TEST OF AN INFRARED LIGHT-EMITTING TURBIDIMETER REPORT CC

A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

REPORT CC

TEST OF AN INFRARED LIGHT-EMITTING TURBIDIMETER

1984

A Study of Methods Used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

A Cooperative Project
Sponsored by the
Interagency Advisory Committee on Water Data
Subcommittee on Sedimentation

Participating Agencies

Agricultural Research Service

Corps of Engineers ** Geological Survey

Forest Service ** Bureau of Reclamation

Federal Highway Administration ** Bureau of Land Management

REPORT CC

TEST OF AN INFRARED LIGHT-EMITTING TURBIDIMETER

By

JOSEPH J. SZALONA

Prepared for Publication by the Staff of the
Federal Inter-Agency Sedimentation Project
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minnesota

Published by
U.S. Army Engineer District, St. Paul

1984

CONTENTS

ILLUSTRATIONS

TABLES

TEST OF AN INFRARED LIGHT-EMITTING TURBIDIMETER

By Joseph J. Szalona

ABSTRACT

A turbidimeter equipped with a pulsed infrared light source was tested for use as a suspended-sediment concentration analyzer. Two alluvial sediments were divided into groups according to particle-size fractions. Various concentrations of each of these groups were analyzed. The instrument readings were nearly proportional to concentration within each group; however, among the groups the proportionality factors varied inversely with particle size.

The instrument readings for mixtures of sediment sizes were predicted from the concentration relationships developed for the individual groups. Predicted values compared favorably with measured values.

The turbidimeter meter reached full-scale deflection at a clay concentration of about 100 milligrams per liter. However, the instrument can be adjusted to read higher concentrations. The instrument was not significantly affected by water temperature, dissolved solids, or by sediment color. The instrument did respond, however, to ambient natural or artificial light. Optical properties of the sediment particles also affected the instrument response.

This turbidimeter, like other types of turbidimeters, cannot measure sediment concentration unless the particle-size distribution is known.

INTRODUCTION

Much time and expense is required to collect and analyze suspended-sediment samples. Currently, samples of river water must be collected and then transported to a laboratory where they are analyzed. A device that could analyze suspended-sediment concentration instantaneously in place would be highly desirable. A turbidimeter, fastened to a streamlined weight, could possibly serve such a purpose.

Turbidimeters have been used by industry since the 1930's to measure the concentration and (or) the size distribution of such things as paint pigments and portland cement. They consist of a light source, such as a tungsten-filament bulb, that directs light onto a photovoltaic cell, which is connected to an ammeter. Light that reaches this type of photodetector produces an electrical current that registers on the meter. Particles suspended between the light source and photocell interfere with the light transmission by scattering and absorbing the rays. This interference alters the meter reading.

History

The basic design of the photodetector-type turbidimeter is attributed to L. A. Wagner (Orr and DallaValle, 1959, p. 120) who was concerned with the laboratory analysis of portland cement. Harner and Musgrave (1959, pp. 172-178, also see Orr and DallaValle, 1959, p. 120) slightly modified this design and developed an analytical procedure to convert light readings to a size distribution. A similar instrument was tested and described in Report No. 14, Inter-Agency Committee on Water Resources (1963, pp. 129-132). Only particles in the 20- to 120-μm (micrometer) range were tested due to instrument operation problems.

Purpose and scope

The purpose of this investigation is to determine the performance characteristics of a recently developed variable-gap turbidimeter and to evaluate its potential for development as an in-place suspended-sediment concentration analyzer that incorporates this turbidimeter's hardware. The variable-gap turbidimeter is manufactured by Markland Specialty Engineering Ltd., Etobicoke, Ontario, Canada.* This model (10-spec) is a laboratory version of the Markland's Model 10 "Sludge Gun," an instrument used for locating sludge strata in storage tanks, ponds, or other such reservoirs. Both instruments incorporate a pulsed infrared light beam which is emitted from a diode. Both instruments also use a phototransistor as a detector. The pulsed infrared instruments are more compact and use less energy than older turbidimeters.

The characteristics of the turbidimeter were tested by using natural sediments, sorted into groups according to particle size, which were analyzed at various concentrations in sediment-water mixtures. Instrument readings were then compared for the different particle-size groups. These data were used to calculate the readings expected when sediments from the groups were mixed. The effects of particle color, particle transparency, dissolved solids, and ambient light were also investigated.

Acknowledgments

This study was conducted as part of the continuing research program of the Federal Inter-Agency Sedimentation Project. The project is funded by the Geological Survey, Corps of Engineers, Forest Service, Bureau of Reclamation, Agricultural Research Service, Federal Highway Administration, and Bureau of Land Management. Supplementary funds for this study were contributed by the Hydrologic Instrumentation Facility of the U.S. Geological Survey.

---

* Trade names are included for information of the reader and do not constitute endorsement by the United States Government.

HARDWARE

The instrument tested is a laboratory version of a device used for locating sludge strata, and is not marketed as a suspended-sediment analyzer. The instrument (fig. 1), is 115-V a-c powered and consists of an instrument box and test chamber. The instrument box contains power and signal-conditioning electronics, gain and zero controls, and a unitless analog voltmeter. The 1-liter test chamber, which houses the infrared light emitting diode (LED) and the photodetector, is connected to the instrument box by a three-wire cable.

Pulsed infrared light is transmitted from the LED to the photodetector. The length of the optical path can be varied from 0 to 100 mm (millimeters). The light converges to a point 25 mm ahead of the LED and diverges beyond this distance. Particles suspended in a medium between the LED and photodetector absorb or reflect some of the incident (oncoming) light, and thereby reduce the amount of light transmitted to the photodetector. This loss corresponds to the reading on the voltmeter. When particulate concentrations are low, the gap between the LED and photodetector may be lengthened to introduce a greater number of particles. Conversely, the gap may be shortened when sediment concentrations are high.

TEST PROCEDURES AND RESULTS

Sediment preparation

Two natural alluvial sediments, with particles ranging from clay to sand sizes, were each divided into groups based on particle size. Lumps of dry sediment were ground with mortar and pestle and then dry sieved through a nest of screens ranging from 125 μm to 44 μm. Sediment retained on the 125-μm sieve was discarded. Sediment in each sieve was placed in the next-coarser sieve, then the sediment was wet sieved after the sieves had been renested. This wet sieving process was repeated; then sediment remaining in each sieve was isolated, dried, and labeled.

The sediment-water mixture that passed through the 44-μm sieve was treated with a chemical dispersant and subjected to ultrasonic vibration. The mixture was then placed in cylindrical containers to depths of

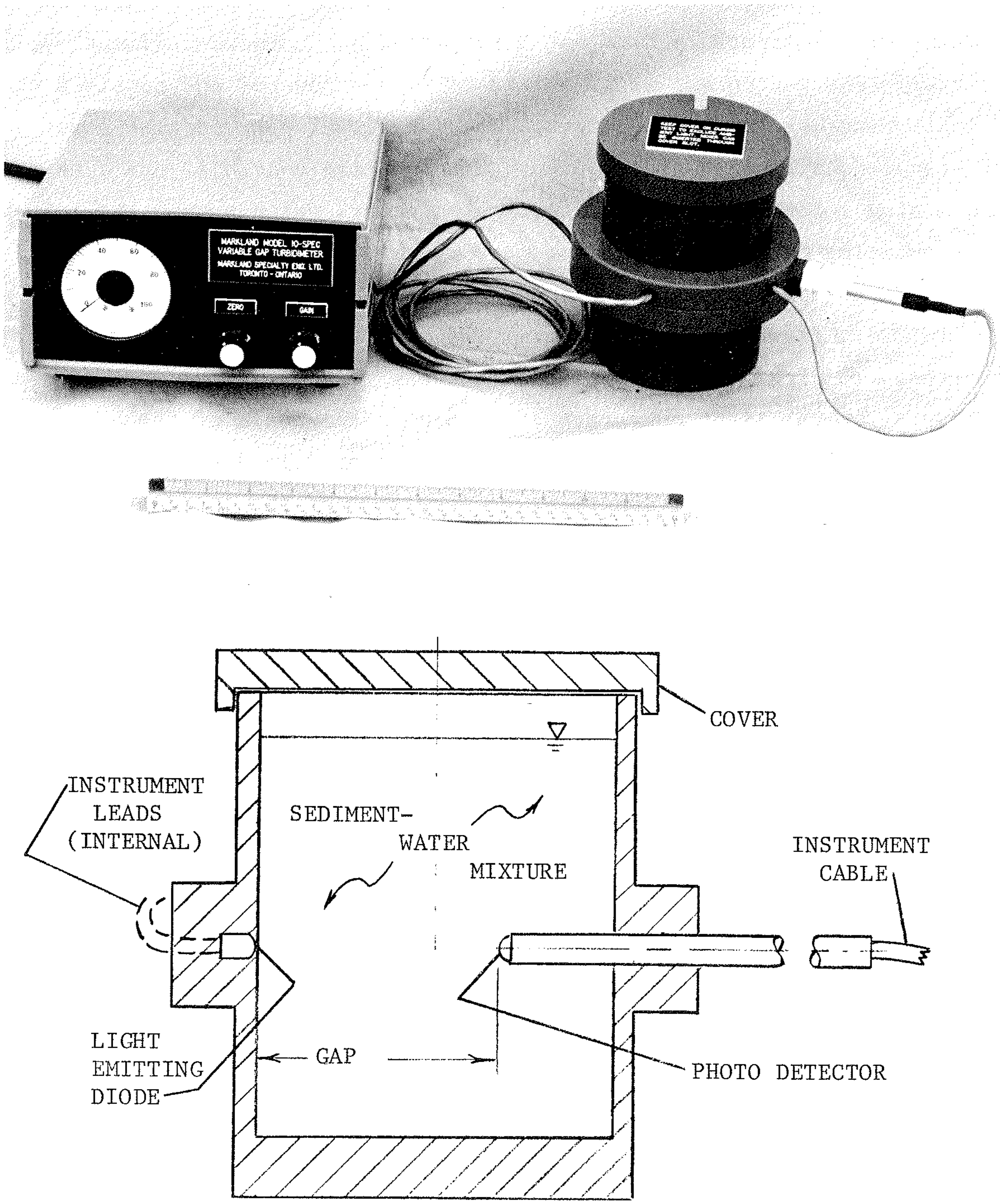

Figure 1.--Turbidimeter. Photograph shows the instrument box on the left and the test chamber to the right. Below is a simplified cross-sectional view of the test chamber (approximately half scale).

10 cm (centimeters), agitated, and then the particles were allowed to settle for predetermined lengths of time. Sediment groups were then isolated by settling and decanting or by siphoning. These sedimentation processes were repeated to purify groups. The silt-sized groups were dewatered and dried. Clay-sized groups were left as mixtures with water. The concentration of each mixture was determined by filtering a known volume of the mixture and then determining the dry weight of the clay residue on the filter.

Sediment description

The two alluvial sediments used in the tests, as well as a processed sediment and glass beads, had the following physical characteristics:

West Bitter Creek, Oklahoma, material consists of red, well-graded fine sand, silt, and clay. The sand-sized particles appear to be quartzose, subrounded, clear, and variably iron-stained red.

Spokane, Washington, material is composed primarily of clay, with a small amount of silt and a negligible amount of fine sand. The material is medium gray.

Bay City, Wisconsin, sand is quartzose, rounded, frosted, and uniformly iron-stained orange-yellow. It is commercially processed from a poorly cemented Paleozoic sandstone.

Glass beads are commercially manufactured spheres which are water clear and have a glossy luster. They are available in various narrow size ranges.

Turbidimeter adjustment

The turbidimeter was adjusted prior to use as follows:

1. The test chamber was filled with clear water.
2. The gap (fig. 1) was set. The proper setting will be discussed later.
3. All light was blocked from the photodetector, then the GAIN control was adjusted until the meter just read 100 on the unitless 0 to 100 scale.

4. The test chamber was covered to prevent ambient light from reaching the photodetector. Then, with the infrared light path unobstructed, the ZERO control was adjusted until the meter read zero.

5. Steps 3 and 4 were repeated as necessary.

The gap can be set from 0 to about 100 mm, but a gap of 75 to 90 mm allowed for a meter reading of zero when the concentration was zero. In this interval, the greatest change in meter reading per unit change in concentration was at the 75-mm gap setting. Gap settings less than 75 mm can be used for concentrations that would cause more than a full-scale meter deflection. The gaps of less than 75 mm produce a zero meter reading at a finite concentration. Increased meter readings are obtained as the gap length is shortened because the photodetector receives more energy from the light source as the photodetector approaches it.

Effect of ambient light and water level on instrument response

A small amount of sediment was added to water in the test chamber. The cover was installed on the chamber and the meter reading was noted. The cover was then removed and the chamber was exposed to ambient light sources. Fluorescent light, incandescent light, and sunlight each caused a reduction in the meter reading. The reduced reading indicated a concentration lower than the known value.

In another test, water-sediment mixture was poured into the test chamber to a level just above the light path. The lid was installed and the meter reading was recorded. Additional mixture was added and the process was repeated several times. The meter readings changed with changes in level for levels less than 20 mm above the light path. Meter readings for mixture levels above this elevation remained constant. All subsequent tests were conducted with mixture volumes of 750 mL to 900 mL. The smaller volume corresponds to an elevation 25 mm above the light path, while the larger volume is the maximum that can be stirred within the chamber.

Measurements of suspended-sediment concentration

The West Bitter Creek material was analyzed for several sediment concentrations of sediment-water mixture up to 1,000 mg/L. Each particle-size group was examined individually. The meter readings for various concentrations of each group are presented in figure 2. In general, the curves are linear to slightly curved, share a common origin, and have slopes inversely proportional to the particle diameters. The curves for the two groups of the clay sizes (0 to 1.4 μm and 1.4 to 4 μm) nearly overlap and therefore are represented by one curve.

The Spokane material was analyzed because its gray appearance contrasted with the red coloration of the West Bitter Creek sediment. The 20- to 44-μm fraction data plotted to the left of the curve for the same fraction of West Bitter Creek material. This can be explained by the skewed distribution within the Spokane fraction which is overly represented by the smaller particles.

The 4- to 20-μm Spokane fraction, likewise, plotted to the left of the curve for the same fraction of West Bitter Creek material. The Spokane material was reprocessed due to suspected clay contamination. Retesting revealed a shift of the curve to the right, as anticipated. Tests on the two clay-size groups produced curves that overlapped the curve for the same sizes in the West Bitter Creek material. Because these groups are least vulnerable to contamination from other-sized particles during group-isolation processing, the results imply that particle color is not an important variable.

Results shown in figure 2 indicate that the turbidimeter response varies with particle size. The turbidimeter readings can be interpreted in terms of sediment concentration only when the particle-size group is known. Experiments were conducted to determine whether turbidimeter readings are meaningful when broader ranges of sediment-particle sizes are analyzed. Various mixtures of sediment from the West Bitter Creek groups were combined and tested with the turbidimeter. Results are presented in table 1. Readings for the same mixtures were calculated and are listed in the same table. The calculation methods are explained in a following section.

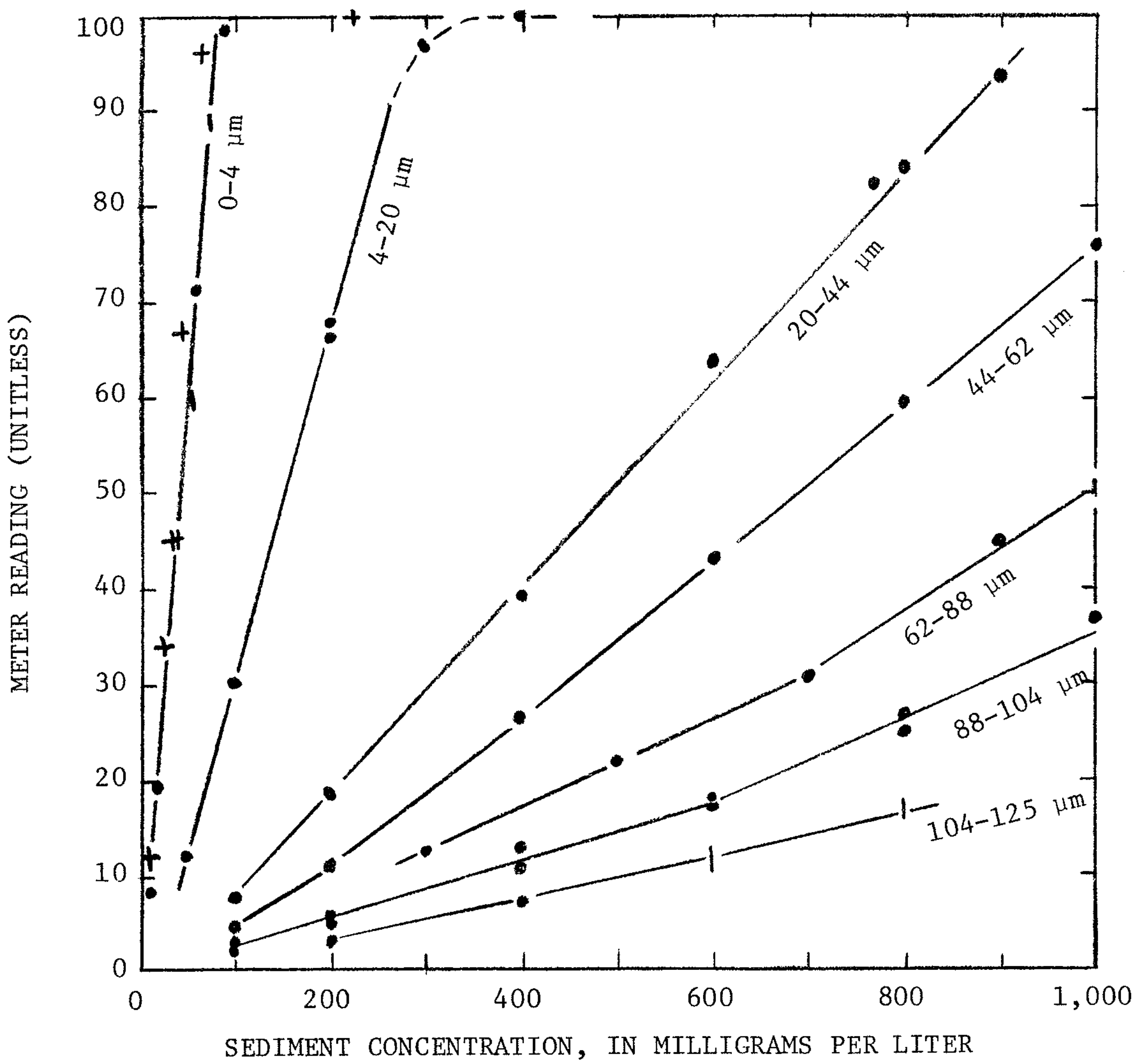

Figure 2.--Instrument response to different concentrations of various particle-size fractions for West Bitter Creek, Okla., sediment. The short vertical lines represent a range of readings where single values could not be determined. The +'s represent datum points for the 1.4- to 4-µm group. The gap was set at 90 mm.

Table 1.--Comparison between actual instrument readings and calculated readings for various combinations of West Bitter Creek material. Calculations were based on data presented in figure 2. Tests on material from single groups were conducted as a check on meter response. Tests 1, 2, and 3 were conducted on different days.

Sediment concentrations, in milligrams per liter, for the following sediment particle-size groups, in micrometers:				Readings	
4-20 µm	20-44 µm	44-62 µm	62-88 µm	Calculated*	Actual
		Test 1			
--	200	400	200	53 (61)	59-60
50	200	400	200	65 (73)	78
--	200	--	--	18-19	18
--	200	200	--	30 (33½)	34
50	200	200	--	42 (43)	51
50	--	--	--	12	12
50	100	--	--	20 (25)	25
		Test 2			
--	--	--	200	8	7-8
--	--	200	200	20 (22)	20-21
--	100	200	200	28 (33)	30
100	100	200	200	58 (64)	69-70
100	--	--	--	30	30
--	100	--	--	8	9-10
50	50	--	--	16 (19)	21
200	--	--	--	67	65-66
100	--	--	--	30	30
100	200	--	--	48-49(50)	53
100	200	200	--	60 (64½)	70
200	--	--	--	67	70
200	200	--	--	85-86(88)	94-95
		Test 3			
56	--	--	--	14	16
56	56	--	--	18 (21)	23
100	--	--	--	30	29
100	100	--	--	38 (43)	43
--	150	--	--	13	9
150	150	--	--	60-61(63)	59-60
--	150	--	--	13	9
150	150	--	--	60-61(63)	58
150	150	150	--	68-69(74)	70
150	150	150	150	75 (82)	80

*Numbers in parentheses are values determined by the second calculation method, as described in the text.

Clear glass beads were tested with the turbidimeter to investigate the influence of sediment optical properties on the readings. Data for the glass beads and similar-sized West Bitter Creek sand were plotted and are presented in figure 3. The glass beads provided lower meter readings for comparable concentrations of the West Bitter Creek material, indicating that more light was transmitted to the photodetector when the glass beads were tested. Handbook values (Bolz and Tuve, 1970, p. 168-169) show that transmittance values for infrared light through clear glass are higher than for infrared light through opal glass, which is probably optically similar to the West Bitter Creek sand. The test and handbook values indicate that the optical properties of sediment particles influence the meter response.

Bay City sand was tested for comparison. Data compared very well with that collected for the West Bitter Creek material.

Dissolved solids

Salt solutions were tested in the turbidimeter to determine the effect of dissolved solids on meter response. A 2,200-mg/L solution of magnesium sulfate was tested, as well as similar solutions of sodium chloride and calcium chloride. Readings ranged from 0 to 2 when the added salts were completely dissolved. This is a negligible effect for such concentrations of dissolved solids.

Source/detector gap

If a sediment concentration produces a meter reading beyond 100, the gap length can be reduced until the reading appears within the range of the meter. Figure 4 shows concentration-meter reading relations for several gap settings for various concentrations of 1 μm or smaller clay particles. The 75- and 90-mm gap settings are the two extremes in gap length at which zero concentrations show a zero meter reading. The slopes are different for the two curves because different gain and zero settings were used. The settings used for the 90-mm gap provided the greatest change in concentration per unit change in meter reading. The gain and zero controls were left at this setting and the gap was

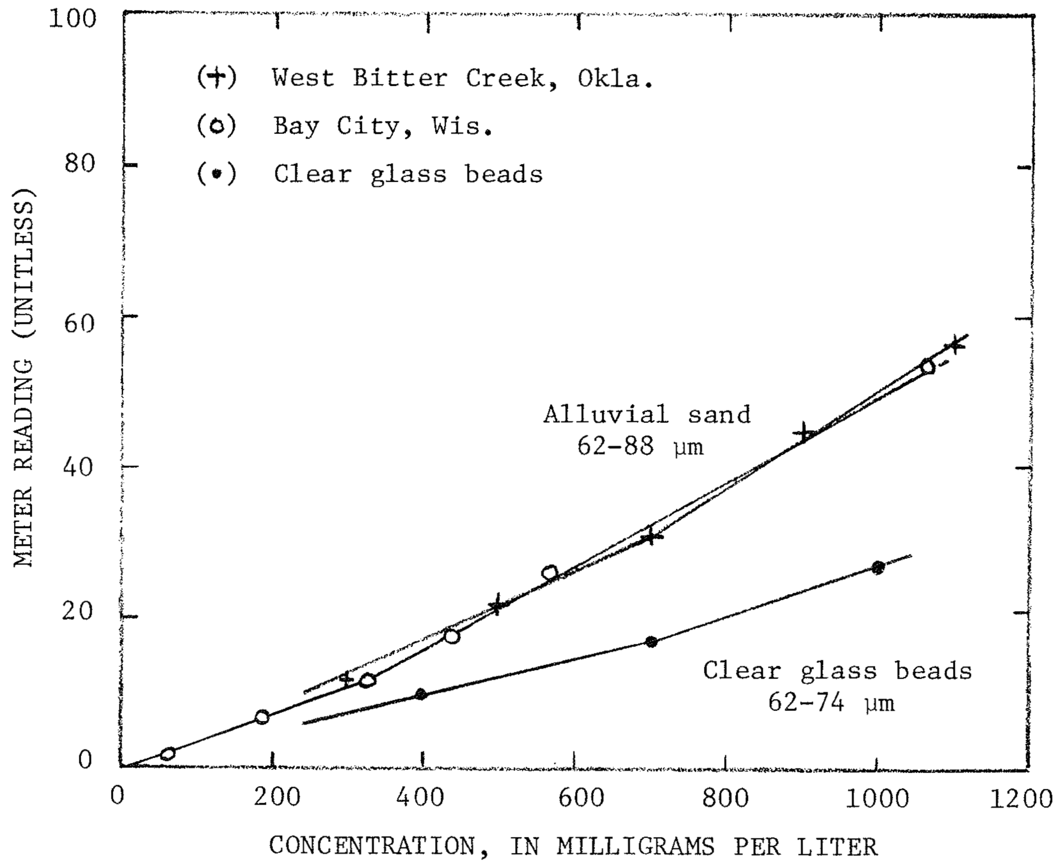

Figure 3.--Comparison of turbidimeter readings for various concentrations of natural sands and manufactured clear glass beads.

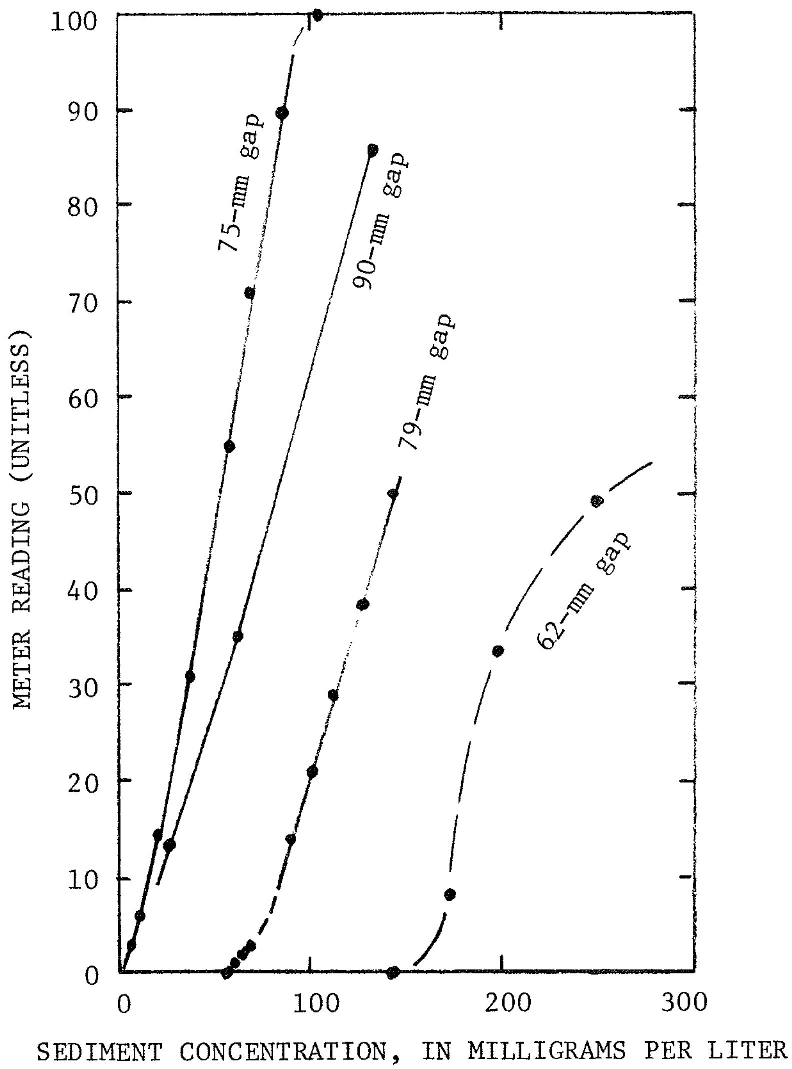

Figure 4.--Instrument response to various concentrations of ≤1-μm clay sizes for several gap settings.

decreased to 79 mm and then 62 mm. The 79-mm gap shifts the linear range for instrument response for concentrations of about 100 to 200 mg/L. The 62-mm gap increases the threshold concentration level, and the response curve becomes nonlinear.

The graph in figure 5, provided by the turbidimeter manufacturer, shows similar curves for higher concentrations of sediment and for smaller gap settings. As readings approach 100, the slopes of the curves approach zero. In this situation, small variations in the meter reading correspond to large differences in concentration.

CALCULATIONS FOR PREDICTING TURBIDIMETER READINGS

The curves in figure 2 were used to calculate meter readings for combinations of sediment from the sediment groups.

The values on the left in the column marked "calculated reading" in table 1 were computed by adding readings for the various components of the mixtures. As an example, a mixture composed of 90 mg of 4- to 20-μm material plus 90 mg of 20- to 44-μm material in 900 mL of distilled water (100 mg/L for each component) had a calculated reading of "38", "30" for the 4- to 20-μm component (at 100 mg/L) added to "8" for the contribution for the 20- to 44-μm component (also at 100 mg/L). Calculated values were generally lower than the measured values, especially for the higher concentrations.

Examination of the graphs for the coarser-sized material in figure 2 shows an increase in slope as concentrations increase. This led to a second method for computing the calculated reading. Using the previous example, we can see that the actual <u>total</u> concentration is 200 mg/L with a 50 percent weight contribution from each component. The new values, therefore, were calculated by taking the 200 mg/L reading for the component size ranges and by multiplying by their respective contribution, that is, (19 x 1/2) for the 20- to 44-μm component and (67 x 1/2) for the 4- to 20-μm component. The final value, 43, corresponds well with the observed reading. There are cases, however, when the second method must be supplemented by the first method. Take, for example, the situation where total concentration is 500 mg/L and where there is a 100 mg/L

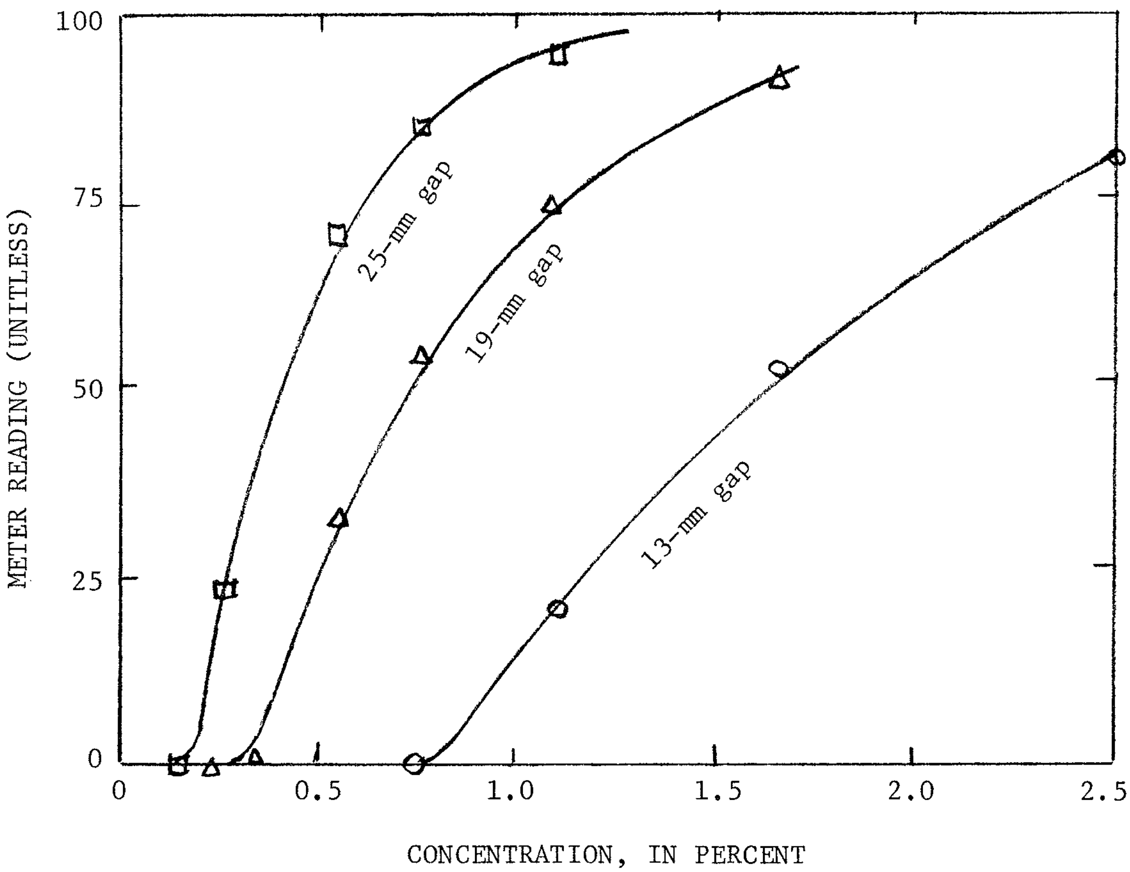

Figure 5.--Meter response to slurry concentrations for several gap settings. Test material was mixed silt, clay, and ash from Mount St. Helens, Wash. The test was conducted for the U.S. Geological Survey by the turbidimeter manufacturer, who also provided the graph.

component of 4- to 20-μm material. The 4- to 20-μm graph is actually only usable in the 0- to 300-mg/L range. The full value for 100 mg/L must be used, as was done in the original calculation.

SUMMARY AND CONCLUSION

The turbidimeter can measure the concentration of narrow size-ranges of sediment in mixtures with water. Readings, when plotted against concentration, form curves that are nearly linear, share a common origin at zero concentration and zero meter readings, and have slopes that are inversely proportional to particle diameters. The curve for the clay sizes, 0 to 4 μm, had the greatest slope, and intercepted the full-scale line at a concentration of about 100 mg/L.

Meter readings were predictable for mixes of sediment from known particle-size groups.

A comparison of red-colored sediment to gray sediment indicated that color is probably not a factor when measuring sediment concentration with the infrared light-emitting turbidimeter. Transparent glass beads, however, did allow more light to reach the photocell than similar sizes and concentrations of translucent alluvial sands.

Dissolved solids had no or negligible effect on the meter reading.

Natural and artificial ambient light decreased the meter reading, and indicated a concentration lower than what actually existed.

Like other turbidimeters, this instrument is influenced by particle-size distribution as well as by sediment concentration. At this time, particle-size distribution is generally not determinable on-site. This instrument, therefore, cannot be used as an in-situ sediment-concentration measuring device.

REFERENCES

Bolz, R. E., and Tuve, G. L., eds, 1970, Handbook of tables for applied engineering science: Cleveland, Ohio, Chemical Rubber Co., p. 168-169.

Harner, H. R., and Musgrave, J. R., 1959, A photoelectric sedimentation method for particle size determination in the subsieve range, in Symposium on particle size measurement; Philadelphia, Pa., American Society for Testing Materials Special Tech. Pub. 234, p. 172-178.

Inter-agency Committee on Water Resources, Subcommittee on Sedimentation, 1963, Determination of fluvial sediment discharge, Report 14 of A study of methods used in measurement and analysis of sediment loads in streams: presently published in Minneapolis, Minn., Federal Interagency Sedimentation Project, 151 p.

Orr, Clyde Jr., and DallaValle, J. M., 1959, Fine particle measurement, New York, N. Y., The Macmillan Company, 353 p.