Techniques for the Characterization of
Suspended Sediment and Selected
Applications for the Acquired Data

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Suspended sediment is a major source of pollutants which are transported by surface waters. Although erosion and sedimentation are natural processes, many cultural practices of man including residential construction, open pit mining, highway construction, agriculture, and logging may increase the quantity of sediment entering waterways by up to orders of magnitude. For example, in one study in suburban Maryland, sediment removal from a 20 acre housing-construction site increased from an estimated 0.75 tons/acre-yr to 189 tons/acre-yr.⁽¹⁾ From this study it was projected that population increases in the next two decades would result in the transfer of 20 million tons of sediment to the Potomac River. This is equivalent to the removal of about 10 tons of sediment for each per capita increase in population in greater Washington, D. C.⁽¹⁾; however, even this estimate may be too low by as much as two orders of magnitude⁽²⁾. Others of the aforementioned cultural practices of man can result in likewise large increases in erosion, and thus considerable attention to these problems are needed.

Erosion serves to pollute waterways by 2 general mechanisms. First, sediment, per se, obviously decreases water storage capacity, modifies water conveyance structure, and causes considerable

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damage to turbines and pumping equipment. Secondly, and more subtly, sediment transport results in the transport of sorbed pollutants which may later be solubilized. Pollutants which fall into the second category include phosphorus, pesticides, heavy metals, and radionuclides. For example, it has been shown that up to 98% of the radionuclides transported by the Columbia River are sorbed particulates⁽³⁾. The purpose of this paper is 1) discuss some techniques which are used to characterize suspended particulates and bottom sediments; 2) to give some selected uses of the acquired data for model development; and, 3) to suggest the use of some possible physical and chemical "treatments" to modify the impact of cultural practices.

Characterization Methods and Data Utilization

Techniques of suspended sediment analysis and characterization can be divided into physical and chemical methods. Of these two physical methods are required to isolate the suspended sediment from the liquid phase to carry out other sediment characterizations. Common methods of separation include centrifugation and filtration. Due to the minimum size and low concentration of suspended sediment through a large portion of the year, large volume, highly efficient solid-liquid separation's systems are required.

Two systems presently are in use on Columbia River Studies to separate particulate from solution^(4,5). Continuous ultracentrifugation was found to reduce the turbidity of Columbia River water to a level approximating that of distilled water⁽⁴⁾.

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Total suspended sediment data ($>53\mu$) attained with this system is listed in Table 1⁽⁶⁾. It can be seen that there is more than a two order of magnitude difference between the maximum and minimum sediment concentration and that in excess of 3000 liters of water would be required to obtain 1 gram of suspended sediment, demonstrating that high volume, efficient system is indeed required. This becomes especially apparent when one realizes that many standard physiochemical sediment measurements require 10-100 grams of sediment.

A second high volume, efficient sediment isolation system is the Battelle large-volume water sampler (BLVNS)⁽⁵⁾. Figure 1 shows the sampler is capable of extracting the suspended sediment from 40 l/min. with retention efficiencies comparable with 0.3μ membrane filters⁽³⁾. Unfortunately, this system has been used only to count α -radiation, which does not require that suspended sediment be removed from the filters. Perfection of the removal of sediment from the BLVNS would be a worthwhile study.

Careful particle size analyses are generally performed using large soil or sediment samples⁽⁷⁾ (upt to 100 gms). A particle size analysis procedure has been developed for sediment weights of less than 1 gram⁽⁴⁾. Mean sediment recoveries of greater than 95% were found with the procedure⁽⁴⁾. Seasonal variation of particle size in the Columbia River was measured with the procedure and is listed in Table 2⁽⁶⁾. It can be seen that there is considerable variability in particle size distribution throughout the year.

Table 1. Seasonal changes in the concentration of particulate matter ($<53\mu$) in river water.

<u>Time of sampling</u>	<u>Concentration* of suspended particulate matter</u>
	$\mu\text{g/l}$
November	310
February	2002
April	34680
June	5788
August	3726

*Based on oven dry (60C) weight.

Table 2. Seasonal changes in the size distribution of particulate matter isolated from river water.

<u>Particle size distribution*</u>					
Equivalent spherical diameter	November	February	April	June	August
<u>μ</u>					
53 to 2.0	70	85	37	78	86
2.0 to 0.5	14	8	39	16	7
0.5 to 0.2	9	5	16	4	5
<.2	7	2	8	2	2

*Based on oven dry (60C) weight and expressed as a percentage of total recovered particulate matter (<53 μ)

Fig. 1 - Percentage Contribution of 2 Particle
Size Fraction as a Function of Silt and
Depth.

In a second study particle size analysis was used to estimate the measure of depth of sediment deposited behind McNary Dam on the Columbia River. Figure 2 shows the percentage composition of two particle size fractions in the sediment ($<2\mu$ & $>10\mu$). It can be seen that maximums in the $<2\mu$ fraction and minimum in the $<10\mu$ fraction occur about every 8 cm., which is believed to represent a yearly cycle.

Relative decay of two radionuclides with different half-lives can also be used to date these sediments from^(7,8)

$$T = \frac{1}{\lambda_2 - \lambda_1} \ln \frac{R_0}{R_1} \quad (1)$$

where

T = time at chosen depth in.

λ = decay coefficient

R_0 = activity ratio of two nuclides in surface sediment

R_1 = activity ratio

Table 3 lists the calculated sedimentation rate (cm/yr) using 3 radionuclide pairs. It can be seen that the average calculated sedimentation rate is in good agreement with particle size analysis calculated rate.

Once the sediment has been isolated and physically characterized, several chemical characterizations may be made on the collected samples including 1) the cation exchange capacity (CEC); 2) organic fraction characterization; 3) inorganic mineralogy; and 4) sorption of some trace components on the sediment.

Table 3. Calculated sedimentation rate (cm/yr) from the relative decay of radionuclide pairs.

<u>Radionuclide Pair</u>	<u>Sedimentation Rate</u>
	<u>cm/yr</u>
$^{65}\text{Zn}/^{152}\text{Eu}$	10.7
$^{54}\text{Mn}/^{65}\text{Zn}$	8.4
$^{65}\text{Zn}/^{60}\text{Co}$	6.5
Average	8.5

Standard methods of cation exchange capacity (CEC) measurement, again, require relatively large quantities of exchanger. However, a small column technique using ^{85}Sr as a tracer has been developed to measure exchanges down to 0.01 meq⁽⁹⁾. Table 4 list the CEC of various particle size fractions from suspended sediment from the Columbia River⁽⁶⁾. It can be seen that there is a considerable increase in exchange capacity of the finer fractions.

Present standard methods of analysis for organic carbon are sufficiently precise to require only small samples⁽⁶⁾. Table 5 lists the seasonal variation carbon content for suspended sediments from the Columbia River. It can be seen that there is a marked seasonal change in percent carbon⁽⁶⁾. This is presumably due to the occurrence of a large amount of phytoplankton cells in the November sample.

Present X-ray diffraction techniques likewise are adequate for characterizing the mineralogy⁽⁶⁾. These methods are generally considered to be semiquantitative and seasonal variation of estimated relative mineral abundances are given in Table 6. This data shows that a large portion of the mineralogy of the suspended, including quartz, amphibole mica is inherited from acidic (granitic) and metamorphic rocks which are atypical of the basaltic rocks of the sample area probably have their source in the Cascade Mts. of Washington and British Columbia. There is some evidence that Columbia Basin Project irrigation return flow may contribute increased montmorillonite to the April, June, and August samples.

Table 4. Cation exchange capacity at pH 7.0 of particle size fractions isolated from river water*

Equivalent spherical diameter	<u>Cation Exchange Capacity[†]</u>	
	Absolute	Relative size fraction contribution to total [‡]
<u>μ</u>	<u>me./100g</u>	<u>%</u>
53 to 2.0	11.5	12.7
2.0 to 0.5	37.1	43.5
0.5 to 0.2	44.4	21.3
>0.2	93.9	22.5

*April sampling

[†]Based on oven dry (60C) weight

[‡]Absolute strontium exchange capacity multiplied by the fraction of total particulate yield (Table 2) and expressed as a percentage of the resulting total (33.3 me./100g).

Table 5. Seasonal changes in the carbon content of particulate matter (<53 μ) isolated from river water

Time of sampling	Contents* of		
	Ash	Total sample	Ash-Free sample
	C		
	----- % -----		
November	65.7	14.4	42.0
February	80.4	7.8	39.7
April	92.1	1.5	19.4
June	86.8	2.8	20.8
August	75.0	7.7	30.9

*Based on oven dry (60C) weight

Table 6. Seasonal changes in the relative abundance of minerals in particulate matter (<53 μ) isolated from river water

Time of sampling	Relative abundance of*					
	Quartz	Feldspar	Amphibole	Mica-illite	Chlorite	Montmorillonite
November	2	2	2	3	2	1
February	2	2	2	2	2	1
April	2	1	2	3	2	2
June	2	2	2	3	3	2
August	2	2	2	2	2	2

*Relative mineral abundance designated as: 1, trace (2-10%); 2, intermediate (5-25%); 3, abundant (>25%)

Sorption of trace components on suspended sediments is generally a rapid process and equilibrium measurements can be used to predict sorption. For those components which can be traced by α -radiation and are sorbed by exchange reactions, a small column technique has been developed to measure sorption⁽¹⁰⁾. Sorption has been shown to be a function of the solution concentration of macroion, pH, and particulate composition. For a given sediment empirical-factorial design experiment can be used to develop equations to predict trace sorption^(10,11).

Models

Two models will be briefly discussed. Much of the data, previously discussed, is capable of obtaining data for model verification.

The first of these models is mass balance, sediment transport model which is being developed for USAEC. Sediment and solute transport is completely described by

$$-V_x \frac{\partial C_i}{\partial x} + \delta_i \frac{\partial^2 C_i}{\partial x^2} + \frac{\partial}{\partial x} \left(D \frac{\partial C_i}{\partial x} \right) = \frac{\partial C_i}{\partial t} + \frac{\partial G_i}{\partial t} \quad (2)$$

$$-V_x \frac{\partial \bar{s}}{\partial x} + \frac{\partial}{\partial x} \left(D \frac{\partial \bar{s}}{\partial x} \right) = \frac{\partial \bar{s}}{\partial t} + S \quad (3)$$

where

V_x = river velocity

C_i = solution concentration of a chosen solute

δ_i = diffusion coefficient

x = distance from chosen boundary

D = dispersion coefficient

G_i = sediment concentration of the chosen solute

s = suspended sediment concentration

S = source term to account for addition of suspended sediment from the system

No completely general solution of equations 2 and 3 are known and thus approximate methods are required. In the Columbia River Sediment transport model, the "method of characteristics" is used to obtain a numerical solution. In the method, the river is divided into a finite number of cells and all processes which act upon solutes and sediments are calculated sequentially. Data for model verification and modification is presently being obtained.

A second model, which has considerable potential value for predicting the erosion of soils from urban and highway construction sites, has been developed by the USDA ^(12,13). In the USDA model

$$E = (C, T, V, S, M) \quad (4)$$

where

E = erosion per unit area per unit time

C = climate factor

T = topographic factor

V = vegetation factor

S = soil factor determined for a given soil

M = cultural practices factor which are determined by man

The USDA developed methods for estimating all of the above factors and thus estimating the amount of erosion which can be expected from a given site. The climatic factor can be directly calculated from Weather Bureau climate data ^(12,13). The topographic factor can be calculated from slope measurements. The

vegetative factor can be estimated from soil type vegetative cover data. The soil factor can be estimated from measured erosion upon large plots of fallow soil of known C and T. The cultural practices of man which only modify the T, V, and S factors and thus can be included in these factors. Unfortunately, eq. 4 is at least approximately soluble determination of the S factor for a given site has been accomplished only with large volume-long term field experiments. A simple laboratory or field method to estimate the S factor would give the construction engineer a valuable tool.

Remedial Measures

Soil erosion consists of 3 principal steps: 1) detachment of particles by the impact of raindrops; 2) transport of the detached particles by flowing water; and 3) deposition of the particles at new locations. Urban, suburban, and highway construction alters the soil-vegetative relationship of a natural system in such a manner accelerated erosion often occurs. Treatments which either increase the ability of soil to resist detachment or increase the infiltration rate of the soil would reduce the erosion of construction sites. Control of erosion at construction sites probable must be controlled by means other than maintenance or improvement of infiltration because vehicular traffic rapidly puddles a soil and reduces infiltration to a negligible amount.⁽¹⁴⁾ Based on this short-term chemical amendment which increases the ability of the soil to resist detachment and sediment, entrapment techniques would seem to be most promising.

Many chemicals are potentially capable of decreasing the detachability of the soil including lignin gelled with alum, carboxymethyl cellulose with alu, petroleum emulsions, and clay formulations⁽¹⁵⁾. A systematic study of these and other amendments could be made.

Use of conventional silting basins to remove sediment from construction site runoff is usually not attractive since these devices are not highly efficient and probably large, non-portable installations would be required. On the other hand, tube sedimentation, a new innovation which has been applied successfully in water and waste treatment operations, appears promising for this application. Shallow tubes are highly efficient sedimentation devices which operate at high throughput rates thus minimizing required sedimentation time⁽¹⁶⁾. It is visualized that a relatively small, temporary facility employing tube settlers could be used for sediment removal at a site during construction. Following construction, such a facility could be moved to another site.

Polyelectrolyte treatment of runoff prior to sedimentation might be desirable to effect removal of fine particulate matter which would otherwise pass through the sedimentation device. The use of polymers to enhance flocculation and sedimentation is quite common in water and waste treatment operations and in-stream silt removal by polyelectrolyte induced sedimentation has been successfully demonstrated⁽¹⁷⁾.

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