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MEASUREMENT OF "TURBIDITY" AND RELATED CHARACTERISTICS OF NATURAL WATERS

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Abstract

Attempts to quantify turbidity have led to a proliferation of methods, instruments, standards, and units of measure. Turbidity data for natural waters are applied to several uses, the most widespread of which is as an indication of the concentration of suspended material; but correlations between unrelated numbers often are made unwittingly. There is a strong feeling that more precise and definitive sets of methods and terminology are required. Turbidity generally is measured as an optical phenomenon and should be reported in optical units.

The U.S. Geological Survey has adopted the following principles: (1) standard instruments and methods should be adopted to measure and report the light transmitting characteristics of natural waters in optical units, thus avoiding the use of "turbidity" as a quantitative measure; (2) reporting of "turbidity" in Jackson Turbidity Units, Hellige Units, severity, or Nephelometric Turbidity Units should be phased out; (3) the basis for estimations of sediment concentrations using light measurements should be documented adequately; and (4) the use of transparency measurement by Secchi disk should be considered acceptable, although light transmittance may prove to be a more precise means of obtaining the same information. A schedule has been established to implement new methods, beginning with Federally-funded programs on October 1, 1976, and with the transition to be completed at all stations by October 1, 1977. Provisions are provided to meet the needs of cooperators who have legal requirements for "turbidity" data.

INTRODUCTION

Few water quality characteristics in natural waters are more difficult to explain quantitatively than is the phenomenon of turbidity. It should be understood that the term turbidity is a non-quantitative term; it is qualitative and relative and is used much in the same manner as the term "warmth." One does not measure warmth, one measures temperature.

Attempts to quantify turbidity have led to a proliferation of methods, instruments, standards, and units of measure, which are summarized in a recent review article by McCluney (1975). The instrument originally designed for turbidity measurement is the Jackson Candle Turbidimeter, a laboratory device that actually measured a combination of optical parameters such as light scattering, absorption, and reflectance, using the human eye as the detector. Efforts to automate the measurement have introduced a variety of other instruments including nephelometers and transmissometers. With these instruments various optical characteristics can be obtained -- percent scattering at a specified angle, percent transmission over a specified path length, and extinction length are several examples.

The original Jackson Candle Turbidimeter was standardized to reflect concentration of suspended material in parts per million. The material used was diatomaceous earth and it yielded units called Jackson Candle Units (JCU's). Later formazin became accepted as the standard because of the more uniform particle size it produced in suspension, and the units became Formazin Turbidity Units, or FTU's. Other standardizing media such as titanium dioxide and polystyrene latex microspheres have also been employed in recent years. A new unit, the Nephelometric Turbidity Unit (NTU), has also been added and is the unit given to the measurement of light scattering at 90° when the nephelometer is calibrated with formazin.

Today it is common practice to calibrate any instrument to be used for turbidity measurement with one of these standards, usually formazin, in terms of FTU's or NTU's. It is then assumed that since the instrument is calibrated with the same standard as are all other turbidity measuring instruments, the output of the devices will all be equivalent. This is not the case. Because of the nature of the various optical measurements being made, each different type of instrument will respond differently to the variety of sizes and shapes of particles suspended in the water sample. For instance, it has been reported by several investigators that when different types of instruments were calibrated with the same formazin standard and then used to measure various natural water samples, the measured turbidity levels were not the same.

Problems of turbidity measurement become even more complicated when one considers the reason behind most measurements of turbidity. Some of the primary applications are:

(1) Biological - as a measure of light penetration, and therefore, depth to which biological activity in green plants will take place.

(2) Aesthetic - people simply do not consider turbid or murky water attractive to drink, to swim in, to boat on, or to sit and gaze at.

(3) Sediment - as an indication of the concentration of suspended material.

Perhaps the most widespread misuse of turbidity measurement data is as an indicator of the concentration of suspended sediment. Within certain size and concentration ranges, and with certain types of suspended material, it is possible to estimate sediment concentration based upon turbidity or optical measurements. However, it is almost impossible to transfer the relationships between sediment concentrations and optical characteristics from one environment or type of sediment to another. Since the various optical techniques used to measure turbidity are all calibrated with the same standard and yield the same units of measurement, i.e., FTU's or NTU's, it would seem to many data users that the measurements are comparable, and correlations between unrelated numbers are often made unwittingly.

RESOLUTION OF THE PROBLEM

Several organizations and individuals have recognized and attempted to resolve the diversity of methods and the associated problems in measurement of turbidity. A May 1974 Turbidity Workshop, sponsored by the U.S. National Oceanographic Instrumentation Center (Austin and others, 1974), elicited participation from nearly 100 representatives of private industry, universities, and state, federal, and foreign governments. Conclusions and recommendations resulting from this Workshop favored abandonment of quantitative measurements of "turbidity" in favor of precise optical measurements which can be reported in scientifically identifiable terminology (see Appendix A). Recommendations of a similar nature now are being considered by the Sedimentation Committee of the Water Resources Council. The matter also is to come under consideration by technical committees of the American Society for Testing and Materials, and is being considered by the Coordinating Council of the Federal Interagency Committee on Recommended Methods for Water Data Acquisition.

It is therefore apparent that among those who have evaluated the matter of turbidity measurement there is a strong feeling that more precise and definitive sets of methods and terminology are required. Because turbidity most generally is measured as an optical phenomenon, it should be reported in optical units. Measurements reporting the effect of water on light in such terms have more precise physical meaning and are likely to produce more accurate and reproduceable results. They also will remove the temptation of data users to make the assumption that turbidity units represent concentrations of suspended sediment.

PRINCIPLES

The U.S. Geological Survey (USGS), has adopted the following principles regarding methods for measurement of turbidity and the light-transmitting characteristics of natural waters:

(1) Measurements of light transmittance and light scattering should be standardized by the adoption of specific types of instruments and should be reported in appropriate optical units, such as "percent of incident light transmitted at 180 degrees over a standard distance," "percent of incident light scattered at 90 degrees," and "extinction coefficient." The word "turbidity" should not be used in reporting such measurements.

(2) Reporting of "turbidity" in Jackson Turbidity Units (JTU's, code 00070), Hellige units (code 00075), severity (code 01350), or Nephelometric Turbidity Units (NTU's, code 00076), should be phased out.

(3) Inclusion in interpretive and basic data reports of estimated sediment concentrations based upon measurements of light transmittance or scattering should be considered acceptable, provided that the basis for establishing the relationship between the two properties is documented adequately.

(4) Measurements of transparency by Secchi disk (code 00077) are recognized as being of wide-spread use in limnology, and therefore are not affected by the recommended changes in methods. However, measurements of light transmittance may prove to be a more precise means of obtaining the same information.

IMPLEMENTATION BY THE U.S. GEOLOGICAL SURVEY

The following actions are being taken by the U.S. Geological Survey, Water Resources Division (WRD) to implement the new methods of measurement:

(1) Tests of instruments for measuring light are being conducted by the Water Resources Division (WRD), and a list of suitable instruments will be provided to field offices by September 1, 1976.

(2) Representatives of instrument manufacturers have been invited to contact the Quality of Water Branch, WRD, to discuss instrument design and conversion.

(3) Instructions naming the acceptable reporting units will be issued to USGS field offices by September 1, 1976. It is expected that these will be based on the three examples given in principle number 1.

(4) USGS will request STORET parameter code numbers for units adopted.

(5) All Federally financed WRD data stations and projects will use recommended methods, instruments, and reporting units beginning on October 1, 1976.

(6) WRD field offices are encouraged to shift all operations (other than Federally financed) to use of recommended instruments and reporting units on October 1, 1976, if possible, but in all cases they will complete the transition by October 1, 1977.

(7) WRD field offices may continue measurement and reporting of "turbidity" after October 1, 1977, in situations where such measurements are tied to legal requirements placed upon cooperators or supporting agencies. However:

a) Such measurements shall be made only at stations at which significant quantities of other water-quality data are being collected.

b) Costs of "turbidity" measurements are to be borne fully by the cooperating agency -- no USGS cooperative funds are to be used.

c) The need for measurement of turbidity to meet legal requirements of supporting organizations will be justified by the operating offices and certified (approved) by the appropriate Regional Hydrologist.

d) Data are not to be entered into WATSTORE. If the supporting agency is required to enter data into STORET, the entry must be made by that agency.

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CONCLUSIONS AND RECOMMENDATIONS

The concept of turbidity is optical; however, the use of the term "turbidity" was, found to be ambiguous, and the practice of calibrating the various instruments for its measurement in JTU, FTU, NTU, or ppm was found to be misleading and in fact incorrect. There was general agreement that the optical instruments in current use provide an inferred and not a direct measurement of suspended solids. Their use for this purpose must be supported by ancillary measurements which demonstrate that the optical measurement is correlated with the concentrations of the specific material to be monitored. It must be recognized that any such correlation may be invalidated by variations in the particle shape, size distribution or the index of refraction of the material normally found in natural waters.

Instrument-to-instrument comparison may be possible if the necessary optical characteristics of the instruments are known and a scattering transfer standard or standards can be defined together with appropriate calibration procedures. For scattering instruments, the angles of measurement together with the size and shape of the optical beams and the scattering volume need to be specified, as well as the spectral distribution of the energy utilized in the measurement.

Scattering instruments using different scattering angles and polarizations may each have individual advantages in specific particle size and/or concentration ranges.

Application of transmissometers may be advantageous where the role of absorption is of special concern, and their use is particularly valuable in investigating the spatial distribution of the total attenuation coefficient.

Calibration of instrument dials in terms of grams per liter, ppm or other mass concentration units are not direct optical measurements, and are the result of calibration techniques producing a specific transfer function for that instrument. It must be pointed out that a transfer function is required and not a single point calibration.

The special requirements of the biologists for optical measurements related to the study of particulate matter and primary productivity have been thoroughly covered by the Working Group 15 of the Scientific Committee for Oceanographic Research of the International Association of Physical Oceanography.

Scientists and engineers who require relatively complete information on the nature of a particulate suspension will probably need to perform a multi-parameter measurement; simple scattering measurements are unlikely to be satisfactory. This subject was addressed recently at the March 1973 ONR meeting on Suspended Solids in Water; the proceedings will be published in the summer of 1974.

RECOMMENDATIONS

1. The term "TURBIDITY" shall be used only as a non-technical appearance descriptor. It is a qualitative and relative term in the same manner as warmth. One does not measure warmth; one measures temperature.

2. The measurements shall be labeled in accepted scientifically identifiable terminology.

3. The instruments shall be named in accordance with the physical parameters measured.

4. The requirements for scattering standards in terms of size and shape distributions, refractive index, concentration, stability and reproducibility should be carefully examined in view of their potential use in widely varying contexts; and appropriate systems should be selected.

5. A phased conversion from existing ambiguous standards must be executed.