it is useful to perform analysis through evaporation, in order to avoid the filter colmatation. If that is so, one could even use more than one filter and sum the sediment residual quantities. Although being used, the sample reduction by bi-partition is not recommended because it may lead to errors. If the sediment contained in the sample is a sandy one, the filtration method may be used for greater concentrations.

The establishment of suspended and bed sediment granulometry is performed through different methods, mainly due to the amount of sediment available in each sample type, and the particles size as well. There are few sediments contained in a suspended sample and most of them present fine granulometry, such as clay and silt, while in bed samples there are many sediments with thick granulometry, such as sands. On the other hand, the sediment on suspended sample comes with too much water, while bed samples are just wet.

The hydrometry expert shall be instructed to collect samples enough for allowing several analyses. Sampling criteria take into consideration section width and stream depth, being collected in 10 to 20 verticals. However, the visual criterion for sediment quantity should be taken into consideration and, sometimes, should even prevail. Therefore, it is necessary to have a permanent understanding between field and laboratory teams, in order to grant proper sample quantities for analysis. (Carvalho, 1994).

For the sieving method, the minimum sediment amount required for analysis is 0,05g, and it is performed by using small sieves. Material finer than 0,0625mm will pass through the thinner mesh sieve (# 200 or 230), and granulometry shall be established by using other method. That last analysis for finer material is justifiable only if its quantity is equal or higher than a given percentage, such as 3 to 5%, in order to meet the restrictions of some methods for sediment discharge computation.

According to Guy, (1969) the limitation of several granulometric analysis methods for suspended material samples is the one presented in Table 4.10.

Table 4.10 -Limitations of granulometric analysis for most usual methods (Guy, 1969 e USDA, 1978).

Method	**Granulometry thresholds**	**Concentration thresholds**	**Sediment amount**
	(mm)	**(mg/*l*)**	**(g)**
Sifters	0,062 - 32	----	0,05 ***
Visual accumulation tube	0,062 - 2,0	----	0,05 - 15,0
Densimeter	0,002 - 0,062	40.000 - 50.000	0,04 - 0,05
Pipette	0,002 - 0,062	3.000 - 10.000	1,0 - 5,0
BW tube *	0,002 - 1,0	300 - 10.000	0,5 - 1,8

* If required, it can be increased in order to include sands up to 0,35mm; however, accuracy decreases as particle size increases. It requires concentration and quantity that may properly increase.
** The threshold figures above-mentioned are presented slightly different by other authors.
*** For bed material, greater amount is used: > 0,5kg.

For bed material, when using the sieve series Tyler, usual size, it is necessary to have at least 0,5kg of sediment. The sum of collected sub-samples shall weight 2kg or so, for allowing the quartering and composition of the final sample to be sieved. When there are few sandy sediments, the visual accumulation tube method may be used. Fine sediment, which passes by the thinner sieve, shall have at least 0,05kg for analysis using the densimeter process. Analysis is worth of being performed only if 5% or a higher percentage of material is less than 0,062mm. If that fine material is fewer than 0,05kg, so it may be analyzed by using pipetting process or BW tube; the quantities for each one are indicated in Table 4.10.

One may conclude that sieve and visual accumulation tube methods are used for analyzing coarse and the use of densimeter, pipette, and BW tube are proper just for fine material. In the following items, the methods will be presented, not taking into consideration the analyses itself. The script may be obtained from the bibliography.

4.3.5 *Concentration analysis – filtration and evaporation*

Concentration analyses are performed by using filtration or evaporation methods. The filtration method is used when the sample reports low concentration - lower than 200ppm, while the evaporation method is used for higher concentration samples. This last may be chosen also due to the quantity of samples obtained, since in large samples, even with low concentration, the great amount of particles may colmate the filter.

The concentration establishment by using the BW tube is a process that leads to water evaporation, in order to obtain sediment residues. Concentration is obtained by dividing the total weight by the volume, or the total weight of the mixture water + sediment. Such values are usually recorded in the proper analysis worksheet.

Concentration is determined by the dry weight of suspended sediment contained in the sample, in relation to its total volume or its total weight.

$$C_s = \frac{p}{V} \qquad \text{or} \qquad C_s = \frac{p}{P}$$

where

C_s – sediment concentration
p - sediment dry weight
V - volume of the water-sediment mixture
P - weight of the water-sediment mixture

When defined in relation to the weight by volume, mg/*l* units are used for low concentrations - up to 100mg/*l*, or up to 1000mg/*l* when greater values either are not expected, or are not usual. From that to higher values, one may use g/*l* or kg/m^3. It is barely expressed in %, and 1% = 100mg/*l*. Data are presented with at least three digits (1,25mg/*l*, 15,5mg/*l* etc.).

When established by the sediment weight in relation to the total weight, it is used ppm, parts per million, which corresponds to the transformation of the total weight in kilos into milligram (1kg = 1.000.000mg) and the measure has no unit. Since the mixture density increases with concentration, the value by weight is not equal to the concentration by volume. In practice just the measure used by units beyond 16.000ppm are sensibly altered by density, thus turning common values into equivalent ones (Guy,1969; Carvalho,1994; USDA,1978).

The concentration analysis process requires some procedures that use all samples from the field. It is wrong to settle all mixture into a single recipient, homogenize it by using any method and, then, take 100ml for proceeding the concentration analysis. It causes the loss of accuracy, because the material is not homogeneous, thus causing the stratification after the supposed homogenization process, besides what, the sediment weight may reach the measurement error band, thus masking the result. The laboratory needs such an amount of mixture that allows for an analysis with the desired accuracy.

Then, the analysis procedure requires a sequence starting by the sample delivery and weighting, in order to ensure that weight of the received sample is known, as previously stated. For the analysis occasion, several sub-samples are dully settled into one single recipient in order to allow for one single trial. That setting requires the removal of all particles from the recipients coming from field. It is worth to notice that this procedure is correct when field sampling was performed through EWI or EDI processes. Total sample rests for 1, 2 or more days and, after that, the excess of liquid with no sediment is withdrawn. Out of that excess, three 50ml portions are removed by pipetting, for determining sediments dissolved by evaporation, whenever applicable. The following steps consist in obtaining concentration through evaporation or filtration methods, drying it in the stove, taking to a dissector and weighting it (see the diagram for analysis sequence, as previously presented in Table 4.6).

If the clean flowing water resulting from the sample rest and sediment decantation processes present few coloration, it is useful to pass it through a low-porosity filter for holding such sediment. For that, it is useful to establish the residue weight to be computed in concentration.

Below, it is presented some useful guidance about the analyses. For further clarification and detailed description of each analysis, it is necessary to see the specialized bibliography as previously indicated.

The material taken to a stove shall never be subject to temperatures higher than 105ºC due to the presence of mineral substances that may be burned and undergo changes, thus reducing its weight in higher temperature and harming concentration or granulometry values. For security reasons, one shall keep the stove temperature as 105ºC.

a) ***Filtration method***

For laboratorial analysis, the same procedure as for filtration "*in situ*", as previously mentioned, may be used (Figure 4.38), bearing in mind that there are filtration units exclusively for use in laboratory.

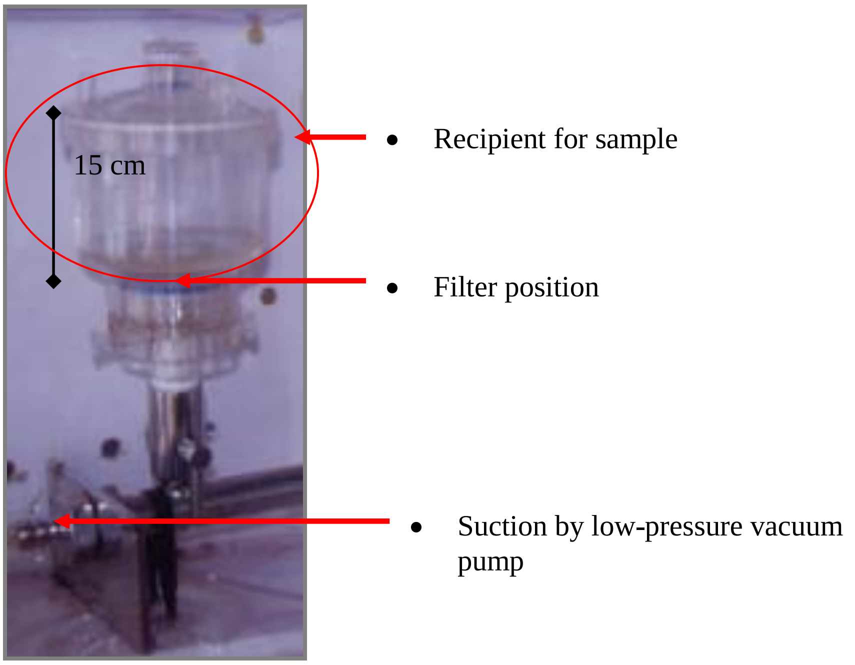


Figure 4.38 –Guide on main elements for a PVC-made filtration unit, part of a stainless steel filtration ramp.

The samples for several verticals of the same section shall be homogenized in laboratory or in field, in order to obtain a single sample, named composite (USGS-Guy & Norman, 1976 and Carvalho, 1994 and 2008). On a following stage, the solution water + sediment is separated, by passing through a filtering paper, previously weighted (Pi), whose mesh is known. The international recommendation is to use filters with mesh of at least 0,45 µm. (Meade, 1985; GEMS/WATER, 1994) in inert material (cellulose acetate, for example).

After filtering a known volume of samples, filters are dried in the stove, at 100 - 105ºC up to one hour; then, they are weighted again (Pf). The difference between Pi and Pf is the MES (suspended material) concentration that, for a known volume of sample (identified on the bottle), is obtained in mg/l.

For both procedures, a filtering set may be coupled to a device provided with a small vacuum pump. Compressor shall not be used on liquid surface for speeding filtration, because the filter will have its porosity increased, so allowing the fine sediments to pass through it.

b) *Evaporation method*

For this method, it is also used to reduce the sample by letting the mixture rest for 24 hours or more and, then, removing the excess of liquid exempt from sediment (if the sediment is so fine it is necessary to rest more than a day). It is important and necessary to establish the quantity of soluble salts; for that three 50 ml pipetting are performed for the part exempt from sediment (flowing water after 24-hour rest), drying it in stove and obtaining the average value. If such portions present yellow coloration, due to the presence of colloids or fine clay, they must pass through a low-porosity filter. If water presents coloration after resting for one or two days, it would be useful to remove water excess through water-bath.

Water-sediment mixture, now reduced in its water quantity is, therefore, settled in a recipient proper for evaporation, and taken to the stove to be dried. After some time or hours, when the sediment is visually dry, it is left for two or more hours in the stove and, then, it is moved to the dissector and for further weighting (see diagram on Table 4.6).

4.3.6 *Granulometric analyses of suspended and bed material*

Granulometric analysis for suspended material is usually performed by using the BW tube, a settling tube for amount of sediment as 0,300 to 5,0g. When concentration allows – in case of greater amount of material - the 24-hour rest process is performed and, therefore, the analysis through pipetting may be carried out, higher than 5,0g, or the densimeter process may be used for greater amounts of sediment, higher than 40g. The minimum amount of sediment required for using the process must be respected; therefore, in this case the analysis through densimeter process would hardly be performed.

For choosing the analysis method, if with BW tube or pipetting, a volume of 25ml must be drawn from the composite sample - already reduced from its clean water – and concentration must be determined, by comparing with the restriction values for each analyses, thus choosing the method. The Table 4.11, prepared by Guy (1969) may be used .

The operation sequence and necessary cares are as follows (CSQA, 1999):

- To pass samples through the proper sifters in order to determine the sandy material granulometry (> 0,062mm);
- To reduce total sample up to l,0*l*, putting it into the test tube; then, homogenize it and proceed a 25 ml pipetting and determine the concentration;
- If it presents from 300 to 5.000ppm, the granulometry analysis by using the settling tube shall be performed;
- If it presents from 3.000 to 10.000ppm, the granulometry analysis through pipette must be performed; there is a range that allows for the laboratory expert to choose the method;
- If it presents low concentration, no granulometric analysis is performed.

Table 4.11 – Choosing the analysis method (threshold figures for granulometric analysis methods) (Guy, 1969)

Material	Kind of analysis	Size band (mm)	Concentration (mg/l)	Quantity of sediment (g)
Sand	Sieve V.A. tube	0,0625 - 32,0 0,0625 - 2,0	- -	<0,05 0,05 - 15,0
Silt an clay	Pipette BW Tube (Settling) Evaporation	0,002 - 0,0625 0,002 - 0,0625 0,002 - 0,0625	2000 - 5000 1000 - 3500 < 1000	1,0 - 5,0 0,5 - 1,8 < 0,5
Note: - If necessary, the table may be expanded in order to include sand grains sizing up to 0,35mm; - Accuracy shall decrease as the size increases; - Concentration and quantity required shall proportionally increase.				

Concentration value is calculated according to the following procedures:

- When using settling tube (BW tube) – that is used to evaporate water – concentration is calculated by the total weight of accumulated sediment, adding the concentration of the 24ml volume taken, divided by total water volume or weight;
- When pipetting is used, all the remaining water with sediment – after removing the flowing water for determining the amount of dissolved sediments – is put into the 1,0*l* tube test. Following the pipetting procedure, the remaining water is put into a capsule and taken to water-bath for reducing water even more; next, it is taken to stove for drying and further weighting; the amounts related to soluble salts are corrected and added to the amounts of pipetting sediments and the residues of the 25 ml previously removed, thus obtaining the total weight of sediments in the sample which, divided by the sample volume or total weight, provides the concentration;
- When densimeter process is used, after the reading procedure, one may put the test tube material in a capsule, take to water-bath for reducing water even more and then to the stove; after correcting the value for soluble salts, the total weight of sediments and concentration is obtained.

Granulometric analysis for bed material is performed through sieving. If fine residue remains after the sieving through the thinner mesh, and is equivalent to or higher than 5%, an analysis is performed, through densimeter, pipetting or settling tube, obeying the limitations for each method.

a) ***Settling tube method (BW tube)***

As previously noticed, this is the method that allows for the use of small quantities of sediment. Considering that many rivers in Brazil present low concentration, lower than 300ppm, it is not possible to perform the analysis with natural sample; therefore it is necessary to have it "concentrated". This process consists in what was previously presented, leaving the total sample resting for 2 or 4 days, or more, and removing the flowing clean water. The tube shall contain a volume equivalent to 0,5*l*; that quantity shall have all sediments from total sample. Therefore, if a river has an average concentration of 50mg/*l* by occasion of the sampling, it will require the collection of about 4 liters of sample, which shall contain a total of 200mg of sediment. In 0,5*l* those 200mg shall correspond to 400mg/*l*, an amount that allows for performing good analysis, as shown in Table 4.10. Therefore, one may conclude that clean waters, with low concentration, require more verticals for collecting sub-samples, and that two sub-samples should be collected by each vertical.

The tube process determines the granulometry of fine sediment, thus requiring the coarse analysis through sieving, as previously explained for the pipetting case.

That analysis takes the whole morning, just for the operational part with the tube, letting the tube free for the afternoon, thus resulting in the possibility of two analyses per day (see Figure 4.39). Therefore, it would be useful to have an adequate set of tubes to perform usual analysis in an established program.

After the mechanical analysis process, the next step is tracing Oden curves. It will allow for obtaining granulometric percentages (Figure 4.40). If analysis restraints are respected, and other required cares adopted, the result shall allow for tracing an accurate granulometric curve.

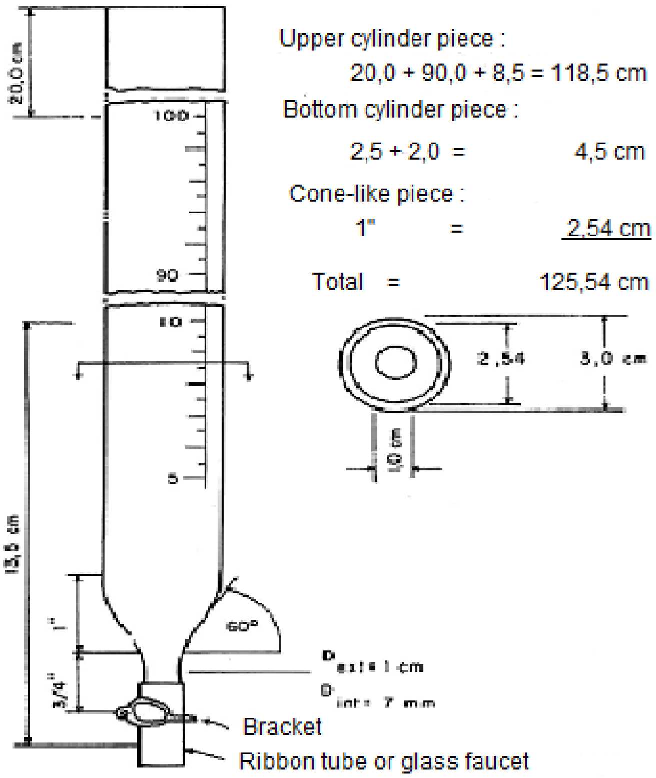


Figure 4.39 –Bottom withdrawal tube - settling tube for granulometric analysis of fine material (Guy1969, modified).

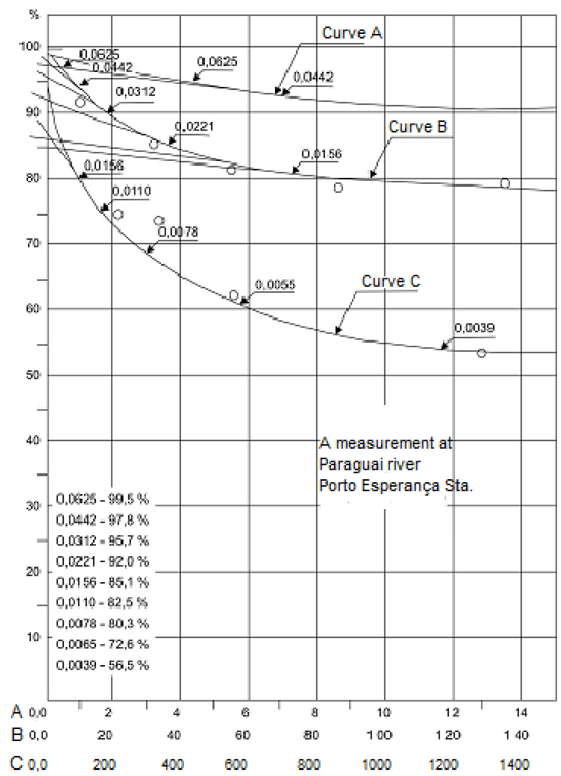


Figure 4.40– Tracing and use of Oden Curve for obtaining the granulometry of fine sediments (Carvalho, 2008)

.

c) *Pipetting*

Pipetting is performed in order to determine the fine material granulometry <0,062mm. It is used for suspended material, and as auxiliary for determining the granulometry of fine sediments for residues from the last sieve, when material >0,5 remains.

The analysis through that method uses 50 or 100m*l* pipettes and 1,0*l* test tube. It may be a manual analysis, or by using several equipment with mechanical process (Figure 4.41). The quantity of sediment for analysis shall obey limitations stated in Table 4.10; therefore, it is necessary to perform the same process for reducing water amount by sediment decantation, after a 24-hour rest, or more.

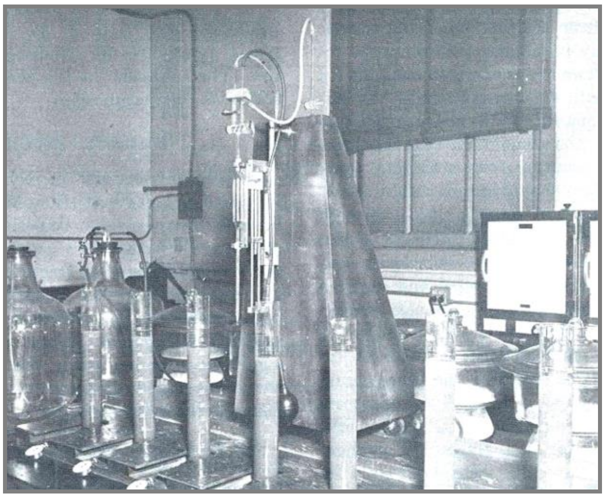


Figure 4.41 – Equipment for pipetting analysis (Guy, 1969).

Pipetting time and height is determined by Stokes law, based on water temperature and particles drops of 0,062, 0,031, 0,016, 0,008, 0,004 and 0,002mm in diameter. Pipettes are filled in 8 to 12 seconds and, then, are emptied in an evaporation recipient. Then, they are taken to be dried in the stove.

Considering that analysis is performed with original water and shall evaporate, there will be a residue of salt with the sediment; therefore, it will be necessary to determine soluble salts for the due correction.

c) *Densimeter*

In Brazil, the most frequently used method with densimeter is that introduced by Casagrande in laboratorial works of Soil Mechanics. Two kinds of densimeter may be used, one with long handle and other with short handle (Figure 4.42). The results of densimeter readings are recorded into the proper form for due computations and use of the adequate abacus for solving the Stokes law.

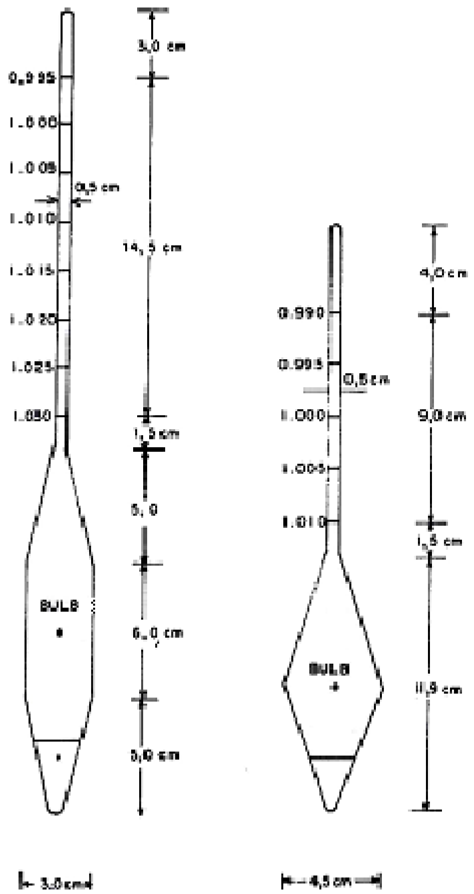


Figure 4.42 – Densimeters for use in fine material granulometric analysis.

d) *Visual accumulation tube*

This process uses tubes duly built in several sizes. They are chosen according to dry weight of sand available for analysis, and also with the volume of such material. It is applicable within the restrictions indicated in Table 4.10. This kind of analyses is going to be abandoned for the others more accurate.

The analyzer is basically made of a glass tube holding the water column, where the precipitation of sediment particles of the sample, initially set on its top takes place. It has also an electrically commanded valve that, once opened, starts the material precipitation through the liquid column. That starting is synchronized to the movement of a rotating drum, where is a graph paper fixed, as shown in Figure 4.43. The arrival of falling particles to the tube bottom is followed by the observer through a lunette that has a stiletto tracing the drum paper. The operator, in charge of that lunette, monitors, through a vertical movement, the accumulation of particles in the tube bottom. The graphical register obtained in this device relates the drop velocity of particles that successively accumulate in the tube bottom, with the corresponding diameters, as established by the Stokes law. The graph presents an overlap of functional scales, thus allowing for obtaining the percentages of materials finer than the diameters indicated (Figure 4.44). In the graph, the inclined ruler indicates the process for obtaining the material percentages (DNAEE, 1967). According to the figure, the curved line intercepts the verticals for the temperature analysis values (20º) where horizontal lines are traced (dashed); on the top line, the ruler is set indicating the percentage of fine sediments from the original sample; the 100 amount remains on the bottom line. Percentages of materials are indicated as the intersection of the ruler and the horizontal lines drawn.

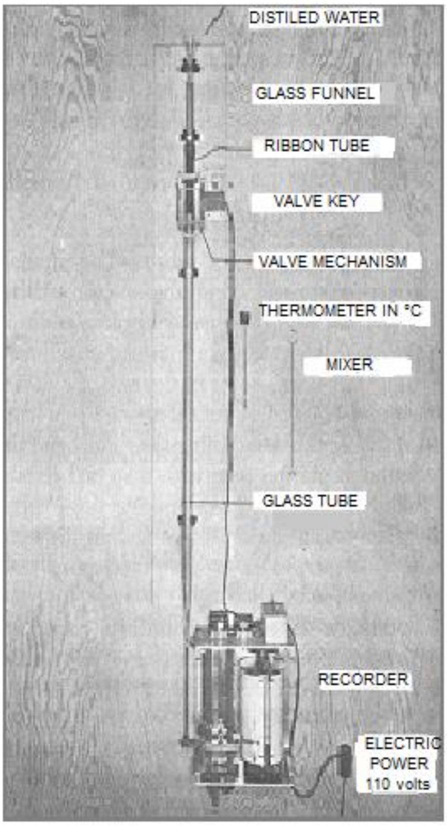


Figure 4.43 – Visual accumulation tube for sand analysis (Guy, 1969).

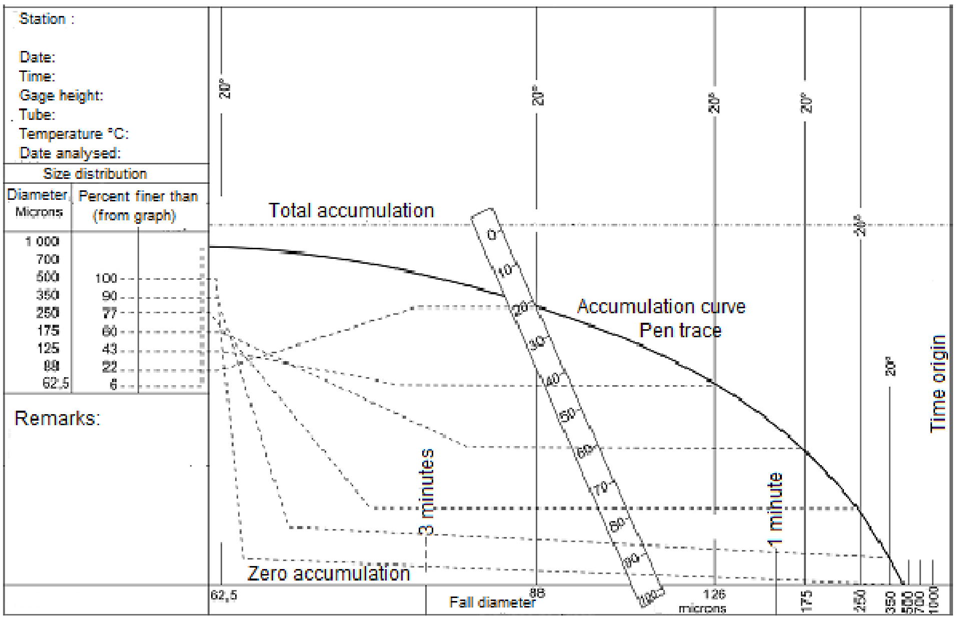


Figure 4.44 – Graph to be used with visual accumulation tube for sand granulometric analysis (DNAEE, 1967).

e) *Sieving*

This method uses a series of standardized mesh sieves; the most frequent ones are the Tyler series. They are pilled up, and the sieve presenting the greater mesh diameter is placed on the top and the one with the smallest mesh diameter is on the bottom, before a support basin. All of them are coupled to a final recipient that receives the fine sediments from the last sieve. They may be manually shaken, but due to the weight of the set, it would be useful to couple them to the equipment (*ro-tap*) that mechanically shakes it. There are sieve series with several diameters, the use of which is a function of the quantity of sediment available for analysis.

There are two sieving processes: wet and dry. For the wet one, the sample is put on the upper sieve, and current water is added in order to force the finer particles to pass through the meshes, and shall not have the final recipient for holding the fine sediments of the last sieve.

Each portion of material held in the sieve is weighted, and the percentage of each sieve mesh diameter is obtained by dividing it by the sample total weight.

f) *Tracing and use of granulometric curves*

The results for granulometric analysis are presented by the percentage of materials in several diameters; granulometric curves are traced in order to be duly used for several studies (Figure 4.45). Usually, the curve for suspended material presents higher percentages of fine material, such as clay and silt, and the bed material curve presents significant percentages of sands.

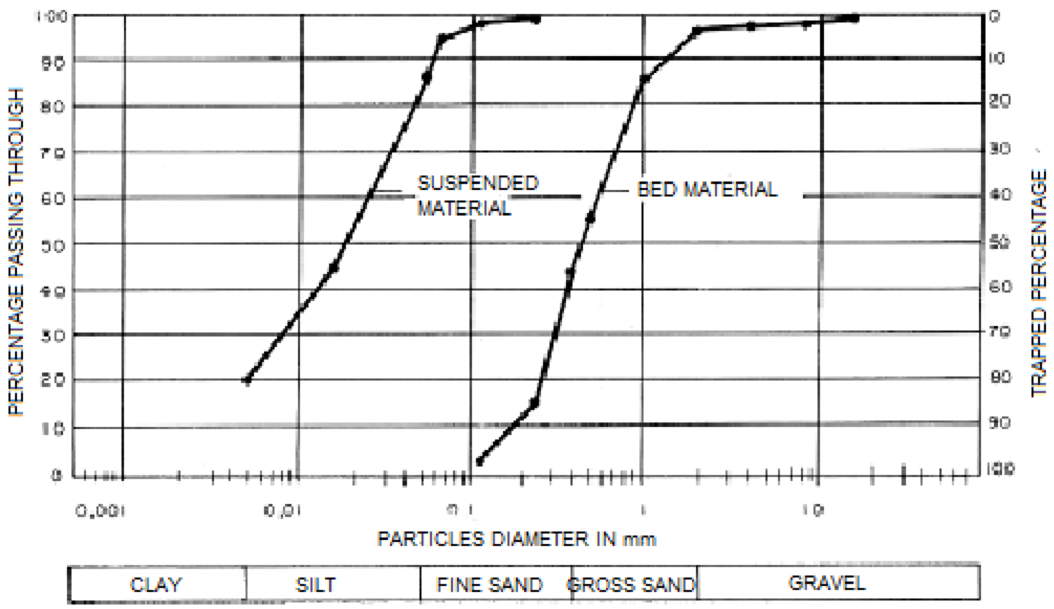


Figure 4.45 – Average granulometric curve for fine sediments present in suspended material and bed coarse - São Francisco River in Morpará (Carvalho, 1994).

For the bed material granulometric curve, the percentage of characteristic diameters for 10, 35, 50, 65 and 90% shall be traced. They are named D_{10}, D_{35}, D_{50}, D_{65}

and D_{90}, respectively. Those values are used for several studies and, mainly, in sediment discharge computations, the focus of this Guide.

The curves for suspended and bed material shall provide the accumulated percentages of particles diameters to be used for calculating the sediment discharge. The diameters shall be those used in these North-American formulas and use AGU granulometric classification, as presented herein. The percentages for each diameter shall allow for obtaining percentages among granulometric bands, as the example below, for a bed material curve (Table 4.12).

Table 4.12 – Data obtained from the granulometric curve for Rio Paraguay gaging station in PCH Alto Paraguay – as of 13/02/1999 (CEMAT).

Diameter – Granulometric band (mm)	**(%)**	**Characteristic diameter (mm)**	
0,002 – 0,0625	0,10	D_{10}	0,195
0,0625 – 0,125	1,00		
0,125 – 0,250	20,03	D_{35}	0,360
0,250 – 0,500	42,87		
0,500 – 1,000	36,00	D_{50}	0,430
1,000 – 2,000	-		
2,000 – 4,000	-	D_{65}	0,500
4,000 – 8,000	-		
8,000 – 16,000		D_{90}	0,595

4.4 *Gross data processing*

This is the last stage for a continuous and dynamical process, which is the operation of a hydrometric network. Here, gross data (field or "in situ" and laboratorial) shall be gathered and consolidated into a single database, so that they can be worked for obtaining final values for net and sediment discharges: i) suspended; ii) bed; iii) bed material; and iv) total (Figure 4.46).

After such determinations, both error and consistency analysis shall be performed for the information produced; afterwards, it may finally be delivered to users community through the proper midia (Internet, CD-Rom, statistical report, etc.).

4.4.1 *Data processing and consistency analysis*

Data processing occurs from the sediment discharge computation until the stage of obtaining average values and parameters to be used in studies. Once having all data on water discharge, sediment analyses and additional information, the instantaneous sediment discharge may be calculated. One may calculate either bed or entrainment suspended discharge, based on bed material and total sediment discharge. Suspended discharge is calculated independently from bed discharge, because they do not follow the same movement law. While suspended material is subject to the stream action, bed material also suffers resistance actions among the particles themselves, and bed interferences as well.

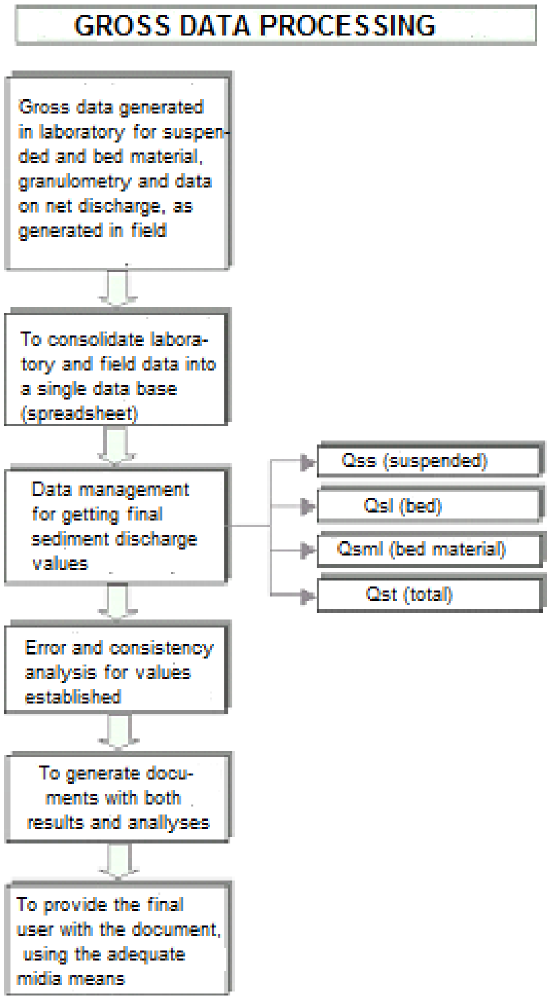


Figure 4.46 – Stages of gross data analysis and processing.

Collection, computation and dissemination of sedimentometric data, as well as for data concerning environment, shall be part of a national program to assess the effects on the useful life and economic aspects of projects and works, in what concerns navigation, flood control, water supply, leisure, pollution, fishing and hydraulics works in general. Sedimentological survey may include the determination of river sediment discharges, reservoir surveys, fluvial morphology studies, survey on basic processes and sedimentometric data interpretation (Porterfield, 1972).

Data, both daily and eventual, shall be duly listed for easy reference on outputs. The list shall have the following columns: number of sediment discharge and water discharge, ruler quota, cross-section width, area, average depth, average velocity, sediments concentration, values of water discharge, suspended sediment discharges, entrainment discharge or bed material and total (see Table 4.13). Besides such information, granulometric curves must be made available. Therefore, gross data are available for consultation and studies according to the intended purposes. Data may have a further processing, in order to become available for other studies.

Table 4.13 –Summary on sediment discharge measurement - Rio Aquidauana at Ponte do Grego (Carvalho, 1994).

Station: Aquidauana river at Ponte do Grego Code: 6692 6000

Measurement no. Sedim.	Water	Date	Level (m)	Width (m)	Area (m²)	Depth (m)	Veloc. (m/s)	Conc. (mg/l)	Discharges Water (m³/s)	Susp. sed. (t/d)	Bed sed. (t/d)	Total sed. (t/d)	
1	4	25.10.79	2,14	56,60	74,61	1,33	0,67	80,90	50,3	351,3	209,7	561,0	E
2	5	21.11.79	3,87	63,70	131,92	2,14	0,96	205,61	125,8	2240,0	5075,3	7310,0	E
3	6	04.12.79	2,79	69,50	121,19	1,73	0,85	147,07	88,0	1124,1	1485,9	2610,0	E
4	7	16.01.80	3,38	59,55	123,40	2,07	0,87	164,53	107,1	1522,9	3627,1	5150,0	E
5	8	05.02.80	2,66	58,15	103,13	1,77	0,82	130,82	84,2	952,2	1074,3	2072,0	E
6	9	02.03.80	4,50	65,80	203,54	3,10	1,15	188,55	233,7	3806,9	18524,1	22331,0	E
7	10	10.04.80	3,15	61,30	134,91	2,20	0,92	129,25	124,6	1391,4	1075,5	2467,0	E
8	11	03.05.80	2,62	58,40	98,16	1,68	0,79	193,88	77,1	1291,0	68,2	1359,0	E
9	12	16.06.80	2,38	55,80	88,47	1,60	0,70	237,90	62,5	1284,5	254,5	1539,0	E
10	13	11.07.80	2,30	56,20	76,30	1,35	0,71	352,57	54,4	1658,3	795,7	2454,0	E
11	14	05.08.80	2,15	53,40	71,10	1,30	0,66	38,07	47,6	147,1	575,9	723,0	E
12	15	06.09.80	2,01	54,90	63,46	1,15	0,62	64,39	39,1	218,2	180,8	399,0	E
13	16	14.10.80	2,47	57,25	83,47	1,45	0,76	1023,99	63,8	5647,3	991,7	6639,0	E
14	17	01.11.80	2,35	57,10	85,10	1,49	0,70	198,49	60,1	1070,1	79,9	1150,0	E
15	18	26.12.80	4,15	63,90	165,02	2,58	1,15	416,19	189,5	6813,4	6327,6	13141,0	E
16	19	20.01.81	3,92	65,20	171,61	2,63	0,51	772,25	86,8	5791,0	52,0	5843,0	MP
17	20	16.02.81	3,58	63,20	149,00	2,36	0,98	270,39	145,7	3404,2	5149,8	8554,0	E
18	21	02.03.81	3,69	62,50	151,35	2,42	1,01	248,49	152,9	3283,6	4962,4	8246,0	E
19	22	06.04.81	2,48	58,10	90,67	1,55	0,76	700,33	68,8	4161,1	265,9	4427,0	E
20	23	18.05.81	2,29	58,10	82,10	1,41	0,71	114,82	58,3	208,9	[illegible]	1030,0	E
21	24	04.07.81	2,28	57,30	85,94	1,49	0,67	112,45	57,1	554,5	360,5	915,0	E
22	25	05.07.81	2,25	57,25	84,17	1,47	0,67	117,27	56,2	569,3	1097,7	1667,0	E
23	26	02.09.81	2,11	56,50	71,36	1,26	0,67	124,56	47,6	512,4	371,6	884,0	E
24	27	04.09.81	2,10	56,60	71,10	1,26	0,68	66,22	48,3	276,2	342,8	619,0	F
25	28	26.11.81	2,11	56,60	65,38	1,15	0,64	94,08	41,7	338,9	208,1	547,0	E
26	29	30.11.81	2,10	55,90	65,30	1,17	0,63	76,66	41,9	277,5	199,5	477,0	E
27	30	21.01.82	2,46	57,90	87,75	1,52	0,69	628,24	60,7	3294,7	1271,3	4566,0	E
28	31	22.01.82	2,59	59,20	100,19	1,70	0,72	209,57	72,5	1312,9	980,1	2293,0	E
29	32	06.03.82	4,55	67,50	201,37	2,98	1,07	565,12	215,0	10497,0	460,2	11958,0	E
30	33	07.03.82	4,54	67,80	204,32	3,03	1,07	213,43	218,1	4039,3	1818,3	5858,0	E

Methods for computations of sediment discharges:
E - modified Einstein procedure; FK - Frijling-Kalinske; MP - Meyer-Peter

a) *Suspended sediment discharge*

Suspended sediment represents, for most cases, almost of total sediment discharge. For that reason, as well as for facilitating the determination, daily measurements, and most of eventual ones, contemplate just suspended sediment. The suspended discharge may correspond, on average, to 70 to 95% of total sediment discharge; that is in function of the cross-section position in water stream and other factors, as well.

The established concentrations do not correspond to the real value; it is a little lower, since the equipment does not reach the whole vertical depth of the sample, thus remaining a non-sampled zone, which presents higher concentration than the sampled part. Since suspended discharge is calculated as total water discharge, the value is partially corrected, rather than totally.

The computation for suspended discharge is performed by taking into consideration that sediment moves with the stream velocity, all along the cross-section, and therefore is equal to the product of water discharge by concentration. Considering the issue of units, which are not homogeneous for the same system, it is necessary to verify the adequate constant. For usual determinations in Brazil, the following equation is used:

$$Q_{ss} = 0{,}0864 Q.C \qquad (4.7)$$

where Q_{ss} is in t/day, Q is the water discharge in m^3/s and C the average concentration measured in mg/l or ppm. The constant refers to the unit conversion factor. The average concentration is obtained by using either EWI or EDI methods during sampling, and a single analysis is performed for the composite sample.

Suspended sediment discharge computation for punctual samples is performed by using the following equation:

$$q_{ssp} = 0{,}0864.c.v.\Delta p.l \qquad (4.8)$$

where

q_{ssp} = partial suspended sediment discharge in the influence position for the sampling point, in t day^{-1} m^{-1}
c = sediment concentration at the point, in mg l^{-1}
v = stream velocity at the sampling point, in m s^{-1}
Δp = depth (or height) of influence for the point being considered; it goes from half the distance to upper point until half the distance to the next lower point measure; extreme points will be considered up to surface and bottom, in m
l = partial width of influence (or width segment), up to half of each vertical position for punctual measurements; extreme verticals are considered until the bank, in m.

Vertical suspended discharge is the sum of partial punctual discharges. Average concentration c_{mv} in vertical is equal to:

$$c_{mv} = \frac{\sum q_{ssp}}{0{,}0864 \sum c.v.\Delta p.l} \qquad (4.9)$$

Punctual measurements for concentration, using fixed recorder equipment (turbidimeter, nuclear recorder, pumping or other) or daily samplings performed by the observer, require the calibration through regular measurement all over the section. Punctual concentrations of the recorder equipment are plotted in a graph in function of average concentrations of measurements all over the section. That graph allows for obtaining average concentrations in the section for other conditions of punctual measurement, as performed by the equipment, or the vertical average concentration, as performed by the observer.

Computation of integration vertical samplings is performed by using the following equation:

$$q_{ss} = 0{,}0864 q_i .c_{mv} \qquad (4.10)$$

where

q_{ss} = suspended sediment discharge for the segment, in t day^{-1} m^{-1}
q_i = water discharge for the segment, in m^3 s^{-1}
c_{mv} = average concentration in the vertical, in mg l^{-1}

Suspended discharge in the cross-section is the sum of discharges in the vertical. Average concentration C in the section is equivalent to:

$$C = \frac{\sum q_{ss}}{0{,}0864 \sum q_i .c_{mv}} \qquad (4.11)$$

b) *Bed sediment discharge and bed material discharge*

The bed sediment discharge represents only the smallest piece of total sediment discharge and is, in average, from 5 to 10%, sometimes reaching 30%. According to some authors, the instantaneous bed discharge may range from 2 to 150% of the suspended discharge (ICOLD, 1989). Therefore, such variation may be significant, thus justifying regular measurements for bed load, and not just for suspended discharge.

Due to the complexity of bed sediment discharge in Nature, it has been studied and there are several methods or formulas for determining it. Since it is made of thicker and heavier material, it may obstruct navigation channels, thus hindering the boats traffic. In reservoirs, the sediment becomes deposited on the backwater area, thus forming the delta usually with a volume much higher than the dead storage, diminishing regulation and capacity reserved for power generation. In small reservoirs, it is taken for granted that riverbed sediment will be held, and it may report a different distribution in relation to large reservoirs. Sometimes, that sediment may come to sediment a small reservoir in short time, or even during one single flood.

The sediment discharge for bed material corresponds to a value that includes entrainment discharge and a portion of the suspended discharge, which is made up by bed material.

c) *Bed discharge in direct measurements*

Direct measurement of bed sediment discharge is performed by using portable or removable measurers set on the bed, or fixed structures, such as wells or crevices. Portable equipment shall be measured in laboratory, in order to know its sampling efficiency.

Equipment is settled on 10 to 15 bed positions along the cross-section and held for a few minutes, in such a way that the recipient is filled in with no more than 30 to 50% of its capacity with bed sediment. If different punctual measurements are not coherent, it is useful to perform more than one sampling by point. All particles entering into the sampler recipient shall be collected through water skeet, transferred to a tray and, further, to a plastic bag (Figure 4.47). The sediment collected has its dry weight and granulometry determined in laboratory.

The computation formula is the following (WMO, 1981):

$$Q_{sa} = \frac{86{,}4}{E_r}\left(\frac{q_{sa1}}{2} x l_1 + \frac{q_{sa1} + q_{sa2}}{2} x l_2 + \ldots + \frac{q_{san-1} + q_{san}}{2} x l_{n-1} + \frac{qsan}{2} x l_n\right) \tag{4.12}$$

where

Q_{sa} = bed sediment discharge for cross-section, in t day^{-1}

E_r = equipment trap or sampling efficiency, value determined in laboratory, ranging from 0,40 to 1,00

q_{sai} = partial bed discharge, obtained from dry weight divided by measurement time and by the sampler entrance width in kg s^{-1} m^{-1}

l_i = distance between half the width of the measured point to half width of the other point, in m; extreme points will have their distances considered up to the bank.

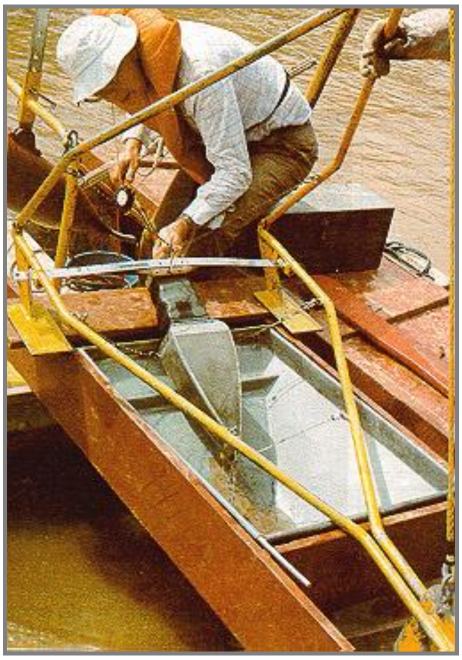


Figure 4.47 –Withdraw of sample in the entrainment discharge measurement using the sampler Arnhem. Coxim river, MS – IPH/UFRGS (02.03.1994).

Point measurements can be calculated through the following equation (Carvalho, 2008):

$$Q_{sa} = L \times q_{sa} = L \times \frac{1}{E_{am}} \times \frac{p}{n \times l \times t} = \frac{p \times L}{E_{am} \times n \times l \times t} \tag{4.13}$$

where

Q_{sa} = total bed sediment discharge in the cross section, in kg.min^{-1}
q_{sa} = point bed sediment discharge, in kg.m^{-1}.min^{-1}
L = total width in cross section, in m
E_{am} = equipment efficiency for sample
p = total dry weight, in kg
l = width of the mouth of sampler
t = time for each position, constant
n = number of measurement points sampled

d) *Bed discharge and bed material discharge in indirect measurements*

The most traditional indirect measurement is made through the collection of bed material samples, determination of water stream characteristics, and sediment granulometric analysis, allowing the computation of bed discharge or bed material discharge, through a given formula or methodology. Those processes are known as *formulas*. They must be accurately chosen, based on both local conditions for water streams and on theoretical development or application facility. Many formulas have been proposed, but none of them is totally satisfactory and applicable to a large range of circumstances (Cunha, 1968).

The selection of the most suitable formula is important for the accurate computation of total sediment discharge for water streams and estuaries, especially when electric power resources are involved, or in water streams where contaminant agents are associated to sediments (Stevens & Yang, 1989).

Stevens & Yang (1989) have selected formulas based on their theoretical support and level of application by either the author or other experts. According to that comparative study, the formulas considered as the most reliable ones were indicated in Table 4.14.

Table 4.14 – Summary of main formulas for calculating entrainment and bed material discharges, as presented by Stevens and Yang (1989).

Formula author	**Date**	**Bed sediment load movement (B) or Bed material characteristics (BM)**	**Kind of formula (1)**	**Kind of sediment (2)**	**Granulome try (3)**
Ackers and White	1973	BM	D	S	S, G
Colby	1964	BM	D	S	S
Einstein (bed load)	1950	B	P	M	S, G
Einstein (bed material)	1950	BM	P	M	S
Engelund and Hansen (*)	1967	BM	D	S	S
Kalinske	1947	B	D	M	S
Laursen	1958	BM	D	M	S
Meyer-Peter and Muller (*)	1948	B	D	S	S, G
Rottner	1959	B	D	S	S
Schoklitsch (*)	1934	B	D	M	S, G
Toffaleti	1968	BM	D	M	S
Yang (sand) (*)	1973	BM	D	O	S
Yang (gravel) (*)	1984	BM	D	O	G

(1) Deterministic (D) or Probabilistic (P);
(2) Granulometric fraction (S), composition or mixture (M) or optional (O);
(3) Sand (S) or Gravel (G);
(*) Considered as the most reliable by Stevens and Yang.

Another work, that is electronically available, was carried out by Lago and Paiva (1995), who selected several sediment transportation formulas.

Sediment discharge depends on several factors, such as hydrologic, geologic and climatic ones, thus turning difficult the selection of either the method or the formula. A given formula may be more accurate than another in its application. The selection of the adequate formula, according to Stevens and Yang (1989), may be performed according to the following criterion:

a. Establish the type of field data, available or measurable, within time, financial and human resources restraints;
b. Review all data and field efforts used for developing each formula, proceeding selection based on independent variables mentioned in *a*;

c. Compare field condition and restrictions of the selected formulas, according to *b*. If there is more than one formula suitable, calculate the sediment discharge value obtained for each and, then, compare results;
d. Decide which formulas are more suitable for the sediment discharge measured, using them for computations under runoff conditions that are not measured.

The following considerations may be made, if there are no direct measurements:

- Meyer-Peter and Muller formula is used when bed material presents granulometry over 0,4mm;
- Einstein formula, when the bed discharge is a significant part of the total sediment load;
- Toffaleti formula is suitable for large rivers with sandy beds;
- Colby (1964) formula is used for rivers deeper than 3m, and bed material with average diameter smaller than 0,8mm;
- Yang formula for sands is used with sandy bed;
- Yang formula for gravels is used when most of the bed material reports granulometry ranging from 2 to 10mm;
- Ackers & White and Engelund & Hansen formulas are for rivers with sand banks and sub-critical runoff;
- Laursen formula is for shallow rivers with fine sand or thicker silt.

Previously to the computer event, it was hard to work with such formulas, due to the great amount of computations involved. Therefore, it was necessary to choose in advance the formula to be used, and work with it until the end of the studies. Fortunately, the situation changed, and now the only requirement is to input the required data into a computer software, thus easily and quickly obtaining the results for several formulas. Therefore, the selection will be according to the engineer experience, which will properly manipulate all data after knowing the regimen and all characteristics of the measurement site in water stream.

The formulas indicated in Table 4.14 demand several hydraulic data and parameters, required by the software; some of them are already built-in. Data obtained during the water discharge measurement, the temperature by the measurement time, the bed material granulometry and the energy gradient slope are indispensable data. The characteristic diameters for D_{10}, D_{35}, D_{50}, D_{65} and D_{90}, as well as the percentages for several usual diameters or percentages of granulometric bands, among diameters, are obtained from the bed material granulometric curve. The critical tangential tension, particle drop velocity and other parameters are built-in the formulas that will be calculated according to granulometric characteristics, water temperature, water discharge and other data. The kinematics viscosity is obtained through the value of temperature.

The slope for energy line *S*, or energy gradient, shall be obtained in field, being one of the most difficult hydraulics measures because, generally, water surface is not parallel to the riverbed, neither is it a straight line. The following rules help in reaching the required accuracy:

- From a basic reference of level, determine the water line profile for a given water stream, in which the cross-section is included (500m or according to the reach slope); in that reach there should be no affluent or derivation;

- To choose two sections in the reach, one upstream and one downstream the main cross-section, 250m far one from another, (note: leveling shall be performed obeying the topography criteria, and there shall be a difference on water level in order to allow determining slope with the required accuracy, not necessarily 500m, as stated by this rule);
- Determine water level for each extreme section, repeating this operation at least three times and obtaining the average (sometimes, it is necessary to determine the water slope on both banks for better accuracy);
- Determine average velocity for both extreme sections, by using the reel (or surveying both cross-sections and determining average velocities by using the section discharge);
- Determine water line slopes upstream and downstream the cross-section, and compare to the slope of the entire main section; if difference is higher than 10%, select another reach;
- Calculate S through the formula:

$$S = \frac{(h_{upst} - h_{down}) + \dfrac{v^2{}_{upst} - v^2{}_{down})}{2g}}{L} \tag{4.14}$$

where,

$h_{upst} - h_{down}$ = difference between downstream and upstream WL's,
v_{upst} and v_{dowu} = average velocities of upstream and downstream sections,
L = distance between sections,
g = gravity acceleration constant.

Considering the need of determining that slope in each measurement, one of the following measures may be adopted:

- Install downstream and upstream national networks level references, definitive, that may assist the slope declivity;
- Install rulers upstream and downstream, taking into consideration the same references, in order to allow simultaneous readings during sediment discharge measures.

In the absence of determination for S in the field, one may use the Manning formula to calculate an approximate value, thus resulting in:

$$S = \left(\frac{Q.n}{A.R^{2/3}} \right)^2 \tag{4.15}$$

The value for hydraulic ray R is considered as equal to the river average depth, and the roughness coefficient value n is obtained in tables. For sand beds, with fine to medium granulometry, n ranges from 0,020 to 0,027; for sands from 1 to 2mm, the value of n ranges from 0,026 to 0,038, while for clays it is equal to 0,030 (Benson and Dalrympe, 1969).

Another way of determining S as an approximate value is the method suggested by Einstein (see USBR, 1955, and Carvalho, 1994). Equation 4.16 is used, and the value for x is established as ranging from 1,0 to 1,6; then, it is checked, by tentative, from equations 4.17 and 4.18 besides Figure 4.48 and, also, equation 4.19 besides Figure 4.49.

$$\sqrt{RS} = \frac{v}{18{,}01.\log\left(\frac{12{,}27.x.p}{D_{65}}\right)} = \frac{v}{7{,}822.Ln\left(\frac{12{,}27.x.p}{D_{65}}\right)} \quad (4.16)$$

$$u'_x = \sqrt{RS.g} \quad (4.17)$$

$$\delta = \frac{11{,}6.\upsilon}{u'_x} \quad (4.18)$$

$$x = f\left(\frac{D_{65}}{\delta}\right) \quad (4.19)$$

where
R – hydraulic ray considered as equal to depth, in m
v - stream average velocity, in m
p - average depth in the cross-section, in m
D_{65} – characteristic diameter for bed material, in m
g - gravity acceleration constant
υ - kinematics viscosity, in m^2/s

The results for S by this method are low; the Manning formula has proved to be more suitable.

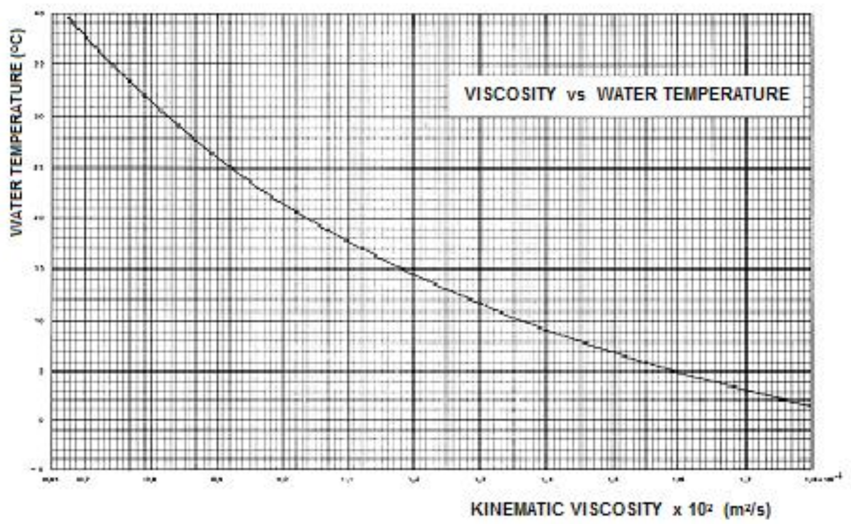


Figure 4.48 –Graphic representation of kinematics viscosity due to water temperature (USBR, 1955 modified for metric system by Carvalho, 1994)

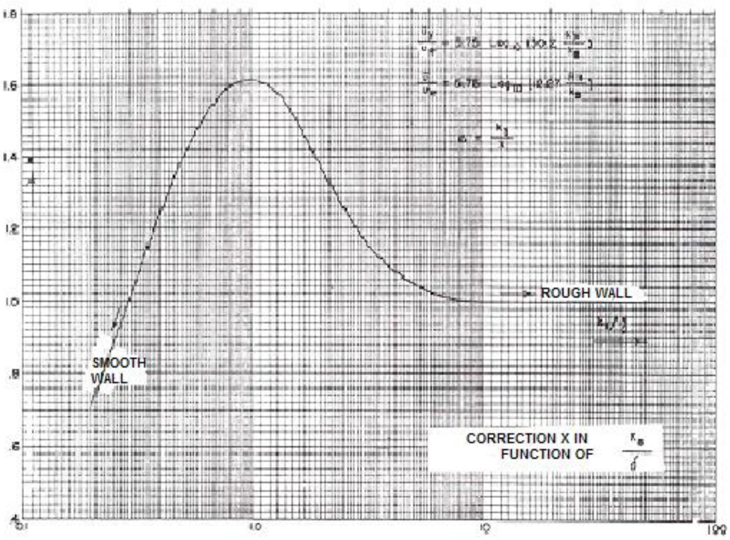


Figure 4.49 – Values of x in function of D_{65} (USBR, 1955).

Other values and parameters are required for using the several formulas for calculating bed sediment or bed material discharges. The value of the average diameter of particles used for some formulas is calculated through equation 4.20:

$$D_m = \sum_{i=1}^{m} D_{si} . i_t \qquad (4.20)$$

where:
D_m = average diameter of the particles;
D_{si} = geometric average diameter between two diameters within a band;
i_f = granulometric fraction between two diameters, usually presented as %.

According to ICOLD (1989), the selection of the method to be used for calculating bed load shall be performed when the sediment sampling program is planned. A convenient guidance for choosing or adjusting computations is provided by Table 4.15. The table shows that bed discharge depends on concentration and granulometry of suspended sediment and bed material.

Table 4.15 – Guidance for choosing or correcting the bed discharge (ICOLD, 1989).

Condition	**Concentration of suspended sediment (mg/*l*)**	**Riverbed material**	**Granulometry of suspended material**	**Percentage of bed discharge as a function of suspended discharge**
1 (*)	< 1.000	Sand	20 to 50% of sand	25 to 150
2 (*)	> 1.000 a 7.500	Sand	20 to 50% of sand	10 to 35
3	> 7.500	Sand	20 to 50% of sand	5
4 (**)	Any concentration	Compacted clay, gravel, rolled flints or rocks	Small amount of sand up to 25%	5 to 15%
5	Any concentration	Clay and silt	No sand	< 2

(*) Under these conditions, special sampling programs for computation through Einstein modified method are required.
(**) A bed sediment measurer, such as the Helley-Smith may be used; the bed discharge may also be obtained through formulas when bed material is gravels or rolled flints.

e) *Total sediment load*

Total sediment discharge is the amount required for most sedimentological studies. It is usually obtained by summing up suspended discharge and bed discharge; however, there are several implications for that simple procedure. Table 4.16 displays a diagram obtained from several authors (see Carvalho, 2008), indicating criteria for obtaining total sediment discharge.

Table 4.16 –Schematic diagram for classifying sediment load for its quantitative obtainment (modified by Carvalho (2008) from schedules of several authors).

	Based on granulometry	**Based on the bed runoff efficiency and on granulometry**	**Based on transportation means**	**Based on quantification method**	**Based on sediments sample**
	1	2	3	4	5
Total Sediment Load	Fine load + Suspended bed material load + Bed load	Fine load + Bed material load	Suspended load + Saltation load + Bed load	Measured load + Non-measured load	Suspended load sampled + Non-sampled suspended load + Bed load

Therefore, one may obtain the value for total sediment discharge following these main processes:

- By summing up suspended discharge and the bed discharge and an additional parcel that takes into consideration the non-sampled discharge; this parcel is obtained from studies on suspended and bed material, which allow for obtaining adjustment coefficients;
- By summing up fine material discharge and bed material discharge;
- Through computation process, with Einstein modified method, requiring samplings and granulometric analyses of both suspended and bed sediments (this method was converted into the metric system by Otto Pfafstetter and Carvalho); through Colby simplified method as well, of 1957, which was converted into the metric system by Carvalho (1981, 1994, 2008). There is software for both methods, available at ANEEL, ANA and on Carvalho (2008);
- For topo-hydrographic survey on a large reservoir and computation of aggraded volume, thus obtaining the average total discharge, it is necessary the knowledge, or an adjustment factor, that takes into consideration the sediment being carried by water runoff at downstream.

The use of Colby simplified method shall not be indiscriminately performed, without a proper study on its applicability. It would be useful if part of measurements, at least 10%, be performed using a reliable method, such as, for example, Einstein modified procedure, in order to allow for calibration and adjustments for values calculated through Colby method.

f) ***Data processing for daily observation***

Daily data are obtained through punctual measurement equipment installed in fixed position, or by sampling performed by the station observer. Both procedures measure suspended discharge and require calibration from regular measurements performed by hydrometry teams. Those calibrations must be annually performed, or at any other period, since turbidity and concentration vary several times along the section.

The punctual measurement equipment may be a recorder turbidimeter, whose turbidity measurement sensor is installed nearby the bank. Periodically, in eventual measurements, hydrometry experts shall perform sampling along the section, in order to determine the section average concentration. The different values obtained along a period shall be correlated to turbidity; each value is to be obtained from the register for the same eventual measurement.

Another equipment, nuclear, ultra-sonic or pumping, may also be installed on the bank for punctual measurement; the value will be measured by the sensor, in correlation to concentration. A laser sampler can be used for efficient measurements.

Measurement performed by observer consists of a sampling at the thalweg position. Calibration procedure is the same as presented above.

Daily data gaps may be studied based on the preparation of a rating curve on sediments, $Q_s = f(Q)$ or $C = f(Q)$, and filled in based on values for Q_s calculated with the value for Q. They may also be filled in by tracing a graph on concentrations (sedimentgraph), also plotted with daily discharges (fluviograph) in relation to time.

Daily average values for sediment discharge are set in a spreadsheet (bulletin) together with daily average discharges. The computation of suspended discharge is made through equation 4.7. The bulletin is prepared for the hydrological year, or civil year, and monthly summaries shall be prepared (total, medium, maximum and minimum) and annual summary (total and average annual transportation, annual maximum and minimum transportation for suspended discharge and concentration, contribution or production of specific sediment discharge, total annual runoff and specific discharge). For illustration purposes, a part of the CEMIG, a brazilian company, an annual bulletin is presented in Table 4.17.

Table 4.17 – Semi-annual bulletin on suspended discharge–São Francisco River at Porto das Andorinhas, Brazil – Hydrological year 1981/82 (CEMIG).

Bacia do Rio São Francisco Posto nº 4010001 Área de Drenagem - 13300 km² Lat 19°18' Long 45°17'
Ano Hidrológico - 1981/82

DIA	OUTUBRO		NOVEMBRO		DEZEMBRO		JANEIRO		FEVEREIRO		MARÇO		DIA
	Descarga Líquida m^3/s	Descarga Sólida t/di	Descarga Líquida m^3/s	Descarga Sólida t/dia	Descarga Líquida m^3/s	Descarga Sólida t/dia	Descarga Líquida m^3/s	Descarga Sólida t/dia	Descarga Líquida m^3/s	Descarga Sólida t/dia	Descarga Líquida m^3/s	Descarga Sólida t/di	
01	60,5	159	214,0	7867	328,0	14087	709,0	24000	1070,0	12100	442,0	13025	01
02	66,,0	5744	209,0	7900	407,0	16166	672,0	20568	1040,0	12376	445,0	12331	02
03	83,2	594	179,0	6153	453,0	14653	670,0	17172	1020,0	14183	456,0	11157	03
04	78,0	270	160,0	4274	578,0	16680	677,0	15878	1010,0	10129	486,0	18010	04
05	79,3	280	166,0	3841	545,0	19589	690,0	64228	995,0	9024	482,0	14240	05
06	84,5	826	202,0	4564	540,0	19581	721,0	60801	978,0	11803	495,0	13107	06
07	101,0	465	273,0	10864	542,0	15806	735,0	26035	963,0	10235	514,0	18551	07
08	108,0	484	284,0	11677	528,0	12672	757,0	24315	949,0	15686	574,0	41663	08
09	94,,9	408	245,0	11377	507,0	10414	777,0	20515	937,0	13262	566,0	18819	09
10	101,0	465	227,0	8345	576,0	10545	791,0	17248	923,0	6113	607,0	19130	10
11	128,0	763	324,0	20073	564,0	9047	807,0	16385	905,0	15619	637,0	17602	11
12	163,0	1267	280,0	7285	632,0	9569	842,0	16761	891,0	14945	675,0	46383	12
13	177,0	9818	358,0	9037	662,0	12278	868,0	16447	876,0	12904	732,0	41484	13
14	192,0	1785	505,0	34526	687,0	15413	862,0	15780	856,0	12327	805,0	40400	14
15	286,0	4113	540,0	36956	704,0	12944	862,0	20889	830,0	12704	810,0	29837	15
16	383,0	7582	590,0	33269	715,0	28036	859,0	19474	799,0	12295	827,0	24432	16
17	403,0	8436	566,0	31314	732,0	29451	853,0	23702	757,0	12205	859,0	20481	17
18	412,0	8835	521,0	21231	754,0	31336	847,0	20261	712,0	12576	876,0	18687	18
19	412,0	8835	509,0	21712	774,0	31102	850,0	18200	665,0	12387	897,0	18568	19
20	373,0	7174	500,0	18232	788,0	34369	888,0	20270	617,0	13211	897,0	16349	20
21	316,0	5068	530,0	18496	799,0	35381	946,0	22408	571,0	15076	897,0	13949	21
22	309,0	4836	574,0	35079	807,0	36128	940,0	18337	528,0	15317	926,0	15156	22
23	316,0	5068	564,0	23645	813,0	36692	952,0	15271	489,0	13587	978,0	8794	23
24	267,0	3561	547,0	23732	813,0	36692	978,0	19312	462,0	12305	1010,0	10993	24
25	202,0	1985	500,0	19344	810,0	36409	1010,0	14462	445,0	12092	1060,0	12703	25
26	157,0	1171	533,0	33321	810,0	36409	1090,0	29030	431,0	10946	1020,0	9154	26
27	132,0	2774	442,0	15127	819,0	37262	1130,0	21049	429,0	8982	978,0	9065	27
28	125,0	726	405,0	8959	816,0	36977	1170,0	14710	441,0	11526	946,0	7244	28
29	152,0	1094	381,0	8995	785,0	34095	1170,0	10081	0,0	0	926,0	8076	29
30	174,0	1452	348,0	8784	743,0	30386	1140,0	7396	0,0	0	908,0	12701	30
31	192,0	1785	0,0	0	715,0	28036	1100,0	7305	0,0	0	894,0	10865	31
TOT	6122,4	97822	11676,0	505980	20746,0	750475	27363,0	658287	21595,0	345914	23625,0	572955	TOT
MED	197,5	3156	389,2	16866	669,2	24209	882,7	21235	771,3	12354	762,1	18482	MED
MAX	412,0	9818	590,0	36956	819,0	37262	1170,0	64228	1070,0	15686	1060,0	46383	MAX
MIN	60,5	159	160,0	3841	328,0	9047	670,0	7305	429	6113	442,0	7244	MIN

SUMÁRIO ANUAL

Transporte Total Anual	3746731t	Deflúvio Total Anual	13412 10**6 m^3
Máximo Transporte Diário	64228t	Transporte Médio Anual	10265t/dia
Mínimo Transporte Diário	87t	Escoamento Específico	32 $l/s/km^2$
Máxima Concentração Anual	1077mg/l	Contribuição de Sedimento	$282 t/km^2$.ano
Mínima Concentração Anual			

Translation for eventual use:

Transporte total anual = annual total transportation Máximo transporte diário = maximum daily transportation Mínimo transporte diário = minimum daily transportation Máxima concentração anual = maximum annual concentration Mínima concentração anual = minimum annual concentration	Sumário anual = annual summary Deflúvio total anual = annual total runoff Transporte médio anual = annual average transportation Escoamento específico = specific runoff Contribuição de sedimento = sediment contribution

g) *Data processing for eventual observation*

Eventual data are periodical measurements performed by the hydrometry expert within an entity program. In Brazil, such measurements, in general, are calculated following the procedure indicated herein and duly listed by chronological order. Data processing includes tracing the sediment rating curve, determining equations and preparing annual bulletins on sediment discharge. Those bulletins are obtained from average daily water discharge bulletins and sediment equations.

Sediment rating curve tracing requires special cares, since there is a huge dispersion of data obtained. The same sediment discharge flow may range from 10 to 100 or above. Several factors may influence the tracing, and the main ones derive from several phenomena, such as the erosion process, seasonal variation, time between sediments concentration peak and discharge peak, and extreme events of huge floods. For years of extreme rains, sediment production may be very high, thus affecting the rating curve. Insufficient data may also affect the remaining data (Glysson, 1987).

Such curves may be traced for seasonal periods or time periods. Usually, they are traced in bi-logarithmic scale, and one may obtain an interpolated line between the points may be obtained, or straighter line, according to the points trend (Figure 4.50). Special care must be taken when a large number of points are concentrated on a variation band, thus mathematically influencing over the curve direction.

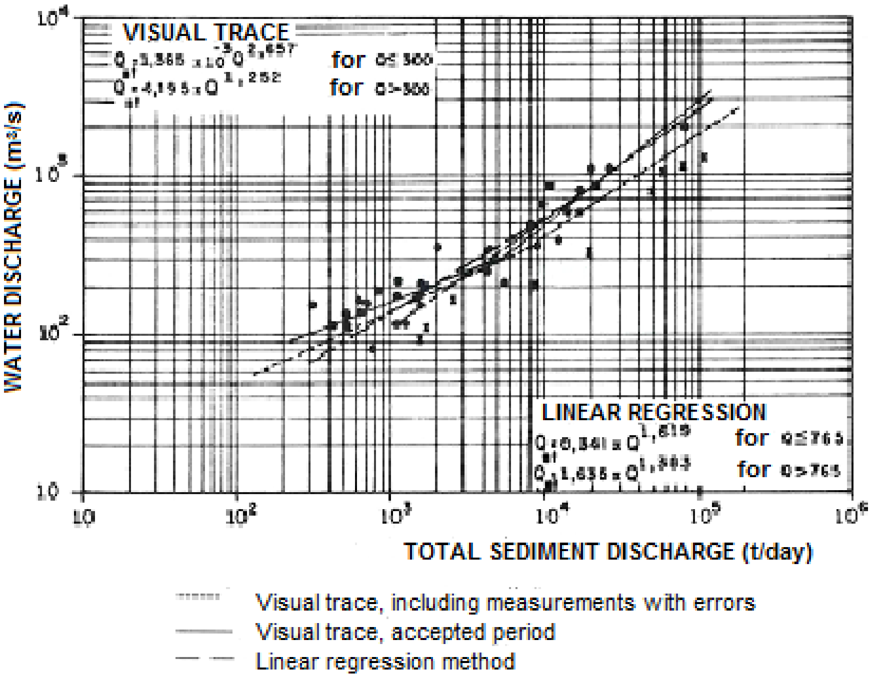


Figure 4.50 – Sediments transportation rating curve for Cuiabá River in Cuiabá, measurements for 1977 to 1981 (Carvalho, 1994).

Once having the equation for the sediments rating curve, then one may obtain, from flow bulletins, the sediment discharge bulletin for the valid period of the curve. If values are reliable, the results shall lead to reliable parameters. The process for obtaining such parameters is similar to that presented in Table 4.17.

For a reservoir sedimentation survey, it is useful to have the monthly average long-term flows (Table 4.18), and the sediments rating curve equation may be used for obtaining total or suspended sediment discharges (monthly average - Table 4.19).

Table 4.18 – Natural flow series for Manso river at Porto de Cima, Brazil (Carvalho, 1994).

Série de vazões naturais (m³/s).

ANO	JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	NOV	DEZ	MED
31	191	256	259	195	129	92,8	65,7	61,5	47,3	161	162	184	150
32	232	217	333	149	111	104	72,3	93,3	58,5	109	121	228	152
33	369	355	190	250	114	83,4	70,5	61,6	66,2	71,7	96,8	166	158
34	200	308	333	215	108	81	67,5	54,2	90,5	77,2	102	238	156
35	360	439	371	440	180	114	94,2	83,5	73,6	90,1	134	190	214
36	215	198	245	123	91,1	70,7	60,9	53,2	50,9	55,4	117	183	122
37	200	195	239	313	118	91,5	67,9	55,3	53,2	82,1	114	170	142
38	258	218	255	172	91,3	74,2	60	51,1	75,8	72,8	76,7	169	131
39	146	342	149	129	87,7	68,9	58,3	49	45,6	82,7	157	255	131
40	366	375	397	225	149	93,8	80	69,6	65,8	82,1	108	128	178
41	265	287	212	178	88,7	72,9	59,9	56,2	50	78,6	116	121	132
42	144	356	545	262	122	95,1	82,9	68,3	74,3	86,3	105	120	172
43	393	262	527	264	95,1	90,3	79,5	66,5	64,3	115	249	233	203
44	157	256	213	168	91,5	75,7	59,7	49,2	44,4	77,5	206	176	131
45	320	568	429	416	155	113	95,1	79,8	72,2	89,5	144	220	225
46	241	449	359	205	143	96,3	83,5	68,7	59,6	73	126	173	173
47	211	290	272	279	134	88,8	70,9	84,9	63,9	179	154	225	171
48	203	288	294	168	94,4	77,3	82,8	53,8	80,2	161	198	290	166
49	360	479	296	156	119	99,2	89	81,4	77,3	102	119	242	185
50	282	266	505	330	132	106	93	83,9	78,1	107	149	193	194
51	365	227	293	217	117	100	84,9	77,6	74,9	88,6	120	197	164
52	231	283	428	267	123	101	89,5	80,8	80,2	82,2	102	186	171
53	218	320	342	219	123	95,6	85,7	77,8	91,7	95,8	101	201	164
54	183	353	380	241	159	108	92,4	83,3	84,1	88,4	156	129	171
55	371	244	320	351	136	109	93	84,3	77,7	92,8	99,6	164	179
56	234	241	227	258	186	124	98,8	86,8	88	100	225	287	180
57	308	410	379	294	138	113	100	87,8	99,6	122	183	215	204
58	234	338	215	264	154	88,5	99,2	63,3	72,2	158	187	287	180
59	380	305	502	229	155	119	103	93	87,1	99,9	151	128	196
60	396	581	343	354	175	120	105	93,2	85,4	105	175	201	228
61	345	411	346	168	146	106	93,7	84,3	81,8	98,1	110	126	176
62	306	292	207	161	104	94,2	81,1	76,7	80	83,3	91,6	261	153
63	251	381	218	145	103	85	77,1	68,7	64,8	66,9	114	96,2	139
64	146	179	165	106	87,9	59,7	52,8	47,4	43,8	104	154	158	109
65	226	312	396	229	124	91,1	78	65,9	60,8	94,9	96,8	141	160
66	115	387	178	110	88,9	70	59,8	53,8	53,7	83,7	94	97,4	116
67	124	237	224	196	115	74,6	60,8	52,8	49,5	61,9	96,1	119	118
68	129	449	296	116	91,7	72,6	62,3	60,1	67,7	90,4	78,1	212	144
69	267	198	184	118	95	67,6	58	51,2	49,5	76,7	107	129	117
70	171	380	382	141	106	77,7	66,4	56,7	57	79,3	81,6	109	142
71	125	169	186	108	85,8	68,8	58,7	53,3	56	91,8	131	152	107
72	171	378	161	138	86,9	74,2	67,2	60,2	57,3	76,9	110	255	136
73	277	217	140	139	113	73,1	64,4	59,1	60,5	84,5	193	164	132
74	297	254	714	353	151	106	85,4	76,2	75,4	106	96,7	180	208
75	240	302	210	293	156	110	92,8	70,9	71,3	79,5	228	239	174
76	172	380	312	196	160	117	84,2	74,2	81	111	144	218	171
77	414	408	225	231	151	106	81,6	73,7	77,6	92,1	126	248	186
78	386	222	333	169	123	99,3	80,8	71,9	78	109	119	451	187
79	569	455	428	284	168	110	93,5	80,6	86	86,7	91,4	209	222
80	453	647	492	209	136	99,7	85,9	72,4	79,3	79	103	265	227
81	451	279	411	219	141	116	98,1	87,6	85,1	111	165	214	198
82	397	436	395	292	142	112	96	91,4	111	98,4	116	143	202
83	330	381	248	193	116	106	86,7	79,6	77,9	101	234	417	198
84	249	268	253	233	172	107	88,7	89,4	96,6	108	136	342	179
85	498	267	365	252	146	102	89,9	82,2	87,1	114	100	116	185
86	348	338	267	134	129	84,6	76,4	77,8	82	91	98,2	315	170
87	273	230	269	256	130	91,3	76,3	69,8	68,3	84,9	127	289	164
88	404	351	363	252	130	99	83,4	75,3	74,1	83,5	108	162	182
89	199	266	220	148	111	103	100	98	97	101	112	144	142
90	242	359	336	185	113	99	93	90	92	95	110	151	164
91	352	610	578	299	210	186	170	159	166	216	114	137	266
92	284	297	301	274	218	187	177	172	178	194	213	280	231
MED	278	330	317	221	129	97,1	83,3	74,8	75,5	99,0	133	201	170
MÁX	569	647	714	440	218	187	177	172	178	216	249	451	
MÏN	115	169	140	106	85,8	59,7	52,8	47,4	43,8	55,4	76,7	96,2	

Table 4.19 – Total monthly sediment discharge average in Manso river at Porto de Cima, Brazzil (Carvalho, 1994).

Descarga sólida total média mensal (t/dia).

ANO	JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	NOV	DEZ	MED
31	2671	4783	4890	2814	992	432	181	153	79	1736	1763	2431	1910
32	3971	3500	7861	1428	679	576	230	438	135	649	844	3843	2013
33	9544	8871	2636	4573	727	330	216	154	184	226	481	1875	2485
34	3000	6783	7861	3439	634	307	194	111	406	272	549	4168	2310
35	9109	13252	9642	13309	2300	727	449	331	241	401	1092	2636	4457
36	3439	2925	4402	880	413	218	149	106	95	118	776	2398	1327
37	3000	2814	4201	6993	793	417	197	117	106	317	727	1991	1806
38	4854	3531	4748	2051	415	246	144	96	259	234	267	1962	1567
39	1356	8268	1428	992	375	204	134	86	72	323	1629	4748	1635
40	9398	9839	10958	3748	1428	444	297	209	182	317	634	973	3202
41	5106	5936	3349	2236	386	235	143	122	91	284	759	844	1624
42	1310	8919	19941	4997	862	460	325	200	247	360	590	827	3253
43	10751	4997	18715	5069	460	404	293	187	171	743	4539	4004	4194
44	1629	4783	3379	1932	417	259	142	87	67	274	3172	2173	1526
45	7291	21561	12687	11970	1577	711	460	295	230	395	1310	3592	5173
46	4267	13828	9061	3143	1287	475	331	202	141	236	935	2081	2999
47	3319	6054	5364	5627	1092	387	219	345	169	2268	1552	3748	2512
48	3086	5975	6213	1932	451	273	324	109	299	1736	2925	6054	2448
49	9109	15625	6293	1603	810	512	389	311	273	549	810	4301	3382
50	5742	5142	17267	7728	1052	605	435	335	280	619	1428	2742	3615
51	9349	3811	6173	3500	776	522	345	275	252	385	827	2888	2425
52	3939	5781	12631	5179	880	535	395	305	299	318	549	2498	2776
53	3531	7291	8268	3561	880	466	354	277	420	468	535	3028	2423
54	2398	8777	10089	4267	1682	634	428	329	337	382	1603	992	2660
55	9642	4368	7291	8683	1134	649	435	339	276	432	517	1818	2965
56	4036	4267	3811	4854	2498	898	506	365	378	522	3748	5936	2652
57	6783	11646	10039	6213	1176	711	522	376	517	862	2398	3439	3724
58	4036	8086	3439	5069	1552	384	512	165	230	1655	2532	5936	2800
59	10089	6659	17073	3875	1577	810	562	435	368	521	1476	973	3702
60	10906	22503	8313	8824	2142	827	590	437	351	590	2142	3028	5055
61	8405	11700	8451	1932	1356	605	443	339	314	497	664	935	2970
62	6700	6133	3202	1736	576	449	308	267	297	329	418	4961	2115
63	4608	10139	3531	1333	562	346	271	202	175	189	727	473	1880
64	1356	2268	1847	605	377	142	104	79	65	576	1552	1655	886
65	3779	6951	10906	3875	898	413	279	182	149	457	481	1242	2468
66	742,7	10443	2236	664	388	212	143	109	109	333	447	488	1360
67	898,2	4134	3716	2851	743	249	149	104	89	156	472	810	1198
68	992,4	13828	6293	759	420	233	158	144	195	405	280	3349	2255
69	5179	2925	2431	793	459	194	132	96	89	267	619	992	1181
70	2021	10089	10189	1242	605	276	186	125	126	291	313	649	2176
71	916,6	1962	2498	634	355	203	136	107	121	421	1032	1501	824
72	2021	9989	1736	1176	366	246	192	145	128	269	664	4748	1807
73	5551	3500	1220	1198	711	237	172	139	147	341	2742	1818	1481
74	6333	4713	33220	8777	1476	605	351	263	256	605	480	2300	4948
75	4234	6536	3290	6173	1603	664	432	219	222	293	3843	4201	2642
76	2051	10089	6951	2851	1709	776	338	246	307	679	1310	3531	2570
77	11862	11539	3748	3939	1476	605	313	242	275	424	935	4505	3322
78	10392	3654	7861	1962	880	513	305	227	279	649	810	13944	3456
79	21633	14179	12631	5819	1932	664	441	303	357	364	416	3260	5167
80	14062	27576	16436	3260	1134	518	356	231	291	288	562	5106	5818
81	13944	5627	11700	3561	1242	759	497	374	347	679	1847	3409	3666
82	10958	13081	10854	6133	1264	695	471	416	679	501	759	1287	3925
83	7728	10139	4505	2742	759	605	364	294	278	535	4036	12025	3667
84	4539	5216	4678	4004	2051	619	386	393	478	634	1134	8268	2700
85	16817	5179	9349	4643	1356	549	399	318	368	727	522	759	3416
86	8544	8086	5179	1092	992	342	265	277	316	411	499	7078	2757
87	5401	3907	5252	4783	1012	415	264	211	200	345	954	6015	2397
88	11326	8683	9253	4643	1012	509	330	255	245	331	634	1763	3249
89	2962	5142	3592	1404	679	562	522	496	483	535	695	1310	1532
90	4301	9061	7996	2464	711	509	435	400	423	459	664	1476	2408
91	8730	24673	22284	6414	3290	2498	1991	1682	1875	3470	727	1155	6566
92	5819	6333	6495	5438	3531	2532	2204	2051	2236	2778	3379	5666	4039
TOT 10^3	381	518	492	239	67	33	23	18	19	37	78	199	175
MED	6153	8356	7928	3861	1087	539	375	294	308	604	1254	3203	2830
MÁX	21633	27576	33220	13309	3531	2532	2204	2051	2236	3470	4539	13944	
MÏN	742,7	1962	1220	605	355	142	104	79	65	118	267	473	

h) *Errors and consistency analysis*

The approach for estimating sedimentometric data accuracy is hard due to the several stages required for obtaining the sediment discharge, and an adequate methodology for the consistency analyses. Errors may be due to the mistakenly selection of equipment, or to defective equipment; error on sampling operation; error due to flow measurement that shall become reflected on computation and even on sampling; errors on sediment analysis, as well as error concerning the selection of the due formula for bed or total discharge. There are even the errors on placement of comma or dot for the obtained result. Accrued errors may result in a significant difference, thus compromising data quality. Usually, sedimentometric data are disseminated with no verification of errors incurred, or information on the accuracy of methodologies used, because there is no correct methodology for consistency analysis available, especially for data on a week frequency of measurements.

According to Burkham (1985), the required accuracy for distinct uses of sedimentometric data differs. For example, for geo-morphological studies it is required a magnitude for result, while during analysis on environmental impacts, it is required that information has the desired accuracy for performing correct studies.

Few sediment data, in terms of operation frequency, may lead to obtaining inadequate parameters. Data on eventual operation shall comprise the entire variation of water level and gaging station drainage, as well as the drought period and, above all, rainy periods. It is essential to have suitable parameters for surveys. Therefore, one may reach the conclusion that even good data, if not obtained with the proper frequency, would lead to correct studies.

Some likely mistakes may be abolished if the necessary care is taken by field work and laboratory teams. For example, equipment shall be tested previously to trip, samples collected in several verticals shall have a coherent graduation (a sub-sample with many sediments in relation to the other shall lead to a sampling on that vertical), and so on. One may conclude that major errors must be eliminated by adopting several careful measurements in both field and laboratory.

During data processing, when preparing a sediment rating curve and verifying the dispersal of incoherent points, the operator shall not just disregard data; rather, he shall review all documentation for each measurement before disregarding it. The points very far from the average curve and that may be introducing errors are the ones to be disregarded, after being verified.

By the use enough measurements for this, one can see about the consistency of data through the tracing of a double accumulation curve and the sediment rating curve presenting a high R^2.

4.4.2 *Data availability (The case of ANA and ANEEL)*

Upon the evolution of legal and institutional framework for water resources management in Brazil, up to the creation of ANA, National Agency for Water, mainly in face of the new regulation as per Federal Law nº 9.433, of January 1997, the management of water bodies by hydrographic basins tends to intensify. Therefore, access to quality, quantity, speedy and easily understandable pieces of information are mandatory requisites for technically subsiding and expediting the decision-making processes for managerial entities.

The baseline is that the strategic value of information lays on its availability to society, thus providing transparence and legality to decision-making processes. Regarding water as a very important input for several economic activities, the investment options are democratically displayed when providing unrestricted information about that natural resource, besides favoring greater development and participation of civil society in the management of such resources.

In order to make available pluviometric, fluviometric, hydro-sedimentometric data, as well as data on water quality for hydrometric network managed by ANA, a System called Hidroweb was developed (http://hidroweb.ana.gov.br) where all data bases may be acquired by anyone (Figure 4.51). This System was previously initiated by ANEEL which had the responsibility of the operation of the national hydrometric network before the creation of ANA.

Figure 4.51 – Homepage HidroWeb System (hidroweb.ana.gov.br).

The HidroWeb System is an applicative developed in order to facilitate access to ANA's historical data bank: quotas, rains, discharges, water quality and sediments concentration. For those, the SIH technical team (Superintendency for Technological Information) structured a way of making available information supported by maps locating rivers and stations, either operational or that have already been operated. Therefore, users interested just on sedimentometric historical data, and who needs a spatial view on the gaging station and the relevant river reach sites, may be geographically oriented based on on-line maps existing on the site of SNIRH Portal - National Information System for Water Resources. (Figure 4.52). The SNIRH is an instrument of the Law 9.433/97, the name "Water Law" establishing the National Water Resources Policy in Brazil. It is a comprehensive system for collecting, processing, storage and retrieval of information on water resources and stakeholders for their management factors. In this Portal are available Hydrological Monitoring System (www.ana.gov.br/telemetria) in which data is inserted the Joint Resolution 3/2010 between the ANA and the ANEEL, establishes the conditions and procedures to be followed by dealers and authorized hydroelectric power generation in Brazil for the installation, operation and maintenance of hydrometric stations aimed at monitoring rainfall, river, sedimentometric and water quality associated with hydroelectric (Figure 4.53) the National Register of Users of Water Resources (CNARH) and several maps (for grants, field watercourses, urban water supply, etc.).

Other means constantly used by ANA for making data and information available are, as follows: issuance of books and midias; exhibitions in events; e-mails, mails and telephone.

Figure 4.52 – Homepage SNIRH portal (www.snirh.gov.br).

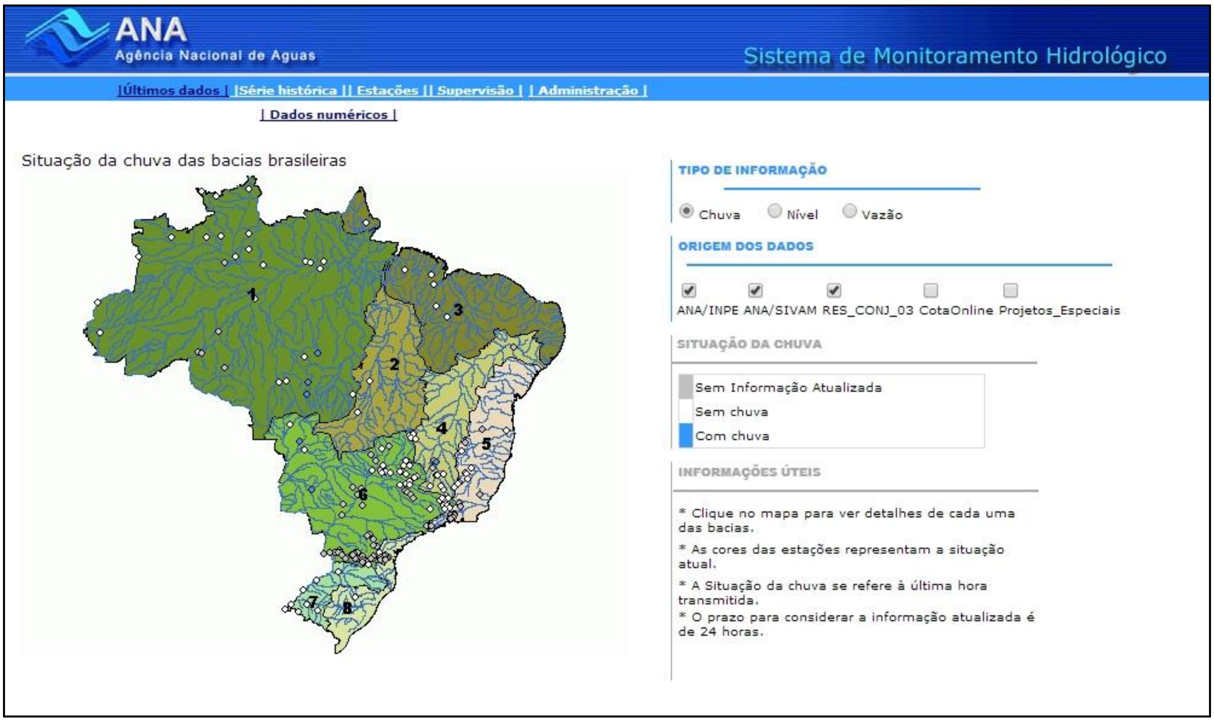


Figure 4.53 – Homepage Hydrological Monitoring System (www.ana.gov.br/telemetria).

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GLOSSARY OF TERMS, SYMBOLS AND UNITS

- ARGYLE or CLAY – particles of sediments smaller than 0,004mm, according to AGU classification. According to ABNT, argyle means particles with granulometry lower than 0,005mm.
- BED or BOTTOM – the bed or floor of a water stream, reservoir or lake.
- BED DISCHARGE SAMPLER – equipment for directly measuring the bed discharge for a part of all the water stream width.
- BED LOAD –Sediment that moves by jumping, rolling or sliding along or nearby the streambed
- BED MATERIAL- material composing the riverbed, usually made of fragmented rocks.
- BED MATERIAL DISCHARGE– the quantity of sediment passing through a cross-section corresponding to bed material particles in movement, both suspended and at the bed.
- BED MATERIAL SAMPLER – equipment for collecting a sediment sampler of the sediment that composes the bed.
- BED SEDIMENT DISCHARGE (usually called as entrainment sediment discharge) – the quantity of bed sediment passing through a cross-section in a time unit.
- CLAY – see ARGYLE
- COBBLESTONE – particles of sediment with dimension ranging from 4096 to 256 mm, according to AGU classification.
- COMPOSITE SAMPLE – a sample made up by the combination of all individual samples, or sub-samples, belonging to a suspended sediment measure performed by the process of equal width increment or equal discharge increment.
- CONTACT LOAD – sediment particles that rolls or slides longitudinally, being almost in permanent contact with bed.
- DENSITY OF SEDIMENT-WATER MIXTURE – mass by volume unit, including water and sediment.
- FINE MATERIAL LOAD or WASH LOAD – that part of the total sediment load that is made up of granulometry whose presence is not in significant quantities at the bed sediment, and consisting of material finer than the bed material. Usually, the fine material load is made up by particles smaller than 0,062mm; nevertheless, it is a function of load being transported by the river.
- FLUVIAL SEDIMENT – all solid materials transported by river water and reporting an average density close to the one for fragmented rocks: 2,65.
- GRAVEL – particles of sediment ranging from 64 to 2mm according to AGU classification. According to ABNT, gravels are with granulometry ranging from 76 to 4,8mm.
- NON-MEASURED SEDIMENT DISCHARGE – the quantity of sediment load that the sampler could not sample.
- NON-SAMPLED ZONE – distance from the sampler nozzle to the bottom of the river, in a sampling vertical, and that is not sampled; part of the cross-section that is not covered by the sediment sampling.
- PARTICLE DIAMETER or SIZE – linear dimension used for characterizing the size of a given particle. The diameter may be determined by any of the several techniques, including sedimentation, shaking, micrometric measures or direct measures.
- PUNCTUAL INTEGRATION – method that allows for obtaining a sample that represents the average sediment concentration for the river discharge, passing by a point during the sampling time.
- PUNCTUAL INTEGRATION SAMPLE – mixture water-sediment continuously accumulated in a sampler set on a point relatively fixed in a river section, and that admits the mixture in a velocity almost equal to the instantaneous velocity of the stream on a given point.
- SALTATION LOAD – sediment that longitudinally jumps along the water stream due to flow impact or other particles.

- SAND – sediment particles with granulometry ranging from 0,062 to 2,0mm according to AGU classification. According to ABNT, they are particles with granulometry ranging from 0,05 to 4,8mm.
- SEDIMENT CONCENTRATION – dry weight of solids contained in the water-sediment mixture in relation to the volume of the mixture (mg/*l*) or in relation to the mixture weight (ppm).
- SEDIMENT DISCHARGE – Rate at which sediment passes a stream cross-section in a given period of time. The sediment discharge may be limited to or refer to some sediment granulometry, as well as be considered at a specific part of the cross-section, due to suspended load, bed load or load for a section segment.
- SEDIMENT LOAD– the sediment being transported by a stream (*load* refers to the material itself and not to the quantity being transported).
- SEDIMENT SPECIFIC WEIGHT - dry weight by sediment volume unit or dry weight of the sediment in relation to volume.
- SEDIMENT YIELD – the total amount of tributary sediment at a hydrograph basin or drainage area in a reference point and during a specific period of time. It is equivalent to the sediment discharge in relation to the drainage area.
- SILT – sediment particles reporting granulometry between clay and sand (0,004 to 0,062mm according to AGU or 0,005 to 0,05mm according to ABNT).
- STONE – particles of sediment ranging from 256 to 64mm according to AGU classification.
- SUSPENDED SEDIMENT or SUSPENDED LOAD – sediment that is transported by ascending components of turbulent streams, and that remains suspended for a considerable time period.
- SUSPENDED SEDIMENT DISCHARGE – the quantity of sediment passing through a stream cross-section in a time unit.
- SUSPENDED SEDIMENT SAMPLER – sampler that collects a representative sample of water with its suspended sediment load.
- TOTAL LOAD – the total sediment being carried along a stream.
- TOTAL SEDIMENT DISCHARGE – the total sediment discharge for a stream. It includes the measured suspended discharged, the non-measured suspended discharge and the bed discharge.
- TRANSIT or ROUTE RATE – velocity in which the sediment load sampler is submerged into a vertical integration sampling.
- VERTICAL INTEGRATION SAMPLE – water-sediment mixture that is continuously accumulated in a sampler that moves vertically in an almost constant transit velocity, between surface and a point a few centimeters immediately above the bed. The mixture enters in a velocity almost equivalent to the instantaneous velocity of the stream at each point in vertical.
- VERTICAL or DEPTH INTEGRATION – sampling method for obtaining a representative sample of water-sediment discharge for the whole vertical, except for the non-sampled zone nearby the bed.
- VERTICAL FOR SAMPLING or just VERTICAL – a line approximately vertical, from the water surface to the bed, where samplings are taken in order to define the sediment concentration or granulometry.
- WATER DISCHARGE or DISCHARGE – the amount of water passing through a cross-section of a stream in a given time.
- WATER-SEDIMENT MIXTURE DENSITY – mass by volume unit, including water and sediment.

Sediment classification according to granulometry by AGU, American Geophysical Union (Wentworth Classification)

Granulometric Classification	Millimeter	Micron	Feed	Tyler Standard	US Standard
	(mm)	(μ)	(in)	(sifter diameter)	(sifter diameter)
Very big *cobblestone*	4096 – 2048		160 - 80		
Big *cobblestone*	2048 – 1024		80 - 40		
Medium c*obblestone*	1024 - 512		40 - 20		
Small *cobblestone*	512 - 256		20 - 10		
Big *stone*	256 – 128		10 - 5		
Small *stone*	128 - 64		5 - 2.5		
Very thick gravel	64 – 32		2.5 - 1.3		
Thick *gravel*	32 – 16		1.3 - 0.6		
Medium *gravel*	16 - 8		0.6 - 0.3	2 - ½	
Fine *gravel*	8 – 4		0.3 – 0.16	5	5
Very fine *gravel*	4 – 2		0.16 - 0.08	9	10
Very thick *sand*	2.000 - 1.000	2000 - 1000		16	18
Thick *sand*	1.000 - 0.500	1000 - 500		32	35
Medium *sand*	0.500 - 0.250	500 - 250		60	60
Fine *sand*	0.250 - 0.125	250 - 125		115	120
Very fine *sand*	0.125 - 0.062	125 - 62		250	230
Thick *silt*	0.062 - 0.031	62 - 31			
Medium *silt*	0.031 - 0.016	31 - 16			
Fine *silt*	0.016 - 0.008	16 - 8			
Very fine *silt*	0.008 - 0.004	8 - 4			
Thick *argyle*	0.004 - 0.0020	4 - 2			
Medium *argyle*	0.0020 - 0.0010	2 - 1			
Fine *argyle*	0.0010 - 0.0005	1 - 0.5			
Very fine *argyle*	0.0005 - 0.00024	0.5 - 0.24			
Colloid	< 0.00024	< 0.24			

Notes: 1) For some countries, including Brazil, the following classification is adopted by ABNT (Atterberg Classification) -

Gravel: 76 - 4.8 mm
Sand: 4.8 - 0.05 mm
Silt: 0.05 - 0.005 mm
Argyle (clay): < 0.005 mm

Symbols and units as recommended for studying sediments transportation in streams (WMO, 1980)

Element	Symbol	Unit	Note
Acceleration due to gravity	g	m s^{-2}	ISO
Area (cross-section)	A	m^2	ISO
Area (drainage area)	A	km^2	ISO (ha also in use)
Chézy coefficient $[v(R_hS)^{1/2}]$	C	m$^{1/2}$s^{-1}	ISO
Conveyance (coefficient)	K	m^3 s^{-1}	ISO
Density	ρ	kg m^{-3}	ISO
Depth, diameter, Thickness	D	m cm	ISO
Discharge			
(river runoff)	Q	m^3 s^{-1}	ISO
(by unit of area $Q\,A^{-1}$, or partial)	Q	m^3 s^{-1} km^{-2} l s^{-1} km^{-2}	ISO
Kinematics viscosity	υ	m^2 s^{-1}	ISO
Length	L	cm m km	ISO
Manning Coefficient $= R_h^{2/3}S^{1/2}v^{-1}$	N	s m$^{-1/3}$	ISO
Mass	M	kg G	ISO
Sediment concentration	C_s	mg l^{-1} kg m^{-3}	Or ppm Also uses g m^{-3}
Sediment discharge (or sediment)	Q_s	t d^{-1}	
Shearing tension	τ	Pa	ISO
Slope (hydraulics, basin)	S	Number with no dimension	ISO
Temperature	θ t	ºC	ISO
Total dissolved solids	M_d	mg l^{-1}	(for diluted solution) ppm also in use
Velocity (water)	v	m s^{-1}	ISO
Volume	V	m^3	ISO
Wet perimeter	P_w	M	
Width (cross-section, Basin)	B	m km	ISO

ANNEX

ANNEX– 1

SUSPENDED SEDIMENT SAMPLING BY *EWI* AND *EDI* METHODS AT THE IGUAÇU RIVER AT PORTO AMAZONAS

- Study of case -

INTRODUCTION

Suspended sediment sampling at rivers is part of the procedures for obtaining sediment discharge, and is performed in a fluviometric station.

Sediment transportation along a water stream is a complex phenomenon, thus making measurement procedures dependent on sampling methods, equipment to be used and distribution of sediments along the cross-section. The samples collected shall be forwarded to the laboratory for concentration analysis and, if required, also for granulometric analysis. The proper sample must take into consideration the quantity of water-sediment mixture required for carrying out a successful analysis. Considering that each analysis method has its limitations for the quantity of sediment available in the collected mixture, it is necessary for the hydrometry expert to make a sampling taking into consideration the suitable volume to be forwarded to the laboratory.

This paper presents a measurement in order to exemplify the practice of collection method through *equal width increment, EWI,* and through *equal discharge increment, EDI,* frequently used for suspended sediment sampling in rivers. They are used for indirect measurement of suspended sediment discharge, when it is not intended to know the sediments distribution along the section. Those methods allow for obtaining average concentration on the cross-section from one single laboratorial analysis. It also allows one single analysis for establishing the average granulometric distribution in the section.

FLUVIAL-SEDIMENTOMETRIC STATION

The station is located in Iguaçu River, at Porto Amazonas, Paraná basin, State of Paraná, and is codified as 6503 5000. It belongs to ANA, and is operated by SUDERHSA and COPEL, with regular measurements of water levels, water discharge, sediments, water quality parameters, relying on recorder equipment and telemetry. Nearby it, there is a station for measuring evaporation, fully operational. It is working since August 1935, initially measuring levels and discharges; its drainage area is 3.662km^2 and coordinates are 25^{o}33’00” S and 49^{o}53’00” W.

EQUIPMENT USED FOR MEASURING

Considering the section’s shallow waters not deeper than 4,5m, the USDH-59 sampler, shrill-operated, duly fixed on a boat, was used. That sampler is light, of the North-American series, and performs collection by vertical integration. The water discharge measurement was performed by using a hydrometric reel previously to the sampling process.

SAMPLING PROCEDURES

Two suspended sediment samplings were performed; the first one using the EWI (equal width increment) and the second using EDI (equal discharge increment) methods.

For both methods, the procedure for collecting water-sediment mixture in a vertical is performed by moving the sampler along the vertical, from surface, in a back and forward movement, using constant velocity during the process. The sampler, on the surface, is moved in a constant velocity, and is immediately lifted when it touches the bed. The velocity while lifting must be different from that for descending it; it must be a non-stop movement, in order to grant the sampling time. One shall be extremely careful in order to avoid taking bed sediment during the process; the bottle shall be examined by the end of the process and the sample must be refused if bed sediment was collected.

For the vertical integration method, two rules must be obeyed: first, if a bottle is being used, it shall not be filled in with more than 4/5 of its capacity (~ 400m*l*) for obtaining a representative sample; second, in order to ensure that the nozzle remains on the horizontal position, it is necessary to slide down or rise the sampler on that vertical in an uniform transit rate, in a maximum ration $v_{t.max}$ in relation to the average velocity v_m. Each nozzle has its own constant, where:

- For 1/8” nozzle the maximum ratio is 0,2:

$$\frac{v_t}{v_{m\max}} = 0{,}2 \qquad \text{so} \qquad v_t = 0{,}2.v_m \qquad (1)$$

- For 3/16” and 1/4” nozzles, the maximum ration is 0.4:

$$\frac{v_t}{v_{m.\max}} = 0{,}4 \qquad \text{so} \qquad v_t = 0.4.v_m \qquad (2)$$

For obtaining the minimum sampling time, the following equations are used in a two-way trip, calculating with the depth p_m for sampling position:

* For 1/8” nozzle, the minimum sampling time is:

$$t_{\min} = \frac{2.p_i}{v_{t.\max}} = \frac{2.p_i}{0.2.v_m} \qquad (3)$$

* For 3/16” and 1/4" nozzles, the minimum sampling time is:

$$t_{\min} = \frac{2.p_i}{v_{t.\max}} = \frac{2.p_i}{0.4.v_m} \qquad (4)$$

It is necessary to perform the water discharge measurement for sediment discharge measurement. Therefore, the values for average depth p_m and the average velocity v_m are easily obtained for discharge computations performed by the occasion.

Equal width increment - EWI

It is the commonest method used for water-sediment mixture due to its simplicity. For EWI method, the cross-section is divided into a series of verticals equally spaced. For each one, the vertical integration method is executed (ETR – equal transit rate), always using the same transit rate among them. Different volumes are collected, which are smaller and smaller following the reduction of velocities and depths.

For dully obtaining samples, one shall first perform the water discharge measurement, also by equal width increment, and the discharge is calculated or, at least, the average velocities. Usually is used half of the verticals of discharge measurement to sample also using equal width increment. Then, the vertical among these presenting the highest average velocity is selected, usually at the river thalweg (for irregular sections, it would be better to obtain the vertical presenting the highest product *depth x average velocity)*. The third step is to perform a sampling in that position, by vertical integration, using a minimum time calculated through equations (3) or (4) for obtaining sub-sample, in such a way as to fill the bottle up to the capacity of 4/5. The remaining sub-samples must be collected by using the same transit rate obtained for the 4/5 volume; it may also be calculated by the proportion with time used in this experimental sampling. If the section is regular, each sampling time for the remaining verticals may be obtained by applying the rule of three between depths and time. For irregular sections, it would be better to calculate the new transit rate through equation (5) below, and new times with (3) and (4). Once the nozzle is selected, it shall not be exchanged during measurement.

$$v_t = \frac{2.p_i}{t} \qquad (5)$$

Such sub-samples may be combined into one single sample for determining concentration and granulometry. In this method, 10 to 20 verticals may be selected for samplings.

Equal discharge increment - EDI

For EDI method, the cross-section area is laterally divided into segments that represent equal discharge increments, so that sampling can be performed by dividing each increment into two equal portions. For this sampling, the first step is to perform the water discharge measurement, and have it calculated. Based on that measure, a graph is made using the percentages of discharge accumulated on ordinates, and the distances on abscissas. Then, one selects the verticals to be displayed on the ordinate axis, divided into the number of verticals desired, and the sampling distances are obtained on the abscissas axis, by the intersection with the graph drawn. Sampling depths and velocities for each collection vertical may be obtained, provided that the cross-section and distribution of average velocities are traced. For each position, the sub-sample is obtained by vertical integration, using the above mentioned equations. The next rule for this method is that two equal volumes shall be obtained for all bottles, filling them in up to 4/5. Then, different transit rates may be used for each vertical, and nozzles may be exchanged.

In practical terms, it may be performed through measurement and computation of water discharge, using a reel and more verticals than usual, i.e., 35 to 40 verticals. The total discharge is divided by the number of desired verticals, e.g., $100m^3\ s^{-1}$ / 10 verticals, equal to $10m^3\ s^{-1}$, that is the increment value to be sampled. The first sub-sampling is performed at the position of $5m^3.s^{-1}$, close to half the position $10m^3.s^{-1}$, obtaining that position from notes on discharge measurement through accumulation of partial discharges. For the next vertical, one should add $10m^3.s^{-1}$ equal to $25m^3.s^{-1}$, or nearby that position, and so on. For each vertical, the nozzle suitable for stream velocity and depth is used, calculating the sampling minimum time through equations (3) and (4). The several sub-samples must present equal volumes for each vertical.

Those sub-samples may be combined into one single section composite sample for establishing concentration and granulometry. For this method, 5 to 10 verticals may be selected for sampling.

Sampling in Porto Amazonas

Table 1 presents the water discharge measurement, using hydrometric reel, performed in Iguaçu River, at Porto Amazonas, on June 4th, 1997.

The points for measuring stream velocity in each vertical were selected at 0,2 and 0,8 of total depth, in order to simplify this example. Discharge computations were performed by using the half section method (Buchanan & Somers, 1969).

Sampling through EWI

In Porto Amazonas, the measurement of water discharge was performed with positions at every 2,00m, totaling 35 verticals, as shows the attached field spreadsheet. The suspended sediment sampling verticals were selected at every 6,00m, totaling 11 sub-samples (see positions **X** indicated). The highest average velocity among such sampling positions is $0,646m\ s^{-1}$ on vertical 15 and 30,00m in distance, which was selected for initial collection, although the section is irregular and not completely suitable for measurements. That position always corresponds to the highest product *depth x average velocity*. Choosing the 3/16" nozzle for the USDH-59 sampler, and calculating the minimum sampling time t_{min}, we have:

$$t_{\min} = \frac{2.p_i}{v_t} = \frac{2.p_i}{0.4.v_m} = \frac{2x1{,}30}{0.4x0.646} = \frac{2x1{,}30}{0{,}258} = 10 \text{ seconds}$$

The collection of about $400cm^3$ was possible only by using 34s, which was considered as standard sample. The transit rate corresponding to that time was calculated as follows:

$$v_t = \frac{2.p}{t} = \frac{2x1{,}30}{34} = 0{,}0765 \text{ m s}^{-1}$$

It may be used for obtaining sampling time for other verticals. Such times may also be calculated by using the rule of three, considering the standard sample time and depths for each vertical to be sampled. Such times are pointed in the spreadsheet and the sample, in practice, may have been performed with 1 or 2 seconds of difference. Despite the poor distribution of partial discharge along the section, times calculated by the two processes were equivalent, except for one vertical.

EDI sampling

In order to have the collection positions through EDI method, it is necessary to trace out a graph that may translate the percentage distribution of discharges, as shown in Table 1 and figures attached (graphs), obtained as previously described .

Table 1 –Iguaçu River at Porto Amazonas – Measurement of water discharge and percentage distribution along the section

Abscissa – Distance	**Partial Discharge**	**q / Q**	**Σ q / Q**
(m)	**($m^3 s^{-1}$)**	**(%)**	**(%)**
0,00	0,000	0,000	0,000
2,00	0,195	0,624	0,624
4,00	0,215	0,688	1,312
6,00	0,304	0,973	2,285
8,00	0,422	1,351	3,636
10,00	0,746	2,388	6,024
12,00	1,056	3,380	9,404
14,00	1,361	4,356	13,760
16,00	1,366	4,372	18,132
18,00	1,260	4,033	22,165
20,00	1,325	4,241	26,406
22,00	1,176	3,764	30,170
24,00	1,154	3,693	33,863
26,00	1,382	4,423	38,286
28,00	1,279	4,093	42,379
30,00	1,680	5,377	47,756
32,00	0,970	3,104	50,860
34,00	0,923	2,954	53,914
36,00	0,583	1,866	55,680
38,00	0,515	1,648	57,328
40,00	0,688	2,202	59,530
42,00	0,806	2,580	62,110
44,00	0,639	2,045	64,155
46,00	0,846	2,708	66,863
48,00	0,764	2,455	69,318
50,00	0,844	2,701	72,019
52,00	1,111	3,556	75,575
54,00	1,077	3,447	79,022
56,00	1,024	3,277	82,299
58,00	1,079	3,453	85,752
60,00	1,119	3,581	89,333
62,00	1,146	3,668	93,001
64,00	1,059	3,389	96,390
66,00	0,611	1,956	98,346
68,00	0,466	1,491	99,837
70,00	0,054	0,173	100,00
71,80	0,000	0,000	100,00
Total	31,245		

For obtaining 10 sub-samples following the EDI sampling criterion, one shall find in the graph the abscissas, depths and velocities of the points for 5, 15, 25, 35, 45, 55, 65, 75, 85 and 95%. In field service, it is always difficult to trace such graphs, and Lane curves may be drawn, according to consulted Bibliography.

In practical terms, it may be performed, as previously indicated, by dividing the total water discharge by 10. The first sub-sample is obtained at the position of half the first discharge increment. The spreadsheet presents those points. Then, we have 31,409 / 10 =

3,140m^3.s^{-1}. The first sampling point is located on 3,140 / 2 = 1,570m^3.s^{-1}, between 8,00 and 10,00m, in 9,00m of abscissa - for the discharge value up to this point; the second point is located on 1,570 + 3,140 = 4,710m^3.s^{-1}, and so on. All of those positions are indicated in the spreadsheet. The technician must perform sampling as closest as possible to the position, using the accumulated discharge value.

The ten sub-samples obtained may be forwarded to the laboratory, for composing one single sample for the required analyses.

BIBLIOGRAPHY

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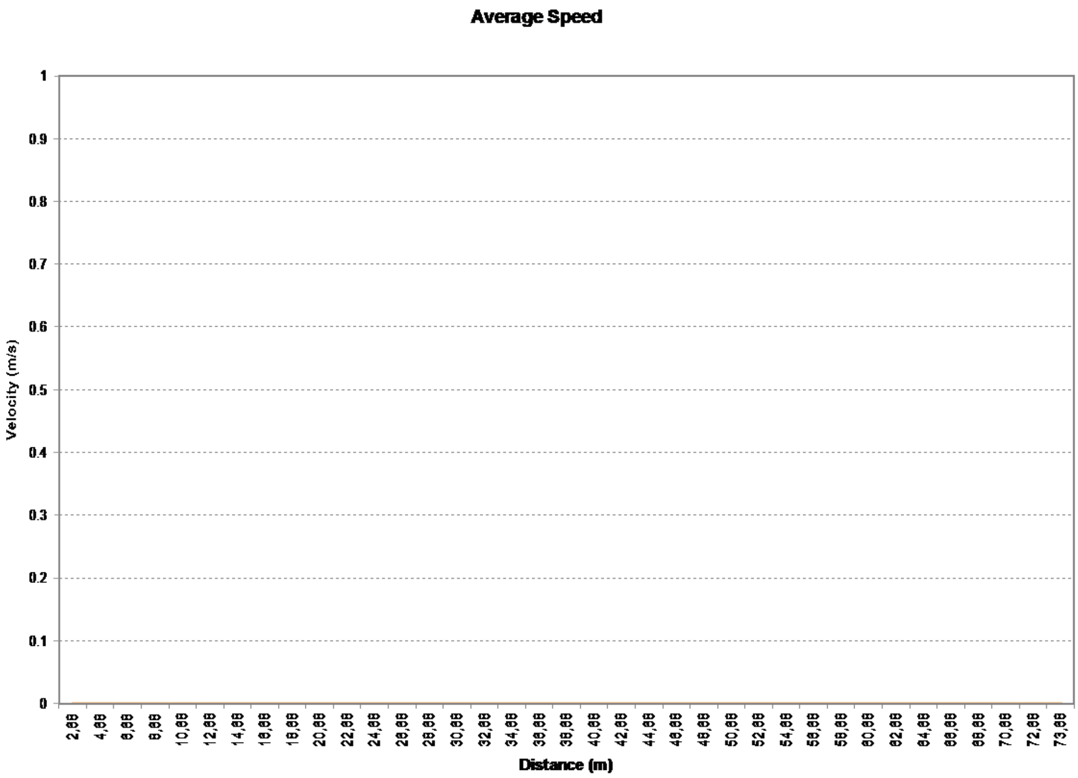
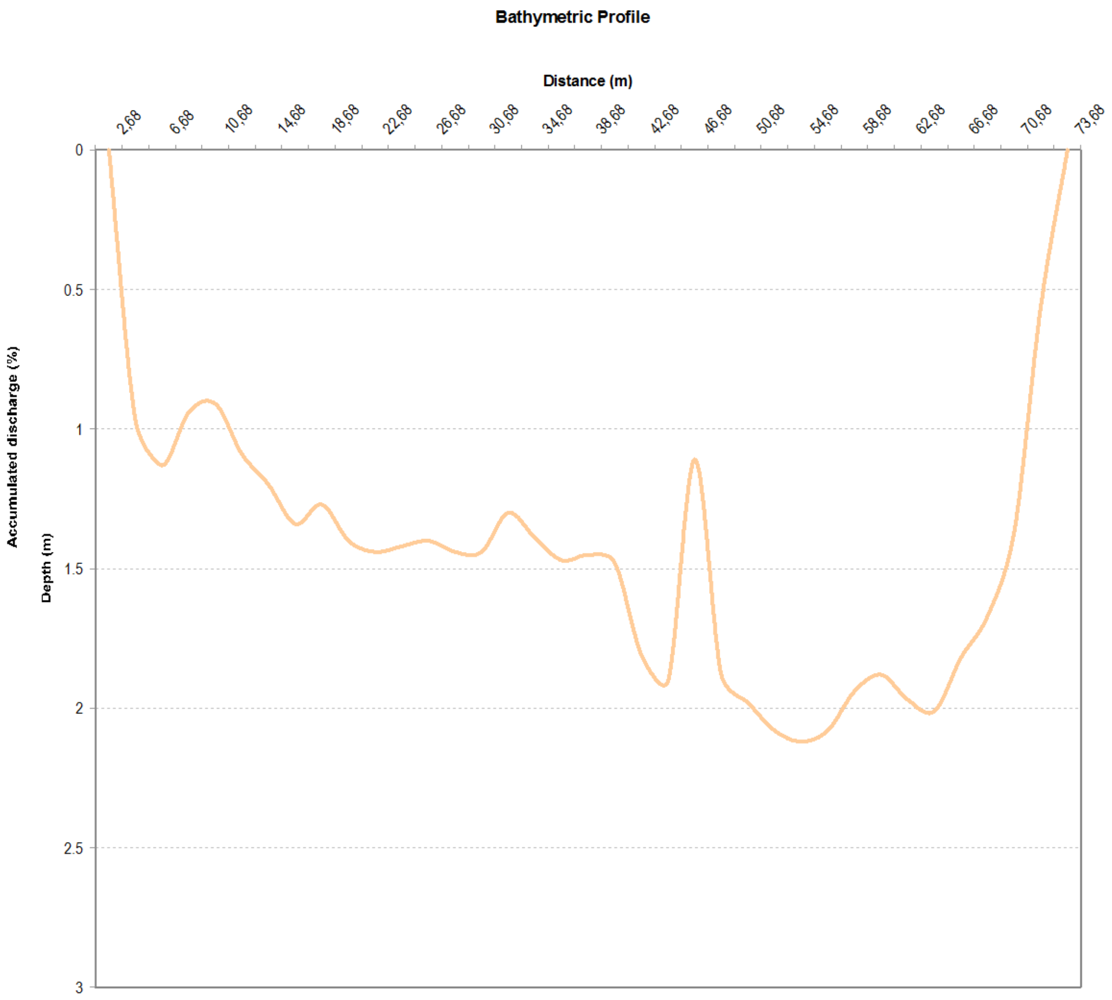
MEASUREMENT OF WATER DISCHARGE AND SEDIMENT SAMPLING, ON JUNE 4TH, 1997 – GAGE HEIGHT = 1,09 M




Bathymetric Profile
Distance (m)
2,68
6,68
10,68
14,68
18,68
22,68
26,68
30,68
34,68
38,68
42,68
46,68
50,68
54,68
58,68
62,68
66,68
70,68
73,68
Accumulated discharge (%)
Depth (m)
0
0.5
1
1.5
2
2.5
3

SEDIMENT SAMPLING BY EWI AND EDI METHODS

Station Name: *Rio Iguaçu at Porto Amazonas* ***Equipment:*** *Reel IH-Hélice 6183* ***Initial water level:*** *1,09m*
Code: *6503 5000* - ***Date: 0****4.06.1997* ***Equation:*** *V = 0,2587n + 0,0064* ***Final water level:*** *1,09m at 11h30*

Vert Nr.	**Absciss Dist. of PI**	**Width**	**Total Depth**	**Reel position**	**Velocity at the point**	**Averag e velocity**	**Partial area**	**Partial discharge**	**Accum. Partial discharge**	**q / Q**	**Accumulate q / Q**	**Notes**
		(m)	**(m)**	**(m)**	**($m\ s^{-1}$)**	**(m/s)**	**(m^2)**	**($m^3\ s^{-1}$)**	**($m^3\ s^{-1}$)**	**%**	**%**	
	PI = 0.0	Point	Initial									
	2,68		0.00					0,000	0,000	0,000	0,000	
1	4,68	1,00	0,97	0,58	0,201	0,201	0,97	0,195	0,195	0,621	0,621	
2	6,68	2,00	1,13	0,90	0,143	0,095	2,26	0,215	0,410	0,685	1,306	
				0,23	0,047							
3	8,68	2,00	0,94	0,56	0,162	0,162	1,88	0,304	0,714	0,968	2,274	**EWI –** 24 seconds
4	10,68	2,00	0,91	0,55	0,232	0,232	1,82	0,422	1,136	1,344	3,618	
												EDI – 1,57 $m^3\ s^{-1}$ – 80 sec
5	12,68	2,00	1,09	0,87	0,321	0,342	2,18	0,746	1,882	2,375	5,993	
				0,21	0,363							
6	14,68	2,00	1,20	0,96	0,428	0,440	2,40	1,056	2,938	3,362	9,355	**EWI –** 31 seconds
				0,24	0,453							
7	16,68	2,00	1,34	1,07	0,492	0,508	2,68	1,361	4,299	4,333	13,688	
				0,27	0,525							
												EDI – 4,71 $m^3\ s^{-1}$ – 42 sec
8	18,68	2,00	1,27	1,02	0,526	0,538	2,54	1,366	5,665	4,349	18,037	
				0,25	0,551							
9	20,68	2,00	1,40	1,12	0,391	0,450	2,80	1,260	6,925	4,012	22,049	**EWI –** 37 seconds
				0,28	0,508							
												EDI – 7,85 $m^3\ s^{-1}$ – 54 sec
10	22,68	2,00	1,44	1,15	0,432	0,460	2,88	1,325	8,250	4,219	26,268	
				0,29	0,488							
11	24,68	2,00	1,42	1,14	0,419	0,414	2,84	1,176	9,426	3,744	30,012	
				0,28	0,410							
12	26,68	2,00	1,40	1,12	0,361	0,412	2,80	1,154	10,580	3,674	33,686	**EWI –** 37 seconds

				0,28	0,462							
												EDI – 10,99 $m^3 s^{-1}$ – 56 sec
13	28,68	2,00	1,44	1,15	0,442	0,480	2,88	1,382	11,962	4,400	38,086	
				0,29	0,519							
14	30,68	2,00	1,44	1,15	0,410	0,444	2,88	1,279	13,241	4,072	42,158	
				0,29	0,477							
												ED I– 14,13 $m^3 s^{-1}$ - 40 sec.
15	32,68	2,00	1,30	1,04	0,778	0,646	2,60	1, 680	14,921	5,349	47,507	IIL – Standard sample
				0,26	0,513							t_{min} = 10 seconds
												$t_{amostragem}$ = 34 sec, 400ml
16	34,68	2,00	1,39	1,11	0,349	0,408	2,78	1,134	16,055	3,610	51,117	
				0,28	0,467							
17	36,68	2,00	1,47	1,18	0,264	0,314	2,94	0,923	16,978	2,939	54,056	
				0,29	0,364							
												EDI – 17,27 $m^3 s^{-1}$ – 88 sec
18	38,68	2,00	1,45	1,16	0,072	0,201	2,90	0,583	17,561	1,856	55,912	**EWI –** 38 seconds
				0,29	0,330							
19	40,68	2,00	1,48	1,18	0,062	0,174	2,96	0,515	18,076	1,640	57,552	
				0,30	0,287							
20	42,68	2,00	1,81	1,45	0,076	0,190	3,62	0,688	18,764	2,190	59,742	
				0,36	0,304							
21	44,68	2,00	1,90	1,52	0,086	0,212	3,80	0,806	19,570	2,566	62,308	**EWI –** 50 seconds
				0,38	0,339							
22	46,68	2,00	1,11	0,89	0,294	0,288	2,22	0,639	20,209	2,034	64,342	
				0,22	0,282							
												EDI – 20,41 $m^3 s^{-1}$ – 40 sec
23	48,68	2,00	1,88	1,50	0,164	0,225	3,76	0,846	21,055	2,693	67,035	
				0,38	0,286							
24	50,68	2,00	1,98	1,58	0,125	0,193	3,96	0,764	21,819	2,432	69,467	**EWI –** 52 seconds
				0,40	0,261							
25	52,68	2,00	2,08	1,66	0,123	0,203	4,16	0,844	22,663	2,687	72,154	
				0,42	0,283							
												EDI – 23,55 $m^3 s^{-1}$ – 104 sec
26	54,68	2,00	2,12	1,69	0,219	0,202	4,24	1,111	23,774	3,537	75,691	
				0,42	0,305							

27	56,68	2,00	2,08	1,66	0,241	0,259	4,16	1,077	24,851	3,429	79,120	**EWI –** 54 seconds
				0,42	0,277							
28	58,68	2,00	1,94	1,55	0,246	0,264	3,88	1,024	25,875	3,260	82,380	
				0,39	0,282							
												EDI – 26,69 $m^3 s^{-1}$ – 80 sec
29	60,68	2,00	1,88	1,50	0,260	0,287	3,76	1,079	26,954	3,435	85,815	
				0,38	0,314							
30	62,68	2,00	1,97	1,58	0,246	0,284	3,94	1,119	28,073	3,563	89,379	**EWI –** 52 seconds
				0,39	0,323							
31	64,68	2,00	2,01	1,61	0,247	0,285	4,02	1,146	29,219	3,649	93,027	
				0,40	0,323							
												EDI – 29,83 $m^3 s^{-1}$ – 80 sec
32	66,68	2,00	1,82	1,46	0,233	0,291	3,64	1,059	30,278	3,372	96,399	
				0,36	0,349							
33	68,68	2,00	1,67	1,34	0,146	0,183	3,34	0,611	30,889	1,945	98,344	**EWI –** 44 seconds
				0,33	0,220							
34	70,68	2,00	1,37	1,10	0,181	0,170	2,74	0,466	31,355	1,484	99,828	
				0,27	0,158							
35	72,68	1,15	0,56	0,34	0,085	0,085	0,64	0,054	31,409	0,172	100,000	
-	73,68		0,00					0,000		0,000		

Total discharge: 31,409 $m^3 s^{-1}$	**Total area: 103,87 m^2**	**Average velocity: 0,302 $m s^{-1}$**	**Width: 71,00 m**	**Average depth: 1,46 m**

ANNEX – 2

COMPUTATION OF SEDIMENT DISCHARGE IN RIO MANSO STATION AT PORTO DE CIMA

- Case study -

1. INTRODUCTION

The sediment discharge computation is the initial part of data processing. Once obtained the water discharge results, sediment analyses and additional information, the instantaneous sediment discharge may be calculated. The measurement program established will surely have indicated the required computations, as well as the methods to be followed.

The suspended discharge, bed or entrainment discharge, bed material and total sediment discharge may be calculated. The suspended discharge is calculated independently from the bed discharge, because they do not follow the same movement law. While suspended material is subject mainly to the stream action, the bed material also suffers resistance actions among its particles, and interferences in bed.

For calculating suspended discharge, it is usually necessary to have only the values for water discharge and average concentration of sediments. If there is a need for the suspended discharge distribution in relation to granulometry, then it will be necessary to establish the granulometric analysis. If distribution of suspended discharge in relation to width and depth is required, then punctual samplings must be performed. Such procedures imply in suitable methods and equipment, and special works or surveys should be used.

There are more alternatives for calculating bed discharge and total sediment discharge, requiring from the technician a deeper knowledge on the subject, in order to choose the working method, as well as better skills in order to properly evaluate the results obtained. There are several formulas for calculating bed discharge and bed material discharge, about 50 or so, each of them established for local conditions. Maybe two or three of them are completely based on theoretical concepts. The remaining ones are based on experimental aspects for water stream (or laboratory) conditions for the occasion and studies conditions.

It is useful to note that sediment discharge computations with North-American programs are performed by using AGU rules for granulometric classification, which are different from ABNT, brazilian rules.

For performing such computations previously to the computer age, it was necessary to choose the formula based on a full knowledge of local measurement conditions, as well as on the formula applicability, under the risk of concluding, by the end of the work, that it would be necessary to choose another method and make new troublesome computations. Considering the work facility provided by the computer, all measurements are currently calculated by using any desired formula, while water stream is observed along time, knowing local hydrological and sedimentological regime, in order to acquire the experience and knowledge required for final studies.

In this study of case, the computations for sediment discharge are presented through several methods. For better knowing processes of measurement, sampling and sediment analysis, as well as the formulas used, it is useful to make reference to the chapter of the *Sedimentometric Practices Guide*, and to bibliography herein presented as well.

2. FLUVIAL-SEDIMENTOMETRIC STATION

The gaging station is located in Manso river at Porto de Cima, tributary to Cuiabá River, Paraguay Basin, State of Mato Grosso; its code is 6624 0000 and 6624 0001. It has a 8.805km^2 draining area and coordinates of 14º53' and 55º52'. It belongs to ANA, being operated by CPRM, with regular measurements of water level and water discharge. Installed in 23.07.1972 and operated until 1990 by the extinguished DNOS, monthly sediment discharges were also performed, from 1978 to 1982. The station was installed aiming at studies for damming and the creation of an impounded river reach area in that site, in order to control floods and regulate Cuiabá River. Afterwards, ELETROBRÁS became interested in electric power generation there, and undertook the responsibility for building the dam, then assigning the responsibility to ELETRONORTE and further to FURNAS, which concluded the work. By that time, additional stations were installed nearby, and other sediment discharges measurements were performed.

3. MEASUREMENT PROGRAM

The sedimentometric measurements program established by DNOS used to foresee studies on Upper Paraguay and, mainly, in swamplands in the State of Mato Grosso. 14 stations were installed and distributed along the main water stream and major affluents. Due to lack of financial resources, sedimentometric networks were deactivated, and were operated from 1978 to 1982 only.

All stations were intended to perform total sediment discharge measurements, calculated by using Einstein modified method. Water discharge measurements were performed in order to obtain the values required for sediment sampling and computations to be performed. Suspended sediment collections were performed by the method of equal width increment, from 5 to 10 verticals, for determining concentration and granulometry based on composite sample. Bed sediment collections were performed for half of previous positions, with a minimum of three sub-samples to compose one single sample for determining granulometry.

During laboratory analysis it were verified some problems in samples due transportation from Cuiabá to Rio de Janeiro.

4. DATA AND RESULTS

Data required for computations and results on water discharge measurement, as well as for sediment discharge, are presented in the attached boxes.

The analyses for suspended material were performed through settling tube (BW tube), which allows for establishing concentration and granulometry. Bed material analyses were performed by sieving up to the lowest sand fraction and, from there, to the finer material with BW tube. The results are also presented.

Due to lack of field measurement, the energetic line slope was established by using the Manning formula, considering the coefficient *n* as for thick sand with some gravel equivalent to 0,029 (see granulometric analysis data). Then:

$$S = \left(\frac{Q.n}{A.R^{2/3}} \right)^2 = \left(\frac{113{,}897x0{,}029}{198{,}36x2{,}37^{2/3}} \right)^2 = 0{,}0001$$

5. SUSPENDED SEDIMENT DISCHARGE COMPUTATION

Suspended sediment discharge was established according to the following equation and computations:

$$Qss = 0{,}0864.Q.C = 0{,}0864x113{,}897x155{,}55 = 1.530{,}7 \text{ t/day}$$

where the constant is a unit conversion faction, Q in m^3/s and C in mg/l.

6 COMPUTATION OF BED MATERIAL AND BED DISCHARGE

The results presented for *discharge of bed material* and *bed sediment discharge* (or *entrainment discharge)* were obtained by using software, as presented by Stevens Jr. & Yang (1989). The adjustment to metric system was performed by Jorge Prodanoff.

TOTAL SEDIMENT DISCHARGE COMPUTATION

Herein, it is presented two computations for total sediment discharge.

The first one was performed by using the *Colby simplified method*, of 1957, as presented by Carvalho (1994), pages 201 to 205; the software is indicated on pages 369 to 371, and this program was developed by Jorge Henrique Alves Prodanoff.

The second one was performed by using the *Einstein modified method* based on the program presented by Stevens Jr. (1985). For this process the sediment discharge distribution was used, according to the material granulometry.

Data for calculating sediment discharge

River : **Manso** ***Site:*** **Porto de Cima**
Basin: **Cuiabá / Paraguay / Paraná** ***Date:*** **25.05.1977** ***Time:*** **-**
Entity: **DNOS** ***Team:*** **HSA**

Summary of measurements on water discharge and suspended sediment discharge

Net discharge			**Suspended sediment discharge**		
Nr. of measurement	*1*		Nr. of measurement	*1*	
Gage height	h = *1,31*	m	Samplers	*DH-59 and Rock*	
Surface width	L = *83,70*	m	Dist. from nozzle to bottom	p_n = *0,102*	m
Section area	A = *198,45*	m^2	Concentration measured	c = *155,55*	ppm
Average depth	p = *2,37*	m	Sampled average depth	p_s = *2,658*	m
Average velocity	v = *0,573*	m/s	Water temperature	T = *23,8*	ºC
Water discharge	Q=*113,897*	m^3/s	Suspended discharge	Q_{ss}= *1530,7*	t/day
			Slope	S = *0,0001*	

Results of granulometric analyses for suspended and bed material

Suspended material		**Bed material**		
Diameter (mm)	% accumulated	Nr. of the sifter	Diameter (mm)	% accumulated
		270	0,055	-
0,0020	-	230	0,060	-
0,0039	*23,90*	200	0,078	*0,10*
0,0050	-	140	0,105	-
0,0055	*30,00*	120	0,125	-
0,0078	*37,00*	100	0,149	*1,70*
0,0110	*44,50*	80	0,177	-
0,0156	*52,00*	70	0,210	-
0,0221	*62,50*	60	0,250	-
0,0312	*67,50*	50	0,297	-
0,0442	*70,40*	45	0,350	-
0,0500	-	40	0,420	-
0,0625	*73,00*	35	0,500	-
0,125	*89,80*	30	0,590	*96,80*
0,250	*95,20*	25	0,710	-
0,500	*100,00*	20	0,840	-
0,840	-	18	1,000	-
1,000	-	16	1,190	-
2,000	-	14	1,410	-
		12	1,650	-
		10	2,000	*96,80*
		8	2,380	-
		7	2,830	-
		6	3,360	-
		5	4,000	
		3/16” (4)	4,762	*98,80*
		5/16”		*99,85*
		3/8”	9,525	*100,00*

Interpretation of granulometric curves

Suspended material				**Bed material**			
Diam.	**%**	**Gran. Band**	**%**	**Diam.**	**%**	**Gran. band**	**%**
0,000	*0,00*	0,000 – 0,0156	*52,00*	0,002	*0,00*	0,000 –0,0156	*0,00*
0,0156	*52,00*	0.0156 –0,0625	*21,00*	0,0156	*0,0 0*	0.0156 –0,0625	*0,20*
0,0625	*73,00*	0,002 – 0,0625	-	0,0625	*0,20*	0,002 – 0,0625	-
0,125	*89,80*	0,0625 – 0,125	*16,80*	0,125	*9,10*	0,0625 – 0,125	*8,90*
0,250	*95,20*	0,125 - 0,250	*5,40*	0,250	*30,40*	0,125 - 0,250	*21,30*
0,500	*100,00*	0,250 - 0,500	*4,80*	0,500	*92,40*	0,250 - 0,500	*62,00*
1,000		0,500 - 1,000	-	1,000	*96,40*	0,500 - 1,000	*4,00*
2,000		1,000 - 2,000	-	2,000	*97,40*	1,000 - 2,000	*1,00*
4,000		2,000 - 4,000	-	4,000	*98,60*	2,000 - 4,000	*1,20*
8,000		4,000 - 8,000	-	8,000	*100,00*	4,000 - 8,000	*1,40*
				16,000		8,000 - 16,00	-
				32,000		16,00 - 32,00	-

Composition of material and characteristic diameters

Material	**Suspended material (%)**	**Bed material (%)**	**Characteristic diameters for bed material (mm)**	
Clay	*28,00*	-	D_{35}	*0,26*
Silt	*44,00*	-	D_{50}	*0,29*
Sand	*28,00*	*98,80*	D_{65}	*0,34*
Gravel	-	*1,20*	D_{90}	*0,48*

Summary on bed material sediment discharge

Formula	**Relative concentration**	**Unitary sediment discharge**	**Sediment discharge for bed material**
	(ppm)	**(kg/s.m)**	**(t/day)**
Laursen	*11,18*	*0,0152*	*110,00*
Engelund & Hansen	*47,31*	*0,0644*	*465,50*
Colby	*26,97*	*0,0367*	*265,36*
Ackers & White (using D_{50})	*22,25*	*0,0303*	*218,95*
Ackers & White (using D_{35})	*24,88*	*0,0339*	*244,82*
Yang Sand (using D_{50})	*15,14*	*0,0206*	*148,93*
Yang Sand (using granul.)	*17,54*	*0,0239*	*172,53*
Yang Gravel (using D_{50})	*0,03*	-	*0,29*
Yang Gravel (using granul.)	*0,04*	-	*0,35*
Yang Sand +Gravel	*17,41*	*0,0237*	*171,30*
Einstein	-	-	-
Toffaleti	-	-	-

Note: The program did not calculate sediment discharge by Einstein and Toffaleti methods, considering the slope adopted.

Bed sediment discharge

Formula	Relative concentration	Unit solid discharge	Bed sediment discharge
	(ppm)	(kg/s.m)	(t/day)
Schoklitsch	-	-	-
Kalinske	-	-	-
Meyer-Peter & Muller	-	-	-
Rottner	-	-	-
Einstein	-	-	-
Toffaleti	-	-	-

Note: The program did not calculate the bed sediment discharge considering the slope adopted.

Summary on total sediment discharge (Colby simplified method)

Suspended sediment discharge	Non-measured sediment discharge	Total sediment discharge
(t/day)	(t/day)	(t/day)
1.530,72	*592,58*	*2.123,30*

Summary on total sediment discharge (Einstein modified method)

Kinematics viscosity	*=0,0000009 m^2/s*	A’	*= 0,038*
Laminar sub-layer thickness	*= 0,0008029 m*	Shearing velocity	*= 0,013264 m/s*
Reference band	*Multiple*	Factor P	*= 18,25*
Percentage of sampled flow	*= 96,88 %*	Factor X	*= 0,40*
Average depth / K_s	*= 6970588,0*	Angular coefficient Z (regression)	*= 0,10*

Granulometry	Susp. Gran.	Bed Gran.	Law Disch. i_fQ_f	Q'_s	Multiplier	Comp. Z	F(J)	F(I)+1	Total Sed. Disch.
(mm)	(%)	(%)	(t/day)	(t/day)	-	-	-	-	(t/day)
0,000 – 0,0156	*52,00*	*0,00*	*0,00*	*772,5*	*0,00*	*0,44*	*1,20*	*0,00*	*927,6*
0.0156 – 0,0625	*21,00*	*0,20*	*0,08*	*312,0*	*0,00*	*0,63*	*1,42*	*0,00*	*444,3*
0,002 – 0,0625	-	-	-	-	-	-	-	-	-
0,0625 – 0,125	*16,80*	*8,90*	*4,16*	*249,6*	*0,00*	*0,75*	*1,68*	*0,00*	*423,2*
0,125 - 0,250	*5,40*	*21,30*	*6,23*	*80,2*	*0,00*	*0,94*	*2,38*	*0,00*	*196,8*
0,250 - 0,500	*4,80*	*62,00*	*4,52*	*71,3*	*0,00*	*0,90*	*2,08*	*34,16*	*154,4*
0,500 - 1,000	*0,00*	*4,00*	*0,00*	*0,0*	*0,00*	*0,99*	*0,00*	*21,53*	*0,1*
1,000 - 2,000	*0,00*	*1,00*	*0,00*	*0,0*	*0,00*	*1,03*	*0,00*	*17,33*	*0,0*
2,000 - 4,000	*0,00*	*1,20*	*0,00*	*0,0*	*0,00*	*1,07*	*0,00*	*14,35*	*0,0*
4,000 - 8,000	*0,00*	*1,40*	*0,00*	*0,0*	*0,00*	*1,11*	*0,00*	*12,04*	*0,0*
Total	*100,00*	*100,00*	*15,00*	*1.485,5*	-	-	-	-	*2.146,3*

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