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CALIBRATION OF A TURBIDITY METER FOR MAKING ESTIMATES OF TOTAL SUSPENDED SOLIDS CONCENTRATIONS AND BEAM ATTENUATION COEFFICIENTS IN FIELD EXPERIMENTS

J. W. Usry and C. H. Whitlock

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NASA
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

SUMMARY

Management of water resources such as a reservoir system requires using analytical models which describe such parameters as the suspended sediment field. To select or develop an appropriate model requires making many measurements to describe the distribution of this parameter in the water column. One potential method for making those measurements expeditiously is to measure light transmission or turbidity and relate that parameter to total suspended solids concentrations. An instrument which may be used for this purpose was calibrated by generating curves of transmission measurements plotted against measured values of total suspended solids concentrations and beam attenuation coefficients.

Twenty-one experiments were conducted by lowering the instrument into the water column. Five measurements were made at John H. Kerr Reservoir and 16 at the NASA Langley Research Center. Total suspended solids concentrations ranged from 0.2 mg/l to 295 mg/l and corresponding beam attenuation coefficients from 0.2 m^{-1} to 240 m^{-1}. Results of these experiments indicate that field measurements made with this instrument using curves generated in this study should correlate with total suspended solids concentrations and beam attenuation coefficients in the water column within 20 percent.

INTRODUCTION

Prudent management of water resources such as a reservoir system requires an understanding of the hydrologic processes occurring in the water column. These processes are best understood using analytical models which describe such parameters as the hydrodynamics, temperature structure, and suspended sediment field. The level of suspended sediment concentration, for example, is related to land uses, type of crops, agricultural practice, type of soil, soil erosion rate and sediment transport, and hydrologic processes of rainfall and runoff (see ref. 1-10).

A prerequisite to selecting an appropriate model to describe a reservoir system is to collect physical, hydrological, limnological, and meteorological information. Part of this research effort involves defining the distribution of total suspended sediment concentrations. Usually two dimensional distributions are sufficient, but this requires many measurements within a short time interval to avoid errors due to changes in local conditions. One method for making these measurements expeditiously is to measure turbidity or light transmission distributions and relate those measurements to the total suspended solids concentrations in the water column.

An instrument which may be used for this purpose was calibrated by correlating transmission measurements with an accurate measurement of beam attenuation coefficient using Langley's small angle scattering meter (see ref. 11) and measurements of total suspended solids concentrations using standard laboratory techniques. The instrument is a turbidity meter, Model TMU-1B, built by the Montedoro-Whitney Corporation, San Luis Obispo, California. This instrument was selected primarily because it was available immediately, whereas other comparable instruments could not be obtained for several months or longer. The calibration consisted of measurements of transmission with the TMU-1B, selected chemical and physical properties of water samples, and beam attenuation coefficient and 90^{0} scattering properties of water samples. This paper reports the results of these calibration studies.

Tables are presented which list the specifications of the TMU-1B and measured chemical, physical, and optical properties of the water samples. A photograph of the instrument and figures relating the transmission measurements to beam attenuation coefficients and to concentrations of total suspended solids are shown. Twenty-one measurements of transmission were made for beam attenuation coefficients ranging from 0.2 m^{-1} to 240 m^{-1}, and corresponding concentrations of total suspended solids from 0.2 mg/l to 295 mg/l.

INSTRUMENTS AND EXPERIMENTS

Instruments

A photograph and conceptual sketches of the TMU-1B (with the Spectra 555 silicon detector) are shown in figure 1 and the company's specifications are listed in table I. The instrument is a combined transmissometer and nephelometer, but for these experiments only measurements using the transmissometer were made because of experimental operational problems. However, measurements of 90^{0} scattering properties were made for each transmission measurement with a standard light-scattering photometer (Model No. 3000 built by the Virtis Company, New York) so that nephelometer field measurements made later could be correlated with the laboratory measurements.

The TMU-1B transmissometer uses a collimated light source that directs a beam at a 180^{0} prism that reflects the beam back into a photocell sensor (see fig. 1). Path lengths of 1, 1/3, and 1/10 meter can be used by adjusting the position of the prism along the aluminum channel. The nephelometer uses the same sensor, but measured light scattered by suspended particles using the 90^{0} prisms. The prism is mounted such that the front face is very close to the light beam (see fig. 1).

The small angle scattering meter used for making beam attenuation coefficient measurements was developed at Langley (ref. 11) and operates on the same optical principle as the Scripps Institute of Oceanography ALSCAT instrument in reference 12. Operational principles of the standard light-scattering photometer used for measuring 90^{0} scattering properties are described in reference 13.

Experiments

Twenty-one experiments were conducted by the TMU-1B by submerging the instrument in the water. Five experiments were conducted at the John H. Kerr

Reservoir in March 1981 by lowering the instrument over the side of a boat into the water to a depth equal to one-fourth the secchi depth. During this time, a representative bottom sediment sample was taken with a Kahlsico screen top sediment sampler (Model No. 214WA010 built by Kahl Scientific Instruments Corp., San Diego, California). This sediment sample was brought to Langley and part of the sample was mixed with filtered, deionized water to make a 150-liter sediment-water mixture. After desired measurements were made, additional sediment was added to the first mixture. This procedure was repeated so that measurements were made on ten 150-liter sediment-water mixtures. Similarly, six other 150-liter mixtures were made by adding 5μ minusil particles to filtered, deionized water.

One-liter samples were taken from Kerr Reservoir and from each of the 150-liter mixtures and analyzed for concentrations of total suspended solids, dissolved organic carbon, and particulate organic carbon. The values are listed in table II. Beam attenuation coefficients were measured for each 150-liter mixture for wavelengths ranging from 400 nm to 800 nm. Also, 90^{o}-scattering was measured at a wavelength of 546 nm for each mixture. These values are listed in table III. Measurements of beam attenuation coefficient at a wavelength of 550 nm were made on two water samples at Kerr Reservoir believed to be representative of samples 48-9, 48-10, and 48-11 and these values are also listed in table III. Transmission measurements of the 150-liter mixtures and those made at Kerr Reservoir are listed in table IV with the path length settings used on the TMU-1B.

RESULTS AND DISCUSSION

Physical and chemical properties of the John H. Kerr Reservoir samples listed in table II, 48-7 through 48-11, were determined several hours after the transmission measurements were made. Similarly, those properties were determined for the samples from experiments 49-1 through 49-10 several hours after the experiments were done, but several weeks had elapsed since the bottom sediment material had been extracted. For this reason, chlorophyll measurements were not made on samples 49-1 through 49-10. Samples 49-11 through 49-16 contained 5μ minusil, a high-purity crystalline silica in filtered, deionized water and measurements for chlorophyll were not considered necessary. Concentrations of dissolved organic carbon (DOC) and particulate organic carbon (POC) in these samples (49-11 through 49-16) probably indicate contamination of the water during experimentation or limitations in the laboratory measurement procedures.

Figure 2 shows the beam attenuation coefficient at a wavelength of 550 nm from table III plotted as a function of transmission as measured by TMU-1B from table IV. Similar curves may be plotted for the other wavelengths. Trends in the variation of transmission with beam attenuation coefficient are similar for all three path lengths. Transmission measurements representing the field experiments (48-7 through 48-11) were made at five locations in the Reservoir as indicated on figure 3. Measurements of beam attenuation coefficient and 90^{o}-scattering were not made on the water samples obtained at these locations as mentioned previously. However, two measurements of beam attenuation coefficient were made on water samples from locations 1 and 2 shown on figure 3. The samples were obtained at 10 a.m. and 2 p.m. and beam attenuation coefficients were 10.9 m^{-1} and 11.0 m^{-1}, indicating a stable water column. Transmission measurements at locations 48-9, 48-10, and 48-11 on figure 3 also indicate a stable water column over most of the length of the reservoir. For these reasons, beam attenuation coefficient was assumed to be 11.0 m^{-1} at points 48-9, 48-10, and 48-11 and was plotted on figure 2 to represent the field experiments.

Figure 4 shows the variations of transmission with concentrations of total suspended solids for the three path lengths. These variations are practically identical to those of transmission versus beam attenuation coefficient in figure 2. The similarity in these variations (fig. 2 and fig. 4) should be expected since the total suspended solids in the water mixtures were predominantly inorganic particles with scarce amounts of chlorophyll and dissolved organic carbon. In addition, the water column at Kerr Reservoir contained chlorophyll and dissolved organic carbon (table II) but the measured transmission values follow the trend line in figure 4 for TMU-1B transmission values between 16 and 84 percent (table IV). Other water mixtures with different amounts of chlorophyll, dissolved organic carbon, or other dissolved substances may have different results, however.

Sediments in the water column of a reservoir would probably be similar in size and shape to the finer particles found in the bottom sediment. For these experiments, the bottom sediment material from Kerr Reservoir was mixed with conditioned water using a small trolling motor. This mixture with the finer particles in suspension was then used to make the 150-liter water-sediment mixtures. Results of studies of Kerr Reservoir bottom sediments (ref. 14) and 5μ minusil particles (ref. 15) indicate greater quantities of finer particles in the Kerr Reservoir bottom sediment material. This implies that the data on figures 2 and 4 for the field and laboratory experiments (49-1 through 49-10 and 48-7 through 48-11) probably best represent the variation of transmission with beam attenuation coefficient and total suspended solids concentrations. Assuming the beam attenuation values measured by the small angle scattering meter are correct (repetitive measurements indicate 1 σ inaccuracies are less than 5 percent, ref. 11), then these data suggest that field measurements of transmission in the water column with the TMU-1B used with the curves in figures 2 and 4 should correlate with beam attenuation coefficient and total suspended solids concentrations within about 20 percent.

CONCLUDING REMARKS

A turbidity meter which measures transmission of light was calibrated by lowering the instrument into the water and generating curves of the measured transmission plotted against measured values of beam attenuation coefficient and total suspended solids concentrations. Twenty-one measurements of transmission were made for beam attenuation coefficients ranging from 0.2 m^{-1} to 240 m^{-1} with corresponding concentrations of total suspended solids from 0.2 mg/l to 295 mg/l. Results of these experiments indicate that field measurements of transmission made with this instrument and used with these curves should correlate with total suspended solids concentrations and beam attenuation coefficients within about 20 percent. The water column at John H. Kerr Reservoir, where five of these experiments were conducted, contained moderate concentrations of chlorophyll and dissolved substances whereas the water mixtures contained small amounts. For these reasons, these results should be used for similar conditions.

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TABLE I. - TMU-1B SPECIFICATIONS

Range:	0-100%, 0-10%, 0-1%
Relative Accuracy:	2%
Linearity:	1%
Resolution:	1% of Range
Recorder Output:	Range Dependent
Recorder Impedance:	0-1500 Ohms
Operating Temperature:	$0\text{-}50^{0}$ C
Operating Pressure:	0-160 psi (Depending on case)
Source Lamp:	PR-17
Lamp Life:	200 hours nominal
Spectral Characteristics:	Relative Sensitivity 0.3, 1.0, 0.3 at wavelength 400, 550, 900 nm
Power:	(2) Gel-Cell, GC-680, 6V, 8 A.H.
Battery Life:	Approximately 10 hours between charges. 400 complete charge/discharge cycles minimum. NOTE: Power requirement for underwater sensor is 10.5-13 VDC, 480ma current.
Cable Length:	50 meters marked in 1 meter increments
Cable Breaking Strength:	400 lbs. minimum
Pressure Windows:	1¼ inch thick plexiglass II
Drum Weight:	38 lbs.
Probe Weight:	15 lbs.
Probe Length:	33½ inches
Probe Orientation:	Support cables for horizontal mounting provided. Vertical mounting also available.

TABLE II. - PHYSICAL AND CHEMICAL PROPERTIES OF WATER SAMPLES

Sample	TSS mg/l	Ch a[1] µg/l	DOC mg/l	POC mg/l
49-1[2]	0.2	-	0.4	0.03
49-2	3.7	-	0.2	0.1
49-3	7.5	-	0.3	0.2
49-4	13.8	-	0.2	0.2
49-5	25.2	-	0.4	0.4
49-6	54.5	-	0.4	0.6
49-7	85.5	-	0.4	1.1
49-8	133.1	-	1.3	1.5
49-9	185.4	-	1.1	1.5
49-10	294.8	-	2.0	1.9
49-11[3]	-	-	<0.04	0.01
49-12	0.7	-	0.04	0.01
49-13	4.6	-	<0.04	0.02
49-14	9.9	-	<0.04	0.04
49-15	18.8	-	0.12	0.02
49-16	38.3	-	0.20	0.05
48-7[4]	22.2	8.1	2.3	0.6
48-8	13.1	4.8	4.6	0.5
48-9	10.1	7.0	2.1	0.6
48-10	9.6	16.9	1.8	0.6
48-11	11.7	12.4	2.4	0.5

Notes:

1. Not measured for samples 49-1 through 49-16.
2. John.H. Kerr reservoir bottom sediment mixed with filtered-deionized water.
3. 5-micron minusil particles mixed with filtered-deionized water.
4. Field measurements performed on March 26, 1981.

TABLE III. - BEAM ATTENUATION COEFFICIENT, m^{-1}, AND VOLUME SCATTERING FUNCTION AT 90^o, $m^{-1}sr^{-1}$, FOR THE 150-LITER WATER MIXTURES

	WAVELENGTH									
Sample	400	450	500	550	600	650	700	750	800	$\beta(90^o)$[1]
49-1	0.5	0.4	0.3	0.2	0.3	0.4	0.6	2.8	2.8	0.209×10^{-2}
49-2	4.3	3.7	3.2	2.9	2.7	2.7	2.6	4.7	4.1	2.004
49-3	8.2	7.3	6.4	5.8	5.3	5.0	5.0	6.7	5.8	4.509
49-4	14.6	13.6	12.2	11.2	10.1	9.5	9.0	10.3	9.3	9.125
49-5	26.6	24.4	21.9	20.4	18.6	17.3	16.5	17.7	16.1	18.720
49-6	58.0	53.0	48.0	44.0	41.0	38.0	35.0	36.0	32.0	63.340
49-7	95.0	86.0	78.0	72.0	65.0	61.0	57.0	55.0	51.0	*1
49-8	144.0	132.0	120.0	111.0	102.0	94.0	87.0	83.0	76.0	*1
49-9	193.0	183.0	168.0	151.0	138.0	128.0	119.0	113.0	105.0	*1
49-10	305.0	282.0	259.0	243.0	219.0	202.0	188.0	176.0	165.0	*1
49-11	1.1	0.6	0.4	0.4	0.4	0.4	0.5	2.6	1.9	*2
49-12	1.6	1.1	0.8	0.7	0.7	0.7	0.8	2.9	2.2	0.598
49-13	6.5	5.5	5.1	4.6	4.5	4.2	4.1	5.8	4.9	2.089
49-14	11.6	10.6	9.9	8.5	8.6	8.2	7.8	9.4	8.2	4.669
49-15	20.5	19.1	18.1	16.7	15.7	14.9	14.2	15.3	14.0	21.230
49-16	41.5	40.0	37.5	34.4	33.2	31.4	29.6	29.8	28.8	35.690
48-7 *3	x *4	x	x	-	x	x	x	x	x	x
48-8	x	x	x	-	x	x	x	x	x	x
48-9	x	x	x	~11.0	x	x	x	x	x	x
48-10	x	x	x	~11.0	x	x	x	x	x	x
48-11	x	x	x	~11.0	x	x	x	x	x	x

1. All measurements made at a wavelength of 546 nm.

*1. Samples too turbid to measure $\beta(90^o)$.

*2. Error in measurement.

*3. Beam attenuation measurements were not made on the specific samples obtained when the TMU-1B transmission measurements were made. Measurements were made on two other samples, however, and are believed to be representative of samples 48-9, 48-10, and 48-11.

*4. x = no measurements made.

TABLE IV. - TRANSMISSION OF THE WATER SAMPLES
AS MEASURED BY THE TMU-1B

Sample	Path Length, cm	Transmission, %
49-1	100	95.00
49-2	100	16.50
49-3	100	2.20
49-4	100	0.14
49-4	33	58.00
49-5	33	12.00
49-6	33	0.24
49-6	10	78.00
49-7	10	21.30
49-8	10	4.20
49-9	10	1.20
49-10	10	0.16
49-11	-	-
49-12	100	63.00
49-13	100	2.60
49-14	100	0.10
49-15	33	9.40
49-16	33	0.26
48-7	33	16.00
48-8	33	45.00
48-9	33	81.00
48-10	33	84.00
49-11	33	76.00

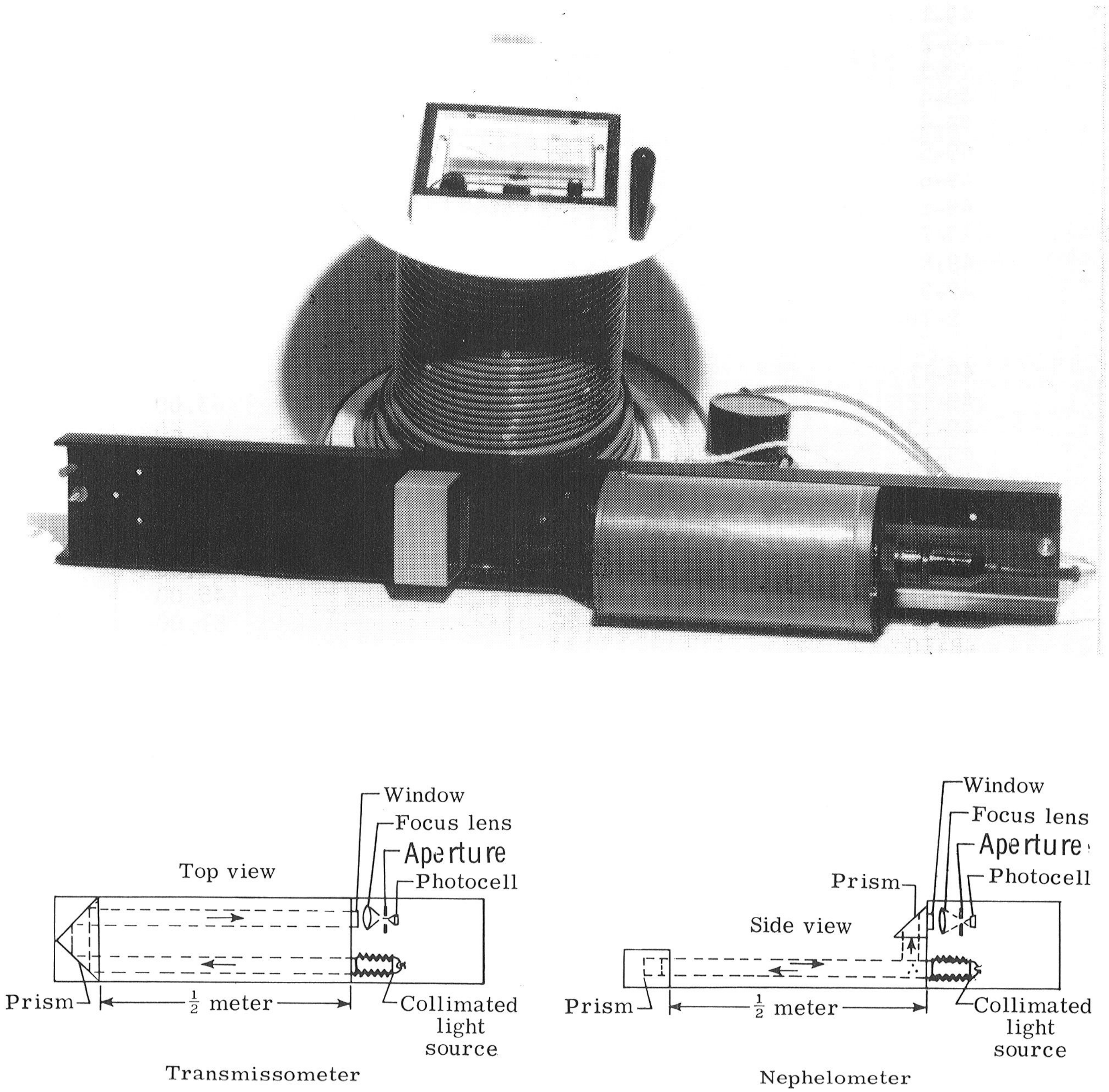


Figure 1.- Photograph of TMU-1B with carousel mounted control unit and conceptual sketches of transmissometer and nephelometer.

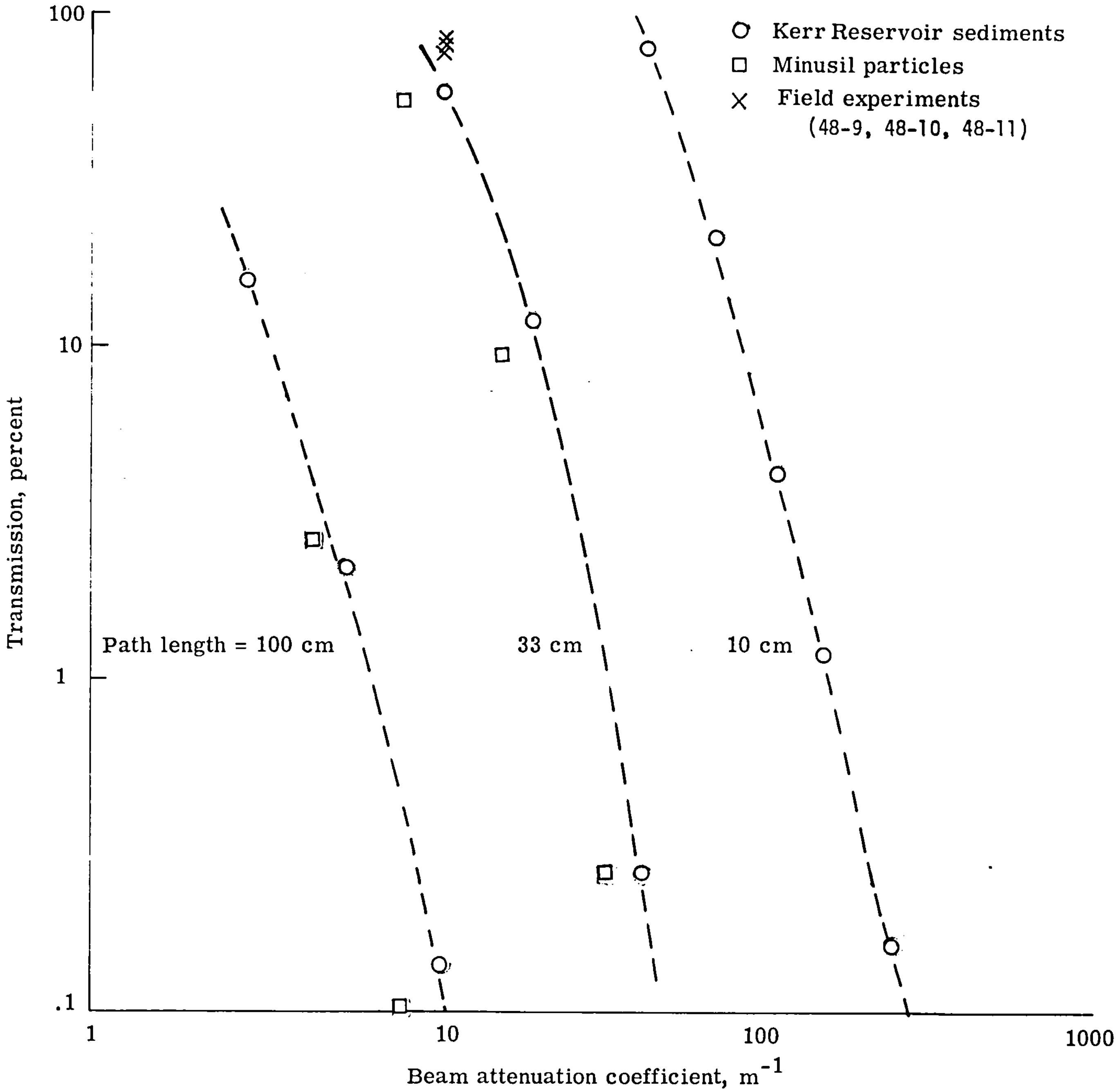
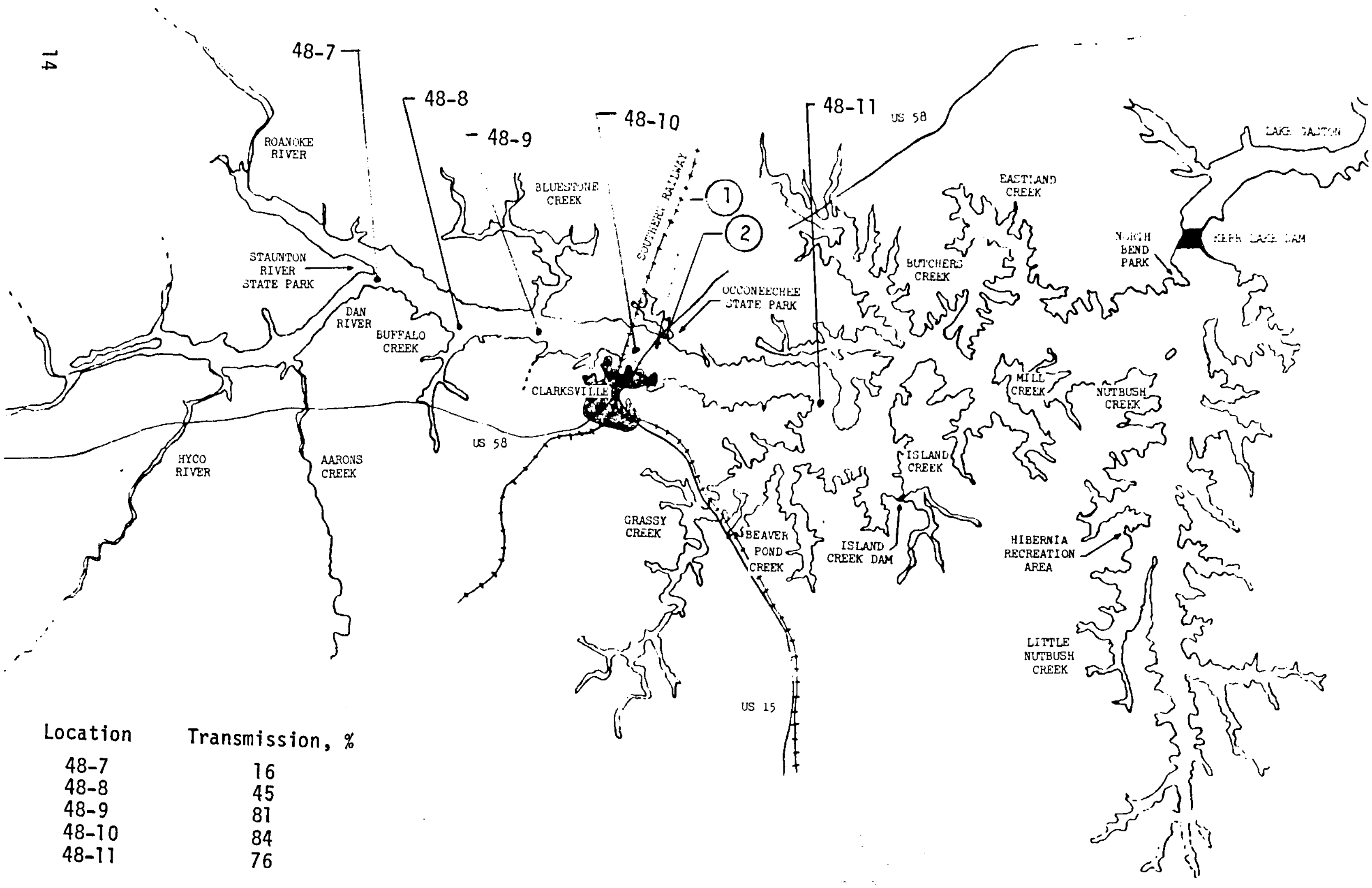


Figure 2.- Beam attenuation coefficient versus transmission



Location	Transmission, %
48-7	16
48-8	45
48-9	81
48-10	84
48-11	76

Figure 3.- Field experiments locations at John H. Kerr Reservoir.

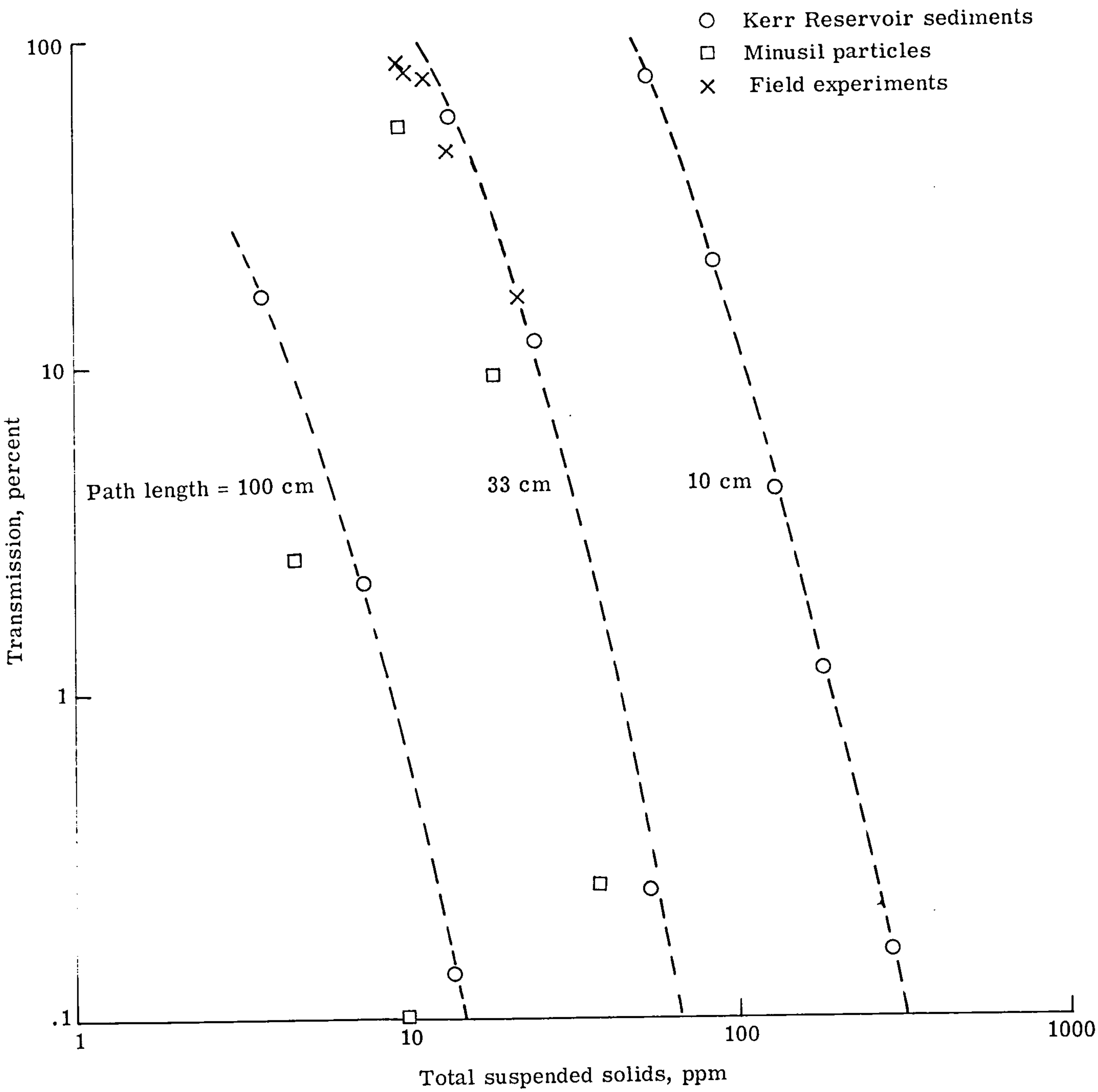


Figure 4.- Total suspended solids versus transmission.

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15. Supplementary Notes

16 Abstract

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