# CONTINUOUS AUTOMATED SENSING OF STREAMFLOW DENSITY AS A SURROGATE FOR SUSPENDED-SEDIMENT CONCENTRATION SAMPLING

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**Abstract** A newly refined technique for continuously and automatically sensing the density of a water-sediment mixture is being tested at a U.S. Geological Survey streamflow-gaging station in Puerto Rico. Originally developed to measure crude oil density, the double bubbler instrument measures fluid density by means of pressure transducers at two elevations in a vertical water column. By subtracting the density of water from the value measured for the density of the water-sediment mixture, the concentration of suspended sediment can be estimated. Preliminary tests of the double bubbler instrument show promise but are not yet conclusive.

## INTRODUCTION

Suspended sediment is the most common contaminant of surface water in the world. Sediment particles can reduce the quality of potable water supplies; increase filtration and treatment costs for drinking water; damage hydroelectric turbines; degrade fluvial, lacustrine, estuarine, and marine habitats; and serve as a transport mechanism for a variety of trace elements, herbicides, insecticides, and other toxic substances (Douglas, 1990). Concentrations of suspended sediment in fluvial systems tend to be relatively large in settings with extensive loess deposits, semi-arid environments with little vegetation, and steeply sloping areas of the humid tropics. Many of the world's highest sediment yields, however, are recorded in human-disturbed regions (Milliman and Meade, 1983). As human populations exploit increasingly fragile environments, the problems associated with fluvial-sediment transport and deposition have worsened.

Monitoring daily and annual suspended-sediment yield is costly and time consuming. For example, the current annual (2000) cost for the U.S. Geological Survey (USGS) to collect and publish daily stream flow and suspended-sediment data at a station is rarely less than $20,000, and in some cases can be nearly triple that, depending on such factors as site location, types and frequency of data collection, size distribution of suspended sediments, and hydraulic characteristics of the reach. The standard monitoring procedure requires frequent manual and (or) automated sampling, particularly during high flows, followed by laboratory processing and subsequent analysis of large data sets. Less costly, safer, and more accurate techniques for measuring sediment discharges in streams are being conceived and developed. Although several techniques show considerable promise (Wren and others, 2000), none is certified by the Federal Interagency Sedimentation Project (U.S. Geological Survey, 2000) as an adequate replacement for conventional sampling methods, nor is deployed as part of a large operational network in the United States.

A newly refined instrument for continuously and automatically measuring the density of the water-sediment mixture as a surrogate for suspended-sediment concentration, referred to as a

double bubbler instrument by the manufacturer, is being tested at a USGS streamflow-gaging station in Puerto Rico. This paper describes a double bubbler instrument for measuring suspended-sediment concentrations for use in sediment-discharge estimates and provides preliminary results from field tests of the instrument that began in October 1999.

## RIO CAGUITAS, PUERTO RICO

The Río Caguitas (USGS ID 50055225) sampling site has a 30.3-$km^2$ drainage area, and land cover is predominately urban and secondary forest (fig 1). The watershed is a sub-basin of the Río Grande de Loíza watershed, which contains the Loíza reservoir. This reservoir supplies about one half of the water supply for the San Juan metropolitan area, with a population of about one million (Molina-Rivera, 1998). Mean annual runoff for the period 1990 - 99 in the Río Caguitas watershed is 1,080 mm, and the flood of record had a peak discharge of 708 cubic meters per second (Díaz and others, 1999). Periods of substantial sediment-transport are frequent and can occur in any month of the year (fig. 2). Most of the annual sediment discharge occurs in runoff from a few storms when concentrations of suspended sediment exceed about 500 mg/L (fig. 3). Mean suspended-sediment yield for the period 1992-99 was about 1,340 tonnes/$km^2$-yr. To-date, the maximum suspended-sediment concentration measured at the site using conventional techniques is 17,700 mg/L.

## DOUBLE BUBBLER INSTRUMENT

The double bubbler instrument measures the weight density, ?, of water by means of two immersed pressure-transducer orifices separated by 304.8 mm (12 in.) in a vertical column of water (fig. 4). Because the density of water increases with increased suspended-sediment concentration, the density data can be used as a relatively inexpensive and continuously measured surrogate for suspended-sediment concentrations obtained from analyses of water samples.

A constant mass flow of gas (dry air or nitrogen) to the two orifices submerged in the measurement fluid (water) is provided by a gas supply system (fig. 5). A water-temperature probe is placed near the bubble discharge orifices to provide the requisite data to correct for the effect of temperature on the density of pure water. The precision differential pressure measurement system developed by Design Analysis Associates, Logan, Utah[1] measures the pressure difference sensed at the two bubbler line orifices. Two solenoid valves feeding the differential unit are used to obtain offset and atmospheric correction for the actual pressure-sensing element. The pressure-sensing element produces a voltage value directly proportional to the pressure difference sensed at the orifices. Once ? has been evaluated, a reference density value (pure water, or stream water with a dissolved solids concentration typical of sediment-transporting runoff) is subtracted to calculate the weight density (concentration) of suspended sediment.

[1] Use of firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Differential hydrostatic pressure is recorded by a data logger at regular intervals and can be downloaded periodically or transmitted via satellite (fig. 5). The differential pressure values are converted to water-density values. Samples from which comparative suspended-sediment concentrations are determined by laboratory analysis are collected with a US DH-48 wading sampler during low stage and a US DH-59, US DH-77, or automatic pump sampler during high stage, based on methods described by Edwards and Glysson (1999). The suspended-sediment concentration data from samples are used to compare to density values computed from double bubbler instrument data. Laboratory testing of the double bubbler instrument was performed by the manufacturer using salt solutions with concentration in excess of 1,000 mg/L.

## FIELD TRIALS

Initial double-bubbler-instrument data collected during October-December 1999, contain a large amount of signal noise that makes interpretation difficult. The data collected on 5-minute intervals were smoothed by stepwise averaging of 6 data points by using a 30-minute moving mean. Although this increased the serial correlation somewhat, a more sophisticated method for data analysis, not yet tested, is required and should include determination of minimum and maximum thresholds so that outliers can be discarded from the data set. To calculate the weight density of suspended sediment and dissolved solids, the weight density of pure water at 27 degrees C (996.515925 $kg/m^3$) was subtracted from the smoothed data value. Data collected after installation of a thermistor for temperature compensation in summer 2000 (several months after the initial installation) will be corrected for pure-water densities that are computed by using the recorded water-temperature values.

The first tests of the correspondence between discharge, suspended-sediment concentration, and water density, showed little agreement (fig. 6). A series of measurements made during a 3-month period in 1999 show that the double bubbler instrument values generally track substantial variations in suspended-sediment concentrations, but a large amount of signal noise remains.

A complicating factor for this method is turbulence in the water column, which introduces noise about equal to the signal of interest, particularly during high discharges when the largest sediment concentrations occur. Additionally, diurnal and storm-related fluctuations in water temperature must be accounted for by using a continuously logging temperature sensor. Differences of diurnal extremes in water temperatures measured at the Río Caguitas test site are as much as 10 degrees C. The high relative-humidity characteristic of this humid-tropical site may also complicate the use of the bubbler because of the sensitivity of the narrow diameter bubbler gas lines to moisture.

## CONCLUSIONS

Initial testing of a double bubbler instrument for continuous automated sampling of streamflow density as a surrogate for suspended-sediment concentration sampling has proven to be a challenging task. Although some correspondence between double bubbler instrument data and measurements of discharge and suspended-sediment concentration is evident, additional field trials are needed. If adequate results can be achieved, substantial cost reduction in sediment monitoring programs can be realized.

## REFERENCES


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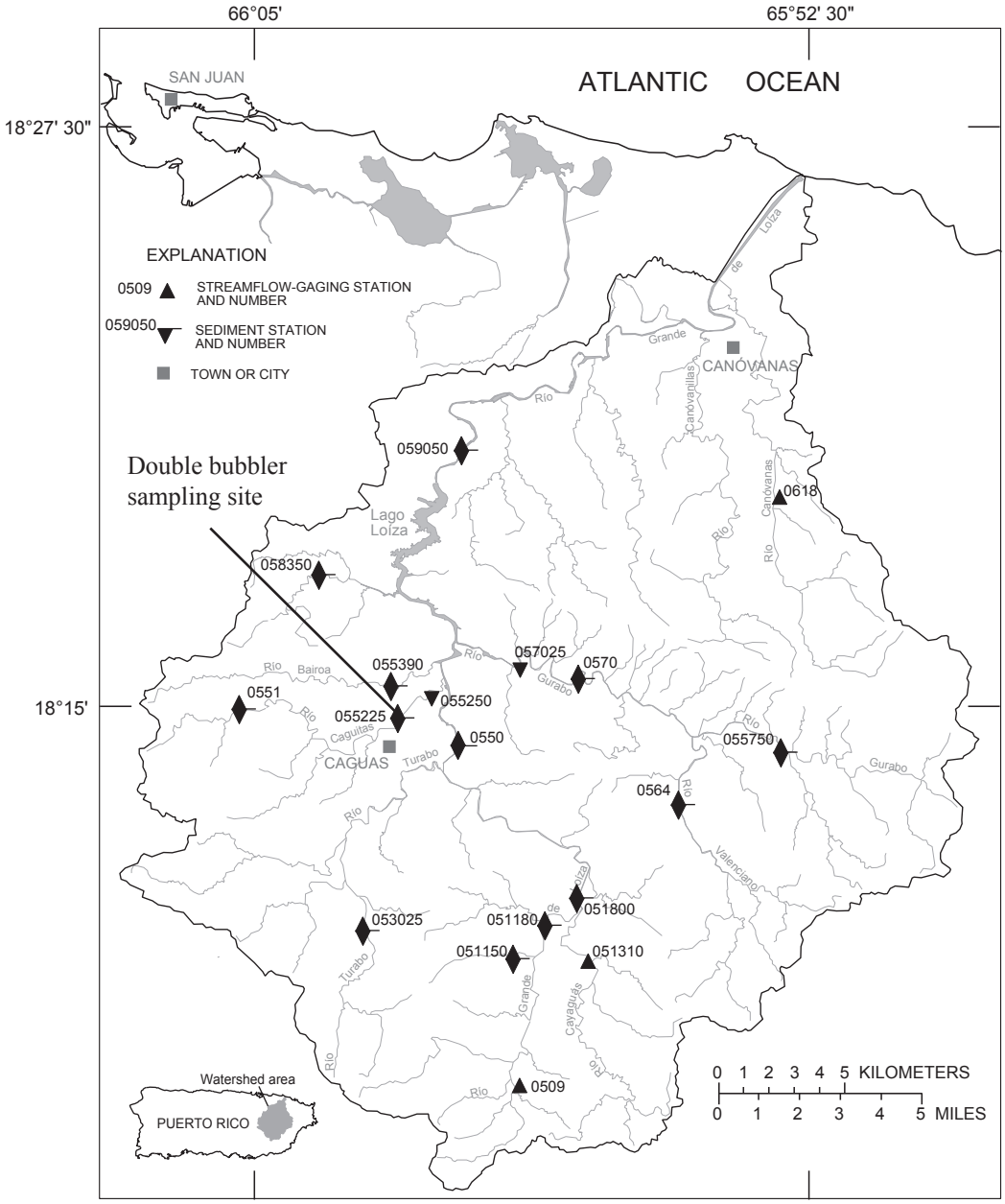


Figure 1. Location of the Río Caguitas (50055225) and other streamflow-gaging stations in the Río Grande de Loíza watershed, eastern Puerto Rico.

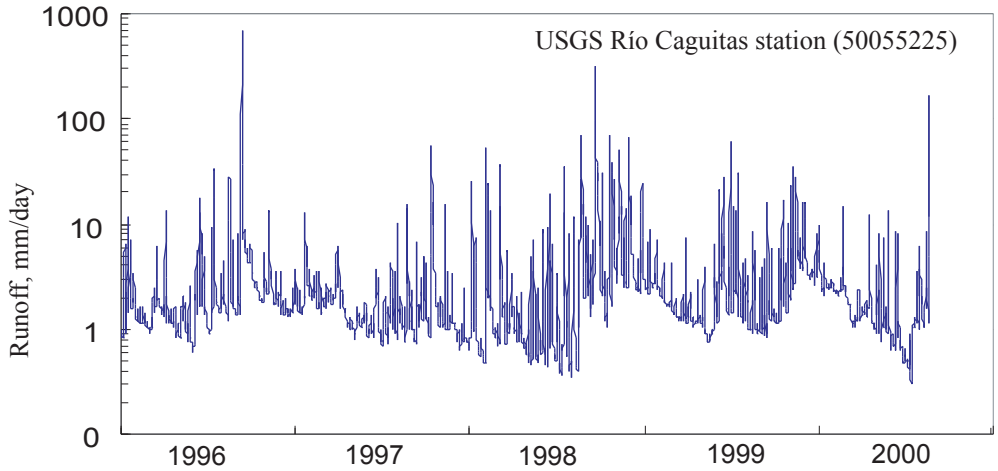


Figure 2. Daily mean runoff at Río Caguitas, showing high frequency and seasonal/inter-annual variability of streamflow events. Mean for period of record, 1990-99, equals 2.96 mm/day (1,080 mm/year) (Díaz and others, 1999).

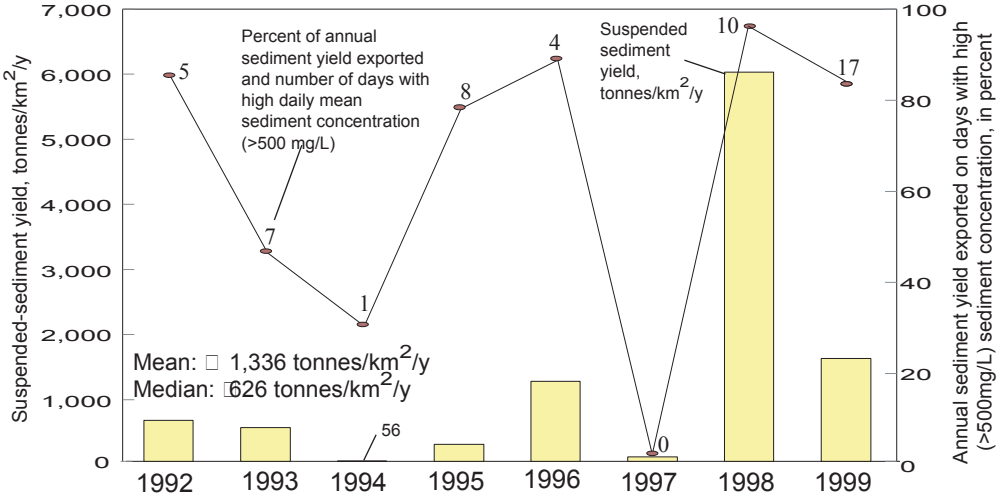


Figure 3. Annual suspended-sediment yield at Río Caguitas, USGS station 50055225, 1992-1999. In 6 of the 8 years, about half or more of the suspended-sediment yield was exported on 2 to 5 percent of the days. The large yield in 1998 resulted from runoff associated with Hurricane Georges.

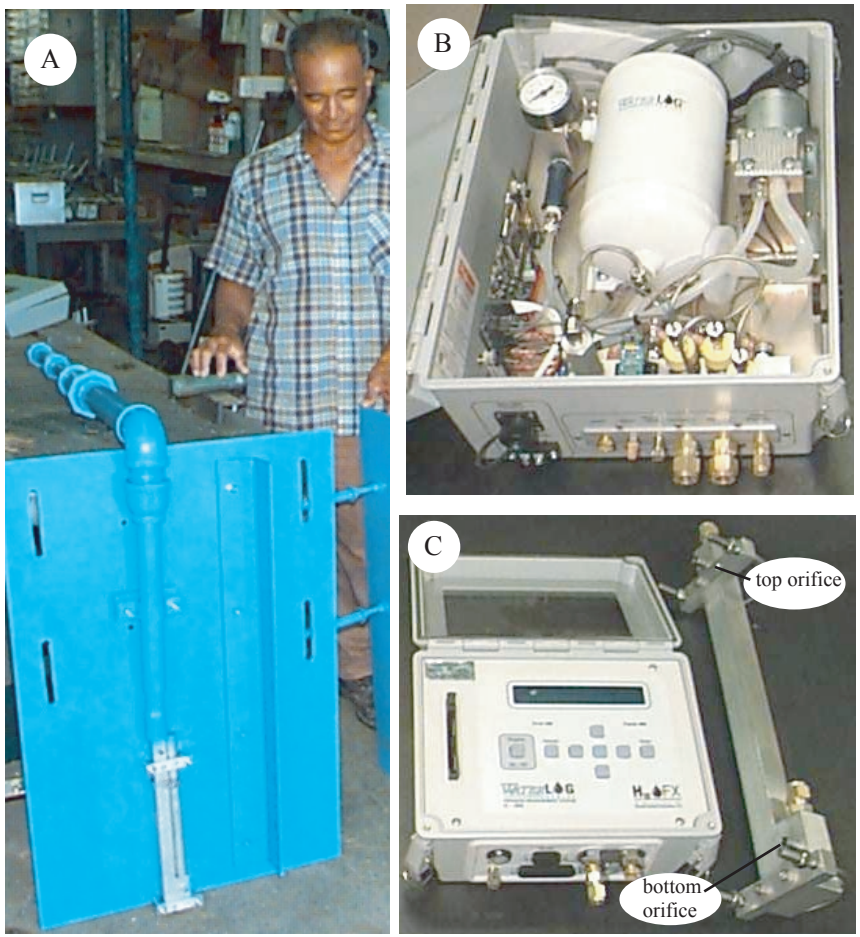


Figure 4. A.Double bubbler and mounting plate. Angle iron on right protects intrument from transported debris. B. Air compressor and hardware for generating bubbles. C. Data logger on left, double bubbler on right. Orifices are 304.8 mm (12 in.) apart.

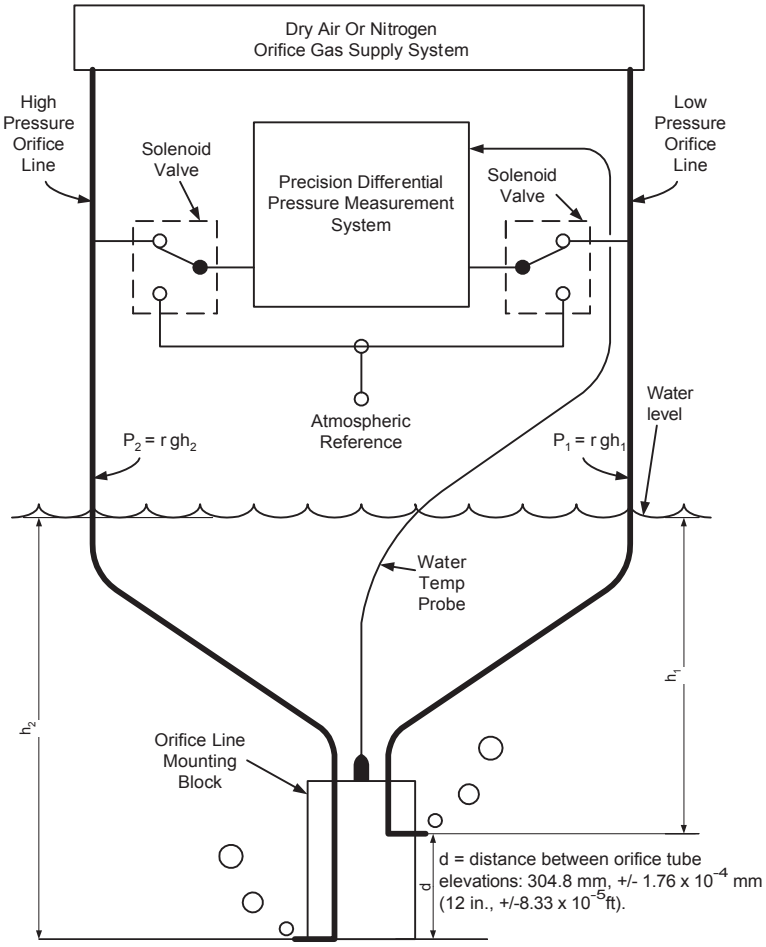


Figure 5. Model of a double bubbler media determination system.

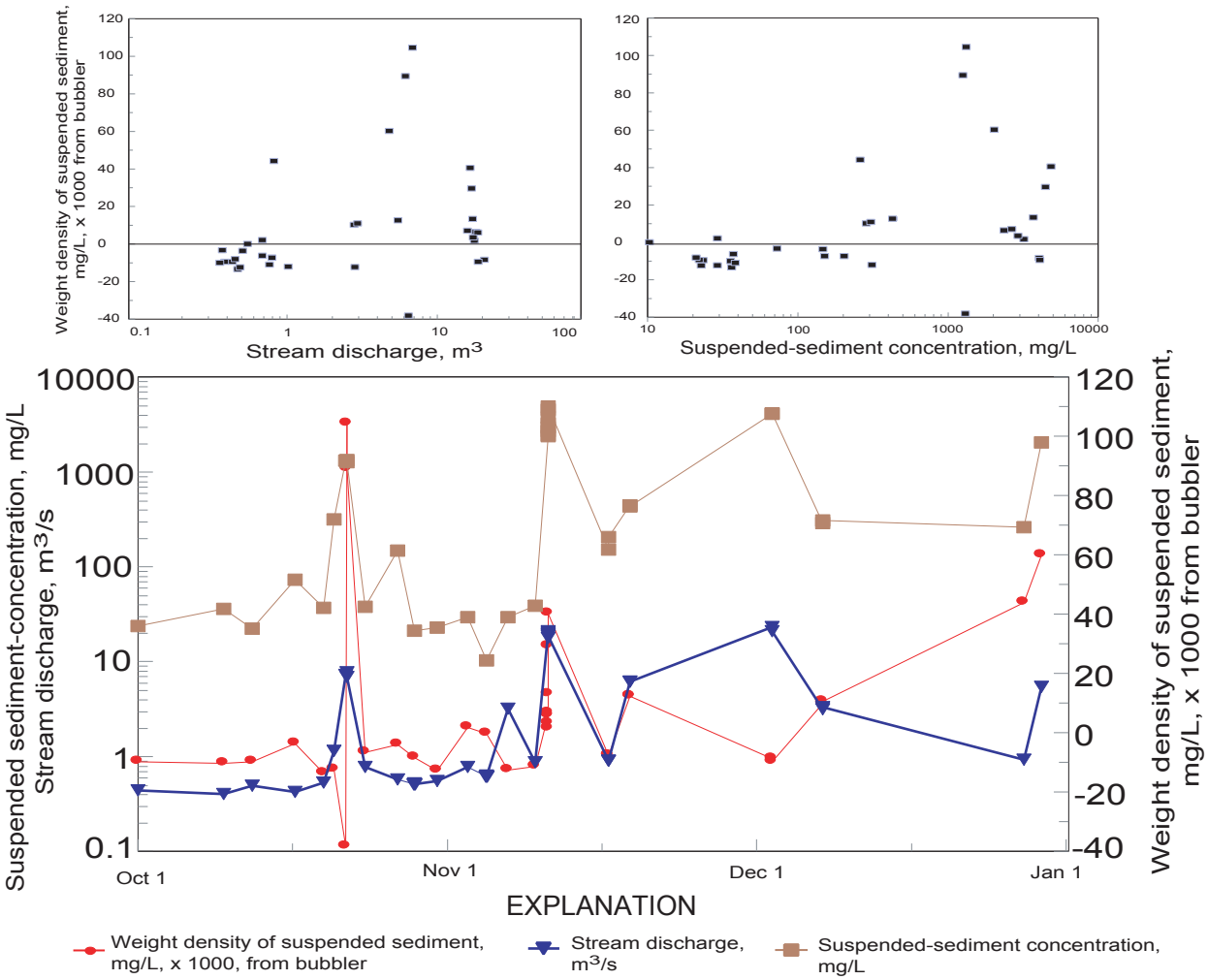


Figure 6. Scatter plots and time series of stream discharge, suspended-sediment concentration, and weight density of suspended sediment and dissolved solids measured with double bubbler, October 1, 1999 to January 1, 2000. Discharge and sediment data are instantaneous samples, double bubbler weight density value is 30-minute mean of measurements made at 5-minute intervals.