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Research and Development

Automatic Sludge Blanket Control in an Operating Gravity Thickener

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AUTOMATIC SLUDGE BLANKET CONTROL IN AN OPERATING GRAVITY THICKENER

by

R.C. Polta and D.A. Stulc
Metropolitan Waste Control Commission
St. Paul, Minnesota 55101

Grant No. S803602

Project Officers

J.F. Roesler
I.J. Kugelman
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and inproved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

One of the methods of improving the cost effectivenesss of treatment processes and systems is to employ automation. This report covers a full-scale demonstration of automation of a sludge thickener.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The purposes of this study were to evaluate some of the hardware required to monitor and control the operation of a gravity thickener and to identify any benefits associated with improved sludge blanket level control.

An automatic sludge blanket level control system was installed in one of the six gravity thickeners at the Metropolitan WWTP. In addition, optical type solids analyzers were installed to monitor the inflow, overflow, and underflow streams of two basins - one with automated blanket level control and one with manual control. The performance characteristics of the instruments and automation system were documented during a series of five tests each lasting approximately two weeks.

The solids monitors used were found to be acceptable for monitoring thickener inflow and overflow but not for monitoring the solids underflow. Automation maintained a more stable position for the sludge blanket than manual control but did not result in an increase the solids level of the underflow. Solids capture, however, was upgraded in that the solids level of the automated thickener overflow was much lower than that of the manual thickener. Based on savings in labor for thickener operation, and lower costs to treat the thickener overflow, the payback period for thickener automation was estimated at less than 6 months.

This report was submitted in fulfillment of Grant No. S803602 by the Metropolitan Waste Control Commission under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers the period from November 15, 1976 to November 30, 1977, and the work was completed as of April 14, 1978.

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FIGURES

TABLES

LIST OF ABBREVIATIONS

sec	-	second
CST	-	capillary suction time
F & I no. 2	-	Filtration and Incineration Building number two
ft	-	feet
gpd/sq ft	-	gallons per day per square foot
gpm	-	gallons per minute
hr	-	hour
in	-	inch
L	-	average blanket level for day, feet below surface
mgd	-	million gallons per day
mg/l	-	milligrams per liter
min	-	minute
ml	-	milliliters
MWCC	-	Metropolitan Waste Control Commission
NPT	-	national pipe thread
PID	-	proportional, integral, derivative
Q	-	basin inflow rate, million gallons per day
R	-	coefficient of correlation
S	-	average daily inflow suspended solids concentration milligrams per liter
sq ft	-	square feet
T	-	temperature of basin inflow, degrees Centigrade
TOC	-	total organic carbon
Y	-	average daily overflow suspended solids concentration for basin, milligrams per liter

CONVERSION FACTORS

English Unit	multiply by	to yield Metric Unit
Feet	0.3048	Meters
Gallons per day per square foot	0.352	Liters per day per square meter
Gallons	3.785	Liters
Inches	2.54	Centimeters
Million gallons	3785	Cubic meters
Square feet	0.0929	Square meters

SECTION I

INTRODUCTION

A cursory examination of the semitechnical literature of the past 2 years demonstrates that when new facilities are constructed and older facilities are upgraded operating agencies, as well as design engineers, are putting more emphasis on process control. Reasons for this apparent trend include: (1) to improve the reliability of the treatment facilities in terms of meeting discharge standards as per NPDES permits, (2) to improve process treatment efficiencies and thereby minimize their size and the corresponding capital investment and (3) to decrease operating and maintenance costs by making more efficient use of energy, materials, and personnel.

Process control can usually be accomplished by manual or automated means. However, because of the increasing complexity of modern wastewater treatment facilities and the advances in the instrument and computer industries during recent years, it appears that increased emphasis will be placed on automated process control using both analog and digital techniques. For example, the Metropolitan Waste Control Commission, MWCC, is currently constructing a new 6 mgd advanced waste treatment plant (AWTP) which will utilize a central computer to monitor and control all of the processes in both the liquid and solids treatment areas. In addition, the capacity of the Metropolitan Plant is currently being expanded from 218 mgd to 290 mgd. The expansion includes the addition of new secondary treatment facilities and expanded sludge handling and disposal facilities. A distributed digital control system is being installed to provide for process control of the new facilities. The older existing facilities may be retrofitted with the necessary hardware at a future date.

The USEPA sponsored a workshop dealing with research needs associated with the automation of wastewater treatment facilities in September of 1974. The summary of the workshop proceedings (1) listed 6 major research needs; one being, the development of efficient and dependable sensors. If process control decisions (made by man, analog or digital computers) are to be based on the output of sensing devices, the significance of their dependability is perhaps best summarized by the old equation in computer technology parlance, garbage in = garbage out.

The purpose of the study described in the following paragraphs was to evaluate the hardware (sensors) required to monitor and control the operation of a gravity thickener and to determine the benefits associated with improved sludge blanket level control. The field study was conducted during the period November 1976 through November 1977 at the Metropolitan Wastewater Treatment Plant.

SECTION 2

SUMMARY AND CONCLUSIONS

A system for controlling the sludge blanket level in a gravity thickener was evaluated at the MWCC's Metropolitan Wastewater Treatment Plant. The performance characteristics of an optical type sludge blanket level detector/controller were documented. The reliability and maintenance requirements for one manufacturer's optical type solids analyzer were also identified for several applications. The following conclusions are based on a series of five tests during which two of the plants six gravity thickeners were monitored.

[1] The sludge blanket level controller can provide reliable control provided the capacity of the sludge withdrawal pump is sufficient.

[2] The probes used to monitor blanket level should be inspected and wiped clean on a weekly basis to preclude malfunctions related to coatings on the optical surfaces.

[3] No significant difference was observed in the dewatering characteristics of the sludges discharged from the manually and automatically controlled thickeners.

[4] Although the labor savings associated with the automated blanket level control are estimated at only approximately $500 per basin per year, the enhanced solids capture provided treatment savings conservatively estimated to be approximately $4000 per basin per year. The pay back period for the installed control system is estimated to be less than 6 months.

[5] The suspended solids concentration of the thickener overflow was found to be significantly affected by both the blanket level and the suspended solids concentration of the influent. This overflow characteristic, however, was found to be relatively independent of both the hydraulic loading rate and temperature in the ranges observed.

[6] The soluble organic content of the thickener overflow was found to be independent of the basin operating parameters.

[7] The solids analyzers used during the study were found to be acceptable for monitoring the thickener inflow and overflow streams; however, the performance characteristics of the analyzer used to monitor the solids concentration of the underflow were determined to be unacceptable.

SECTION 3

FACILITY DESCRIPTION

GENERAL

The existing Metropolitan Wastewater Treatment Plant, herein identified as Metro, was designed to treat a flow of 218 mgd having biochemical oxygen demand and suspended solids concentrations of 250 mg/l and 315 mg/l respectively. The plant, as initially placed into service in 1938, consisted of primary treatment and sludge disposal facilities - vacuum filtration and incineration. Facilities for secondary treatment by the high rate activated sludge process were put into service in 1966. The solids processing facilities were also expanded at that time. In 1972 the secondary facilities were expanded to permit operation by the step aeration process. The plant is presently operated in excess of its design capacity and is being expanded to treat a flow of 290 mgd and meet secondary effluent standards. A plan view of the existing facility is presented in Figure 1.

Approximately 50% of the primary sludge is thickened, dewatered by vacuum filtration and incinerated. The six filters and four incinerators used to treat the primary solids are located in Filtration and Incineration Building (F & I) No. 1. The remaining primary sludge and all of the waste activated sludge are mixed, diluted with plant effluent, and discharged to six gravity thickeners. The thickened sludge is discharged to two sludge holding tanks, 260,000 gal capacity each, and subsequently dewatered by vacuum filtration and incinerated. The 12 vacuum filters and four incinerators used to treat the mixed sludge are located in F & I No. 2. The control room for the gravity thickening, vacuum filtration, and incineration processes is located in F & I No. 2. Under normal conditions most of the operating parameters are monitored from this location.

The overall treatment efficiency at Metro, in terms of BOD removal, is currently limited by the capacity to process solids. Insufficient incinerator capacity is the physical constraint which limits solids throughput for both the filters and thickeners and eventually dictates sludge wasting rates and the performance level of the secondary treatment facility.

THICKENER BASIN

The six gravity thickeners are arranged in two banks of three thickeners each. Basins no. 1, 3 and 5 form the west battery and basins no. 2,4 and 6 form the east battery. Each battery is served by a common feed line to distribute the mixture of primary and secondary sludge and dilution water. Each basin is 65 ft in diameter with a 10 ft sidewall depth and is equipped with a rotating sludge collector, skimmer and peripheral launder as illustrated in Figure 2. The units were designed for loadings of 300 to 1000 gpd/sq ft (1 to 3.3 mgd).

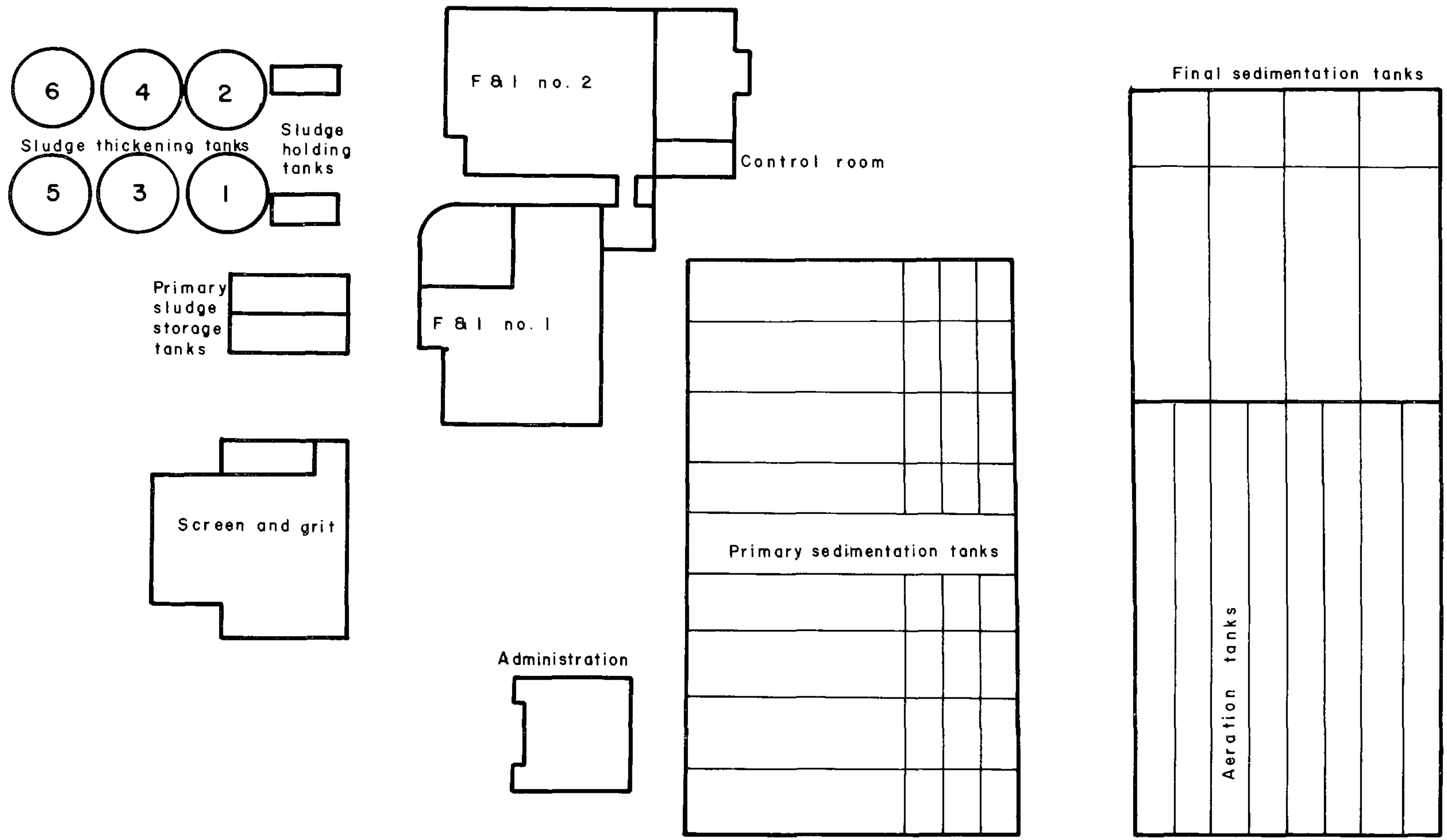

Figure 1. Plan view of existing treatment facilities at Metropolitan WWTP.

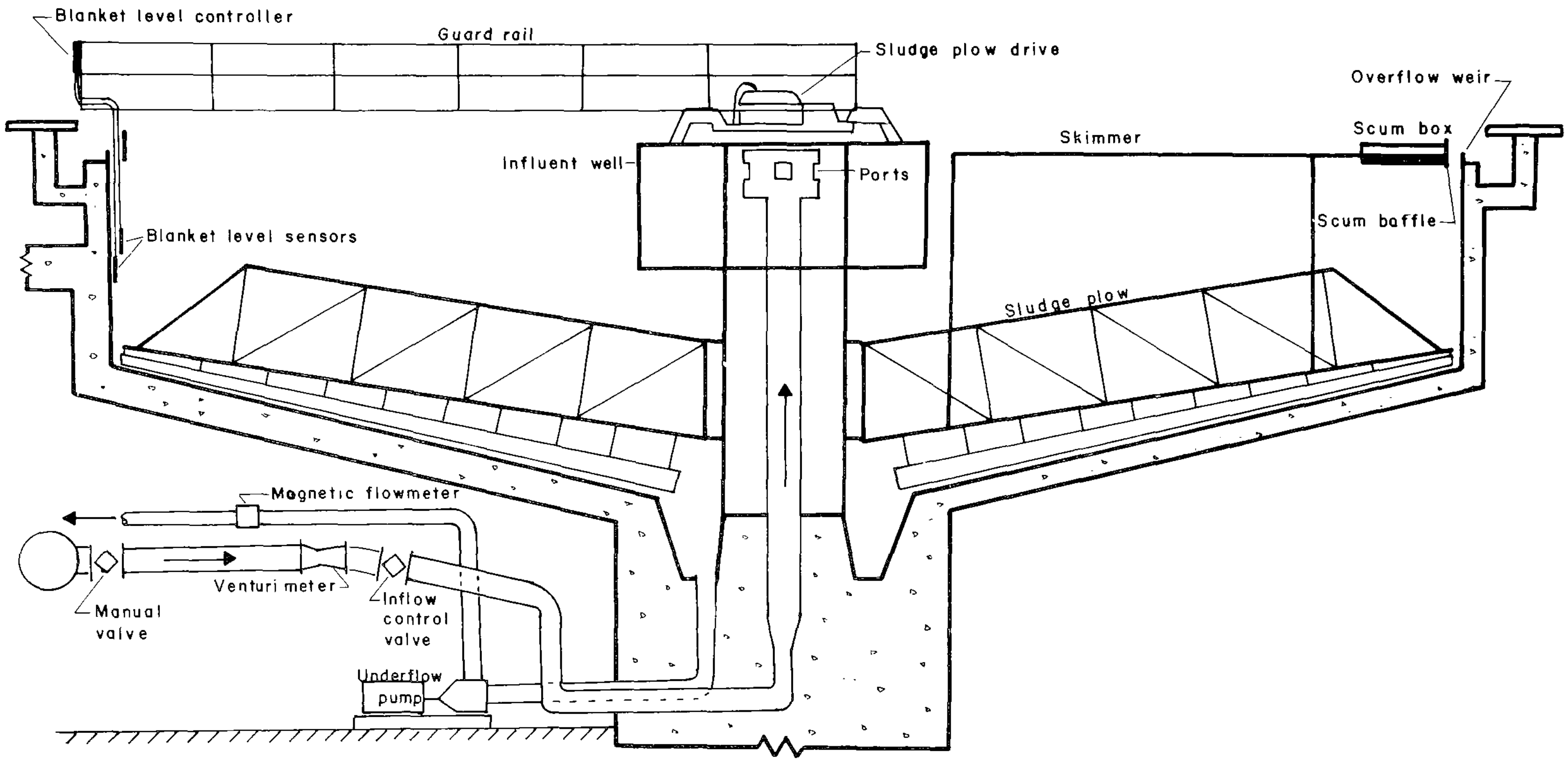

Figure 2. Typical profile for gravity thickeners.

The thickened sludge is pumped from the center well of each basin and discharged to one of the holding tanks by way of a common discharge manifold for each battery. Each basin is served by two sludge pumps, a variable speed centrifugal pump and a fixed speed positive displacement pump. The centrifugal pump is normally used and operated at speeds to yield discharges in the range of 50 to 200 gpm. The sludge pumps, influent and thickened sludge flow meters, local control panels and all piping and other appurtenances are located in the thickener gallery between the two batteries below grade.

Each basin has three sidewall sample taps at depths of 4, 6.5, and 9 ft. One inch lines are used to transport the samples to sinks located in the center of the gallery and allow the operator to monitor sludge blanket height from that location.

SLUDGE BLANKET CONTROL

A Biospherics Model 56 sludge blanket detector was installed in basin no. 4. The unit, pictured in Figure 3, consists of two submersible probes suspended from a control box by waterproof cables. Each probe consists of a light source and photocell separated by a 3/4 in. sensing gap. The light transmitted to the photocell is a function of the concentration and characteristics of the solids slurry in the sensing gap. In service each sensor is suspended in the thickener with a cable which also provides power to the light emitting diodes and photocell and transmits the photocell output to the control unit.

The control unit is housed in a NEMA 4 enclosure mounted on the thickener handrail and consists of control circuits, power supplies and output relays. A two position response switch is provided for fast or delayed response to changes in photocell output. Three indicating lights labeled, LOW, MEDIUM, and HIGH, are mounted on the enclosure to indicate the sludge blanket position as below, between or above the two sensors. The unit is powered from a 120 VAC source and the output relays are rated at 10 amp at 120 VAC.

When probe 'A' is located above probe 'B' in the thickener basin the control unit functions as follows. The energy source in each probe emits radiation through the optical sensing gap to the photocell which senses the amount of energy transmitted through the liquid and produces a signal related to the suspended solids concentration of the liquid in the gap. This signal is compared, in the control circuit, to an adjustable density threshold setting. When the signal representing the concentration of solids in the liquid at probe 'A' exceeds the threshold setting an electronic 15 min timer is activated. If the sludge blanket level remains at or above probe 'A' at the expiration of the 15 min interval,the output relay is energized and the HIGH lamp on the control box illuminates. The output relay is used to energize the starter of the thickener underflow pump motor. After a period of sludge withdrawal the sludge blanket level drops below probe 'A' and the photocell output drops below the threshold setting. At this time the HIGH lamp is extinguished and the MEDIUM lamp illuminates. After continued sludge withdrawal the sludge blanket drops to the level of probe 'B' and the signal representing the concentration of solids falls below the threshold setting.

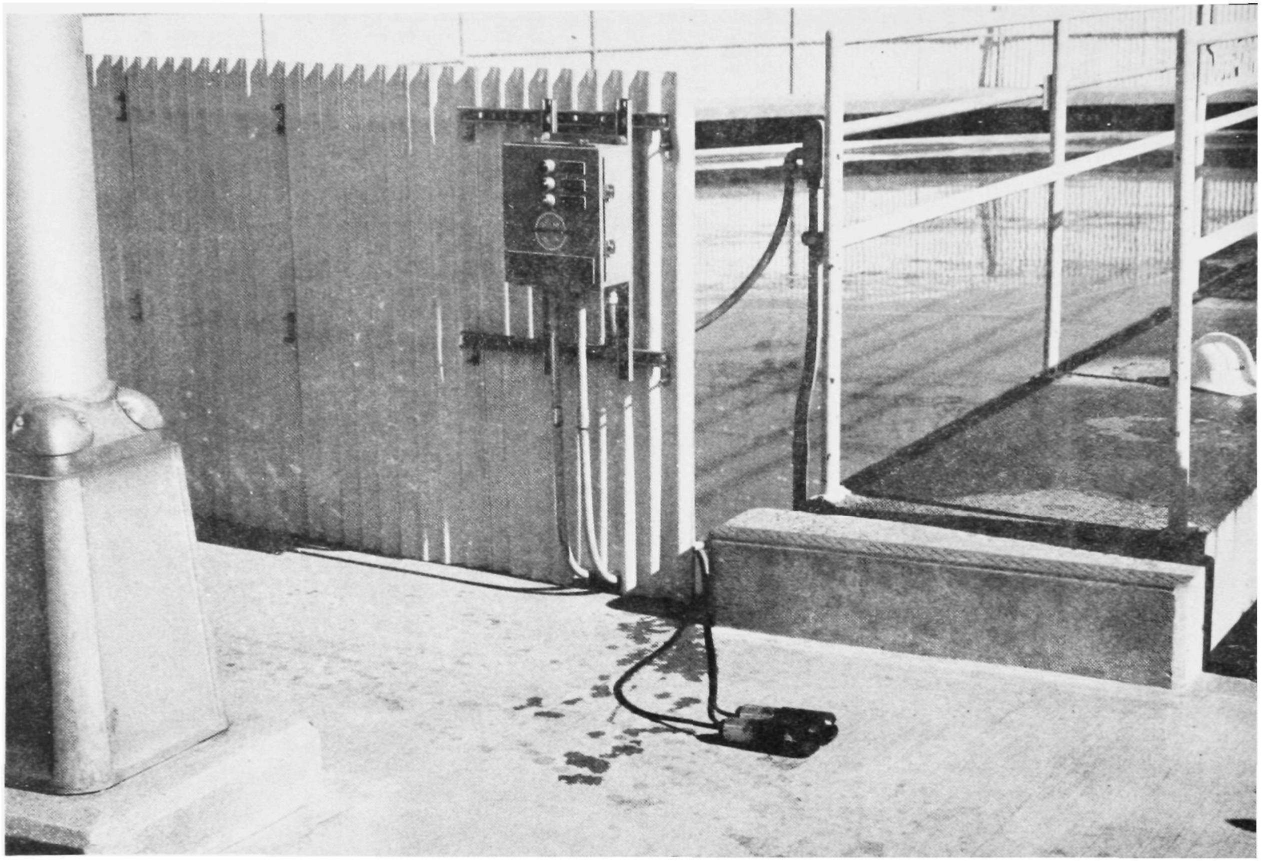

Figure 3. Sludge blanket detector installed in thickener basin no. 4.

At this point in time a second 15 min interval timer is activated. If the sludge blanket level remains below probe 'B' at the expiration of the 15 min interval the output relay is deenergized and the MEDIUM lamp is extinguished and the LOW lamp illuminated. The underflow pump starter is disengaged when the output relay is deenergized. When the sludge blanket level rises to probe 'B' the photocell output increases above the threshold setting and the LOW lamp is extinguished and the MEDIUM lamp illuminated. The above cycle is repeated as the sludge blanket level rises to probe 'A'.

A three position switch (HAND, OFF, AUTO) was installed in the control room to allow the operator to establish the mode of operation. This flexibility was required to minimize problems associated with instrument failures and high sludge levels in the holding tanks downstream of the thickeners.

MONITORING

Suspended Solids

General--

Optical type solids analyzers were installed in the inflow, overflow and underflow streams of thickeners no. 2 and 4 to aid in the collection of data on thickener performance and to more fully evaluate their own performance characteristics. During the early months of 1976 MWCC staff evaluated the short term performance characteristics of analyzers which employed several operating principles. Based on the results of these tests the decision was made to utilize the self cleaning optical type analyzers for both the high and low concentration ranges. Specifications were prepared (Appendix A) and advertised. Two proposals were received. A contract was subsequently awarded to supply four Biospherics model 52LE suspended solids analyzers and two Biospherics model 52H sludge density analyzers.

The analyzers were installed in the influent and underflow pipes through a pipe insertion adapter mounted in a 2 in. NPT threaded hole. The overflow analyzers were mounted in the sample sinks in the thickener gallery. The installation locations are illustrated in Figure 4.

Inflow--

The influent solids analyzers consist of a one foot long sensing head housing a glass sampling chamber, a motor drive mechanism that moves the plunger which is positioned in the sampling chamber, and a control unit connected to the sensing head by a multi-conductor cable. The analyzers were mounted in the 12 in. influent lines as illustrated in Figure 5. The control units were mounted in an instrument panel located in the thickener gallery as illustrated in Figure 6.

The sensing head of the analyzer contains a light source that transmits a light beam across the sample chamber to a photocell. The plunger is equipped with a wiping seal that cleans the optical surfaces of the photocell and light source with each operating stroke. The signal from the photocell is linearized in the control unit producing a meter reading that is designed

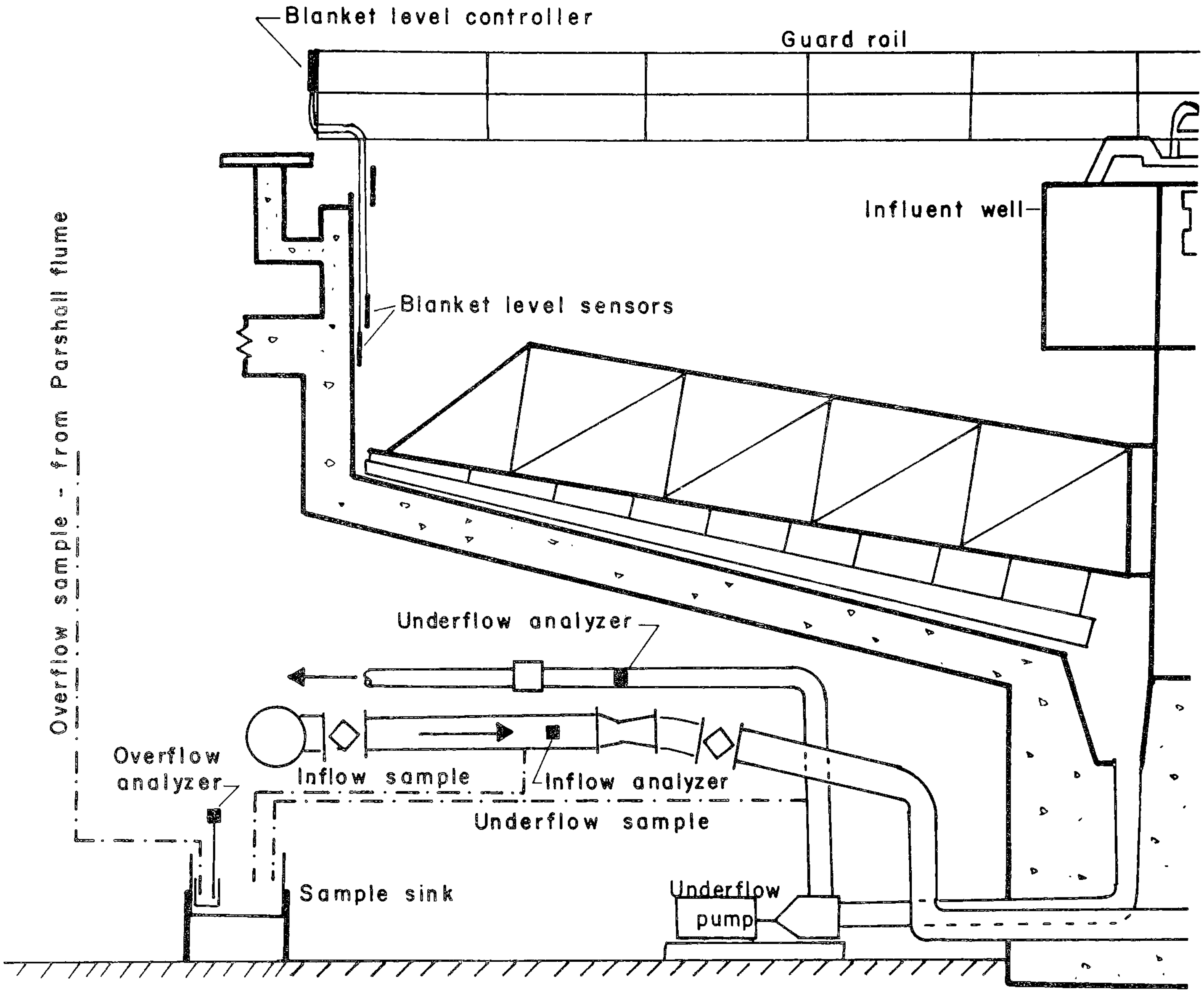

Figure 4. Location of solids analyzers and sampling lines.

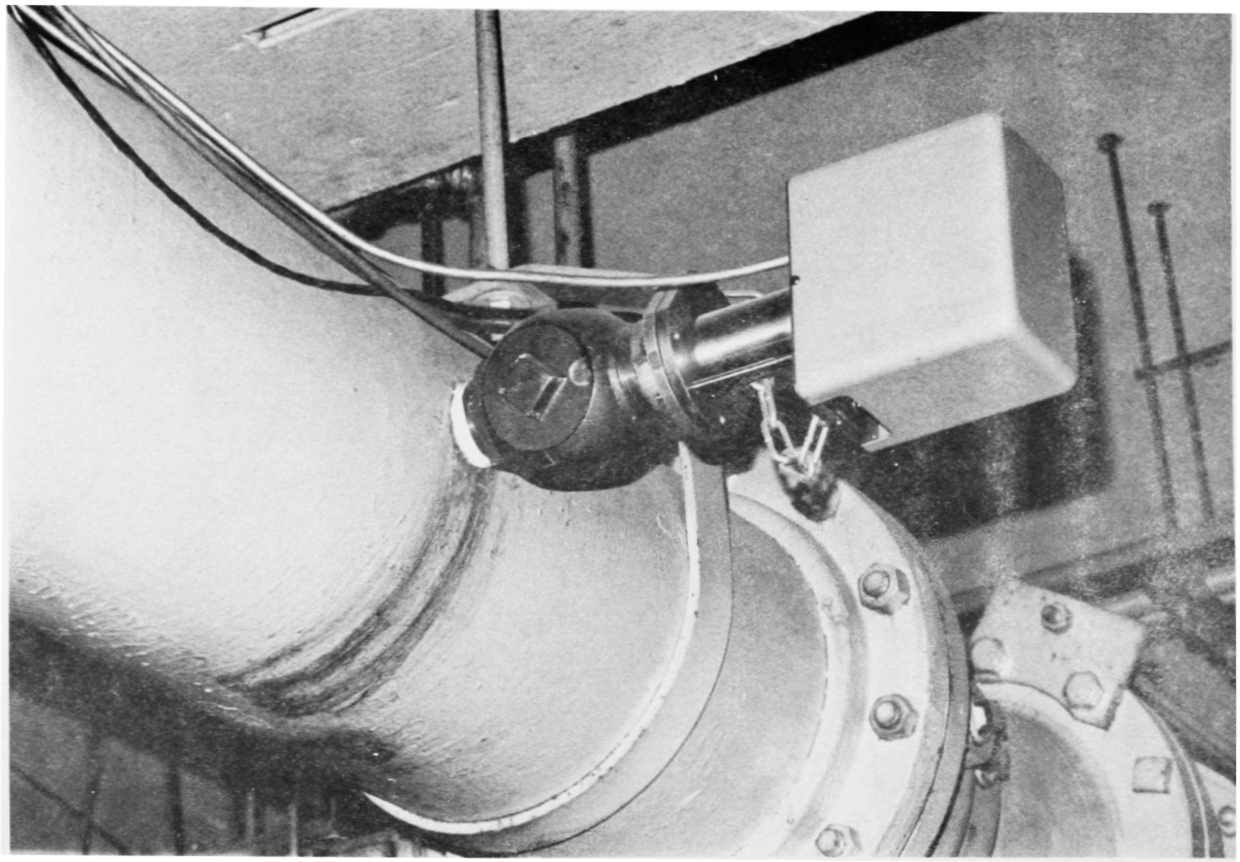

Figure 5. Solids analyzer mounted in basin influent pipe.

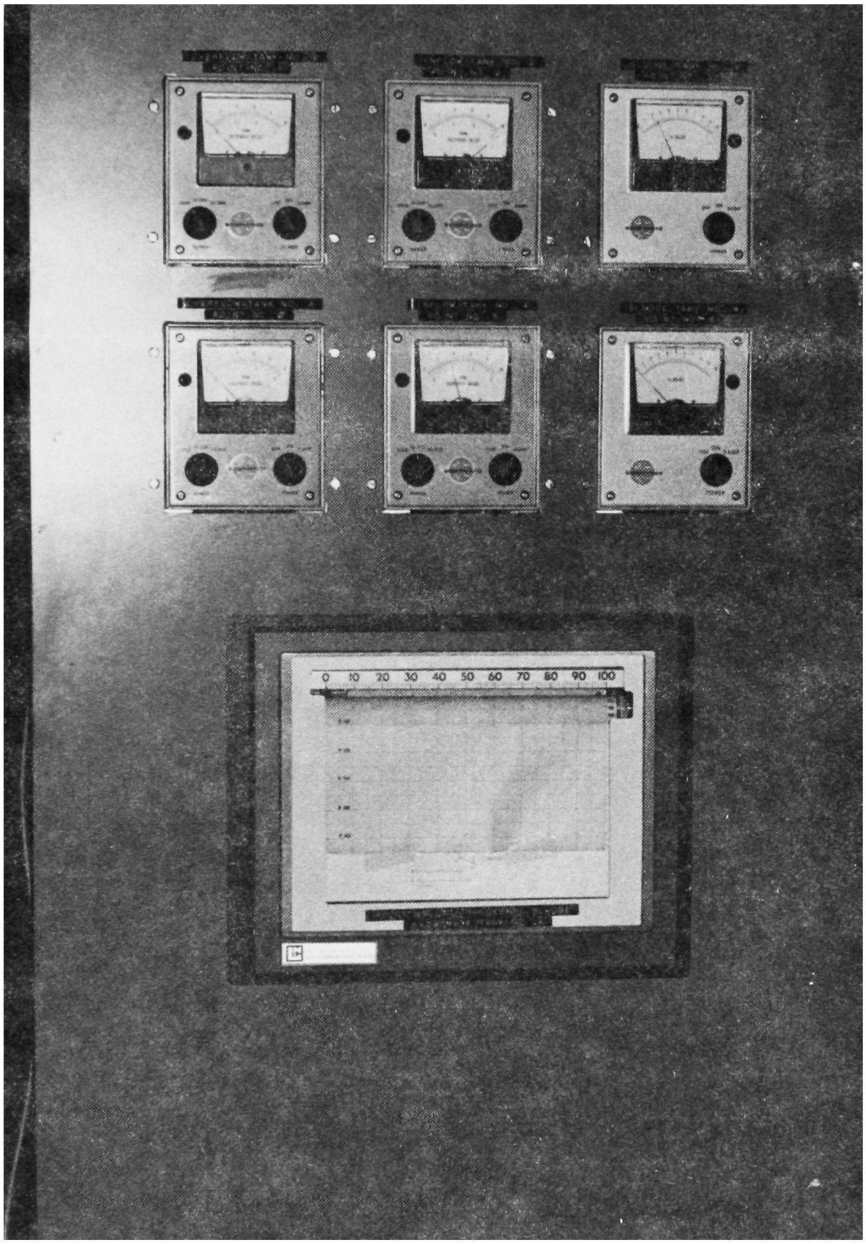

Figure 6. Instrument panel in thickener gallery.

to be proportional to the suspended solids concentration of the sample.

The unit completes a sample and analysis cycle every 15 sec. The plunger retracts and draws a sample into the sampling chamber similar to the operation of a common laboratory syringe. The light transmission measurement is made and the sample is expelled. The instrument output (meter and/or recorder) is maintained constant during each cycle. A range switch on the face of the control unit provides for operation in the range of 0 to 3000, 0 to 10,000, and 0 to 30,000 mg/l. An ON/DAMP switch allows for recording of the actual output fluctuations at 15 sec intervals or only a portion of the step change when the fluctuations are large.

Zero and span controls are located at the rear of the control unit. The zero control is used to adjust the output with clear water present in the sampling chamber. The span control is used to adjust the slope of the calibration curve. A test plug which consists of two fixed resistors and a high/low switch can be attached to the control unit in place of the signal cable. The resistors simulate photocell output in the 0 to 10,000 and 0 to 30,000 mg/l ranges. The meter readings with the test plug in place can be used to identify malfunctions in both the control unit and sensing head.

Overflow--

The overflow analyzers are functionally identical to those used to monitor inflow, however, the sensing heads are four feet long. The units are mounted in the sample sinks serving thickener basins 2 and 4 as illustrated in Figure 7. Thickener overflow is piped from the overflow flumes and discharges to one gal containers located in the sample sinks. The analyzers are supported above the sinks and the sensing heads extend into the sample containers which overflow continuously.

Underflow--

The underflow monitor is externally identical to the inflow unit; however, the underflow analyzers contain three photocells in the sensing head, one each for measuring light transmittance, 90^{o} light scatter and color compensation. The parallel combination of the light transmittance and light scatter photocells provides an output related to the suspended solids concentration in the sludge sample. The color compensation photocell adjusts the input current to the control unit amplifier to reflect changes in sludge color. A linerization module in the control unit corrects the nonlinear response of the transmittance and light scatter photocells. The unit completes a sample analysis cycle every 40 sec.

The control units are equipped with the ON/DAMP switches and span adjustment controls. The instrument range is fixed at 0 to 10% solids and is calibrated in terms of total solids. A test plug is used to simulate the output of the sensing head and check for drift in the control circuitry.

Recording--

The outputs of the six solids analyzers along with the output of the

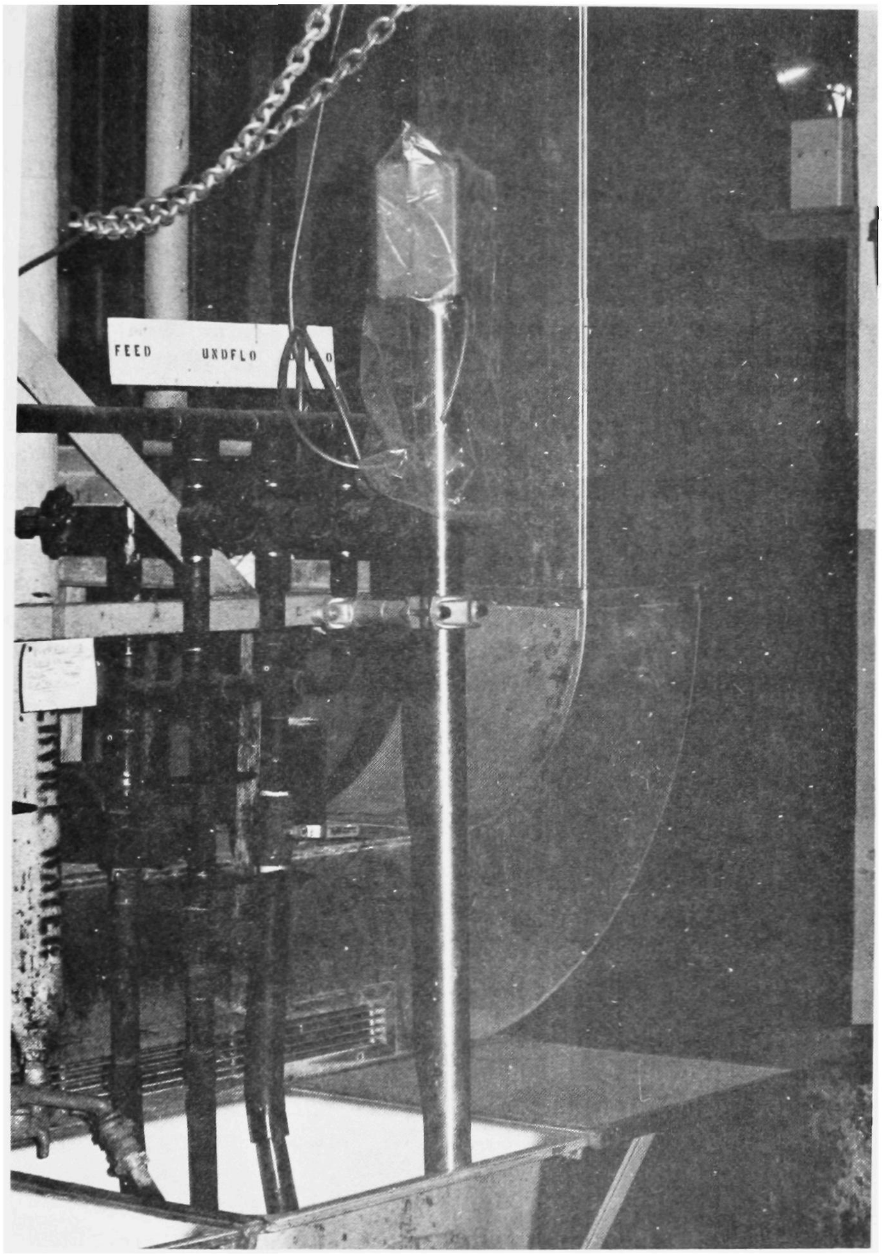

Figure 7. Solids analyzer mounted in sample sink.

thickened sludge (underflow) flowmeter serving basin 4 were recorded on a Leeds and Northrup Speedomax W multipoint recorder - Figure 6.

Flow

The rate of flow to each thickener is monitored by a 12 in. by 8 in. venturi meter as illustrated in Figure 2. The flow rate is indicated locally and is recorded and totalized in the control room in F & I No. 2. A PID controller is used to compare the metered inflow with an operator entered set point and adjust the pneumatically operated control valve accordingly.

The overflow from each basin is metered with a 9 in. Parshall flume. A standard bubbler arrangement is used to determine the discharge head. The output of the pressure transmitter and signal characterizer is fed to a local flow indicator and to a recorder and totalizer in the control room. In addition, the individual flows for the six basins are summed and displayed on one totalizer.

Four inch diameter magnetic flow meters are used to monitor the flow of thickened sludge discharged from each of the basins - Figure 2. The flow signal is indicated locally and recorded and totalized in the control room.

The flow metering and indicating equipment is calibrated periodically by the plant instrumentation crew on request of the engineering staff when problems are encountered or suspected.

SECTION 4

METHODS

SAMPLING

The location of the solids analyzers and sampling lines are illustrated in Figure 4. Samples for analyzer calibration and dewatering tests were collected at the sample sinks in the thickener gallery. The lengths of the inflow and underflow sample lines are approximately 25 ft and 35 ft respectively. The overflow sample line extends from the Parshall flume to the sample sink, approximately 70 ft. All thickeners have the same sampling configuration.

The following procedure was used to collect the inflow and overflow samples used to calibrate the solids analyzers.

[1] Allow sample line to discharge for several min.
[2] Record meter reading of solids analyzer.
[3] Collect sample (approximately 40 ml) and transfer to 250 ml plastic bottle.
[4] Repeat steps [2] and [3] four times at 15 sec intervals.

The suspended solids content of the composite sample was determined and compared to the average of the 5 meter readings.

Underflow samples were collected only when the underflow pump was operating. The procedure outlined above was used. The total solids concentration of the composited samples was determined along with the pH and capillary suction time.

Underflow samples for filter leaf tests were collected from the underflow sample lines in 5 gal plastic carboys. Approximately 6 l of sample were collected to provide for duplicate tests. Total solids analyses and filter leaf tests were conducted on the day of collection.

ANALYSES

Solids

Samples collected for suspended and total solids analyses were thoroughly mixed prior to removing portions for analysis. Suspended and total solids analyses were conducted on the day of collection according to procedures described in Standard Methods for the Examination of Water and Wastewater (2). Suspended solids concentrations between 0 and 1000 mg/l were recorded to the nearest 10 mg/l. Concentrations greater than 1000 mg/l were recorded to the nearest 50 mg/l. Total solids analyses were recorded to the nearest 0.1% solids.

Filter leaf cakes were dried overnight at 103° C and checked for constant weight. Results were recorded as total dry weight.

Total Organic Carbon

Portions of the samples collected for TOC analysis were filtered through glass fiber filters to remove suspended solids. The unfiltered and filtered fractions were acidified to a pH of 2 with concentrated hydrochloric acid. The samples were refrigerated at 4° C until the analyses were performed.

After removal from storage, the samples were diluted with deionized water, acidified as required and blended if suspended solids were present. The analyses were performed on an Astro Ecology Model 1200 TOC Analyzer after purging the samples for 5 min with air to remove inorganic carbon in the form of carbon dioxide.

Temperature and pH

Temperature measurements were made on samples from the inflow, overflow and underflow sample lines using a 0-100° C thermometer.

pH measurements were recorded at the time of sampling using a portable pH meter previously calibrated with pH 4 and 6.86 buffer solutions.

Capillary Suction Time

Capillary suction time (CST) determinations were made on pumped thickener underflow samples at the time of collection using a Triton Type 92/1 CST Timer as described by Baskerville and Gale (3). All CST determinations were conducted with a 1.8 cm x 2.5 cm (diameter x height) cylinder. Whatman no. 17 chromatography paper was used as the absorbent medium. CST tests were repeated several times on the same sample to provide a measurement of precision.

Filter Leaf

Filter leaf tests were conducted on underflow samples on the day of collection. Selected dosages of ferric chloride and lime were used to condition the sludge samples prior to performing the filtration. Chemical dosages were based on the total solids content of the sludge samples.

The ferric chloride conditioning reagent was analyzed for $FeCl_3$ content using a dichromate-stannous chloride acid titration (4). Lime concentration (as CaO) in the lime slurry conditioning reagent was determined by titrating a measured quantity of mixed slurry with standard hydrochloric acid to a phenolphthalein end point.

A measured quantity of the ferric chloride reagent was blended into a 2000 gram sludge sample for 30 sec at moderate speed using an electric cake mixer. A measured quantity of lime slurry was added and blended into the ferric chloride conditioned sludge for an additional 30 sec. The conditioned sludge was filtered immediately using a 0.1 sq ft filter with polypropylene filter medium. The filtration was conducted at 15 in. of Hg vacuum for 90 sec. After a drying time of 160 sec, the cake was removed and dried overnight at 103^{o} C. Filter yields were calculated based on total dry cake weight and a filter cycle time of 6 min. Duplicate filter leaf tests were performed on all samples. The filter medium was acid cleaned and a trial filter leaf test was discarded before proceeding with the actual filter leaf tests.

TIME STUDY

On three occasions the movements of thickener operators were monitored for an 8 hr shift to determine the actual time required to perform their duties. Each specific task was identified and the time required recorded in minutes. Three operators were observed, each during the day shift. The monitoring was accomplished without the knowledge of the operators.

SECTION 5

CALIBRATION PROCEDURES

SOLIDS ANALYZERS

General

The six analyzers used for monitoring thickener solids were installed in December, 1976. The inflow and overflow suspended solids analyzers were zeroed with water using the zero adjustment. Zero readings on the underflow analyzers were checked using water but no adjustments could be made. Initial calibrations were completed prior to initiating the sludge blanket control in basin 4. Calibration samples, however, were collected during each of the 5 test runs to establish the reliability of the instruments. Several of the instruments were recalibrated after component failures. In addition the test plugs supplied with each instrument were used to identify the drift characteristics of the individual control units.

Inflow

Inflow suspended solids analyzers were calibrated using the zero and span adjustments on the control unit to match meter readings with inflow suspended solids concentrations. Because the analyzers were pipe-mounted and could not be conveniently calibrated directly, a trial and error procedure was used in which the zero and span adjustments were made according to the previous day's sample analysis and meter readings. Although the analyzers were zeroed with water when installed, a linear calibration plot spanning a range of suspended solids concentrations (1000-5000 mg/l) could not be obtained after several trials. After the zero adjustment was offset to lower the readings obtained for samples with low suspended solids concentrations, better calibration linearity was obtained. Several samples were required to determine if the calibration adjustments produced a linear response over a given suspended solids concentration range.

The samples were collected as previously described with the control unit in the ON, undamped, position. The average meter reading and the corresponding suspended solids concentration of the composited sample represented one point on the instrument calibration curve. After several points were identified, covering a range of suspended solids concentration, new zero and/or span adjustments were made as required to improve the linearity of the suspended solids - meter reading relationship. Two or three adjustments were usually required to establish a satisfactory calibration plot.

The meter scales were read to the nearest 25 mg/l using the 0-3000 mg/l range and to the nearest 50 mg/l when the 0-10,000 mg/l range was used. The inflow analyzer control units were set on the 0-10,000 mg/l range and left in the DAMP position during normal operation to reduce meter fluctuation.

Overflow

The overflow suspended solids analyzers were calibrated using the same procedure described for the inflow analyzers. Both the 0-3000 and 0-10,000 mg/l ranges were used during test runs. The control units were left in the DAMP position during normal operation to reduce readout fluctuation.

Underflow

With the underflow sample flowing continuously, six grab samples were taken at 40 sec intervals corresponding to six consecutive meter readings. A composite sample was constructed and analyzed for total solids. The solids concentration along with the average of the six meter readings represented one calibration point.

Meter readings were recorded to the nearest 0.1% solids on the 0-10% solids scale. The ON, undamped, position was used during calibration and the DAMP position used during normal operation to reduce meter fluctuation.

Because the thickener underflow solids concentration did not change appreciably during the test runs, calibration plots covering a wide range of solids concentrations were not obtained. A direct calibration was, however, conducted on the thickener 2 underflow solids analyzer following the conclusion of test run 5. The calibration was performed over a wide range of solids concentration by diluting an underflow sample with selected volumes of overflow. The analyzer was removed from the underflow pipe and placed in the diluted underflow. The solids suspension was mixed gently to prevent sedimentation and the meter readings recorded for several consecutive sampling/analysis cycles.

FLOW METERS

General

Flow totalizers on thickeners 2 and 4 were checked against flow rate measurements in order to assure reliable flow information for the thickener control study. Overflow and underflow totalizer values were compared to calculated flows based on discharge head observations and basin volume measurements respectively. The flow checks were repeated to test the reproducibility of the comparisons.

Overflow

A two step procedure was used to calibrate the overflow measuring and recording system. Flow values, displayed on the local indicator, were compared to calculated flows - based on observations of flume discharge head. Subsequent comparisons were made between the local indicator and the totalizer over known time increments. The calibration data for the local indicator were obtained as follows:

[1] Install point gage above Parshall flume and establish elevation.

[2] Record local indicator reading - mgd.
[3] Determine discharge head - average of 3 observations.
[4] Record local indicator reading a second time.
[5] If the readings in steps [2] and [4] differed by more than 0.03 mgd the observations were discarded. If the readings were within the above limit the calculated flow and the average observed flow established one point on the calibration curve.

The local indicators and flow totalizers were compared on three occasions as follows.

[1] Record local indicator reading - mgd
[2] Record totalizer reading - gal, and time
[3] Record local indicator reading - mgd
[4] Record totalizer reading approximately 10 to 15 min after step [2], record time
[5] Record local indicator - mgd
[6] If the three values for the local indicator varied by more than 0.05 mgd (max-min) the observations were discarded. If the values were within this limit the average of the 3 readings of the local indicator and the flow rate, calculated from the two totalizer readings and known time interval, established one point on the calibration curve.

Underflow

The calibration status of the underflow discharge totalizers was checked by measuring the basin drawdown rate with the influent valve closed. Drawdown measurements were made with a point gage and the underflow pumping rate was in the range of 100 to 150 gpm.

SLUDGE BLANKET DETECTOR

The sludge blanket control system was checked prior to test run no. 1 to determine if the blanket control hardware started and stopped the underflow pump as designed. With the relay switches in the DELAY position and the pump control switch in the AUTO position, the probes were placed in covered containers of sludge and water to simulate both a rising and falling sludge blanket in the thickener. It was observed that the pump started 30 min after both probes were placed in the sludge sample and that the pump stopped 30 min after both probes were placed in clear water. The manual supplied with the instrument indicated the time delay was 15 min in each case. No attempt was made to modify the timers supplied.

SECTION 6

THICKENER OPERATION AND CONTROL

GENERAL

The thickener influent is a mixture of primary sludge, waste activated sludge and dilution water with volume ratios of approximately 1:1:2.5. For the four month period August through November 1977 the influent averaged 1.9 mgd per basin and the solids loading averaged approximately 22 psf/day. The ratio of primary solids to waste activated solids was approximately 1:1 for that time period.

The underflow solids concentration ranges from 3% in the summer months to 6% in the winter and spring. The observed increased thickening efficiency in the winter and spring is most likely due to an increase in the primary to waste activated solids ratio. This may be caused by decreased activated sludge production at the lower temperature and the increased inorganic solids loading on the plant associated with spring runoff.

As previously indicated the solids handling capacity of the Metro Wastewater Treatment Plant is currently limited by the capacity of the incinerators Because of this constraint it is often not possible to operate the thickeners so as to obtain maximum efficiency in terms of thickening and solids capture.

Chlorine is added to the dilution water flow to control both slime growth and floatation caused by gasification. The gaseous chlorine dose falls in the range of 10 to 20 mg/l based on total basin inflow.

The operation of the thickeners is controlled by one operator per shift stationed in the control room in F & I No. 2. The operator's duties include: recording all flow totalizers on an hourly basis, adjusting inflow set points as required, monitoring sludge level in holding tanks and controlling underflow pumping. In addition several times each shift the operator makes sludge blanket measurements, collects samples and conducts the normal housekeeping tasks around the thickeners and in the gallery.

EXISTING

The operators determine the location of the sludge blanket in each thickener six times each day as follows, 0100 hr, 0500 hr, 0800 hr, 1300 hr, 1700 hr, and 2100 hr. A portable photoelectric device, consisting of a light and photocell separated by a fixed gap and an audio output, is used to make the depth measurements. The photocell output is converted to an audio output (intensity of high pitched tone decreases as light transmission decreases and end point is not defined) rather than a meter. Thus, the measurement precision is not great because each operator may interpret the sound of the end point differently. The accuracy of the measurement is also a function of the interface characteristics (defined or diffuse). Additional sludge blanket observations are conducted, using the sidewall sample taps, at four hour intervals.

The operator bases the control of the underflow pumps on the sludge level in the holding tanks, and on the status of the incinerators and vacuum filters. No attempt is made to control the sludge blanket level other than to maintain sufficient underflow pumping to prevent the discharge of high concentrations of suspended solids in the overflow and to prevent the development of extreme septic conditions in the sludge. The basin with the highest sludge blanket has the first priority for pumping.

The underflow pumping rates are normally maintained in the range of 50 to 200 gpm. The rate used by the operator is based again on the blanket levels and the available capacity in the holding tanks. Rates above 200 gpm are not used because of what appears to be 'ratholing' and the associated discharge of more dilute sludge.

SLUDGE BLANKET CONTROL

A total of five tests, each lasting approximately 2 weeks, were conducted to document both the operating characteristics of the blanket control system and effects of blanket control on process performance. The thickener operators were not directly involved in the control scheme used for basin no. 4. During each test run they were instructed to maintain the sludge pump control for basin no. 4 in the AUTO position (controlled by blanket detector) and maintain a reasonable pumping rate. No. 4 underflow pump was operated manually periodically during the test runs to collect underflow samples for analyzer calibration. On several occasions the pump control was not returned to AUTO immediately and the sludge blanket level was lowered substantially.

A test run was not initiated if it was anticipated that maintenance requirements would decrease the incinerator or vacuum filter capacity. On several occasions, however, when problems developed downstream of the thickeners the operators deactivated the sludge blanket control system.

SLUDGE BLANKET DETECTOR

Because of the nature of the application it was anticipated that the optical surfaces of the probes would be fouled with coatings of grease and/or slime. If these coatings were allowed to accumulate they would eventually become equivalent to the sludge blanket in terms of light transmission from the source to the photocell. For this reason the photocell output was determined periodically, with the probes in clean water, to establish the cumulative effect of the coating and the associated cleaning requirements.

The manufacturer reported that the photocell resistance with the probe in clean water falls in the range of 5,000 to 10,000 ohms. With the probe in a solids suspension of 2000 mg/l the resistance was reported to fall in the range of 50,000 to 60,000 ohms.

SECTION 7

CHRONOLOGY

GENERAL

The sludge blanket detector and control system was evaluated by a series of five tests during which inflow, overflow, underflow, sludge dewatering, blanket level and instrument maintenance data were collected. The tests ran for periods of 10 to 16 days and were conducted during the period August through November, 1977 - TABLE 1. The data were collected to determine the precision and reliability of several types of hardware and to establish the relationship between blanket level control and basin performance in terms of thickening, solids capture and sludge dewatering characteristics.

TABLE 1. SLUDGE BLANKET CONTROL TESTS

Test run	Dates - 1977	Blanket control points feet from surface	
		Upper	Lower
1	August 1-16	5.5	6
2	August 31 - September 16	7.5	8
3	September 30 - October 14	5	5.5
4	October 17-27	3	3.5
5	November 8-18	5	5.5

The events, operational problems and observations recorded during the field inspections are summarized in the following paragraphs. The field observations are presented in more detail in Appendix B. Inspections were made as frequently as possible during the work week and both during and between test runs.

TEST RUN NO. 1

The inflow suspended solids concentration varied considerably during this period. Concentrations greater than 10,000 mg/l were observed for periods of 1/2 to 2 hr on August 2, 4 and 6. For the three day period, August 9-11, the concentration was consistently high, ranging from 4,000 mg/l to 10,000 mg/l. The concentration decreased to the range of 1,000 mg/l to 4,000 mg/l for the remainder of the period. Both the sludge blanket level and the overflow suspended solids concentration increased during the periods of high solids loading.

Relatively large, fibrous clumps of sludge solids accumulated in the overflow sample container on several occasions. This material did not have a significant effect on the overflow analyzer readings; however, on two occasions the material filled the sample container and could have blocked the overflow sample line if left unattended.

Problems were encountered with the underflow solids analyzer serving basin no. 4. The 4 to 20 ma output, used to drive the recorder, did not correspond to the instrument's meter readings. The control unit was shipped to the manufacturer for repair.

For the period August 11-16, the overflow totalizer for basin no. 4 indicated flow rates significantly lower than the corresponding inflow totalizer. Visual observations of the overflow weirs of basins no. 2 and no. 4 indicated that the inflow meter was generating an erroneous signal. On August 29 debris, which was found to be lodged in the influent well of basin no. 4, was flushed out by closing the inflow valves to basins no. 2 and no. 6 and thus increasing the flow to basin no. 4. After the influent well was cleared of the obstruction the inflow and overflow rates corresponded. The material which had caused the obstruction is pictured in Figure 8.

TEST RUN NO. 2

All of the vacuum filters located in F & I No. 2 were taken out of service on September 5 because of maintenance requirements. Because of the filter shutdown, inflow and underflow pumping, to and from, all thickener basins was terminated on September 5. All basins were put back into service late on the following day.

The inflow analyzer serving basin no. 2 failed the first day of run no. 2 and was out of service for the entire period. The motor which drives the plunger was replaced and the analyzer put back into service on September 27.

Problems were encountered with the underflow analyzer serving basin no. 4. The meter read off scale on the upper end with the motor and plunger operating normally. The instrument was removed and a grease accumulation cleaned from the entrance of the sample chamber. The instrument functioned properly when it was replaced in the underflow pipe.

TEST RUN NO. 3

The underflow analyzer serving basin no. 4 failed off scale several times during this period. It was finally determined that the light source was causing the problems and a new lamp assembly was ordered from the manufacturer.

The operators were notified to maintain the underflow pumping rate for

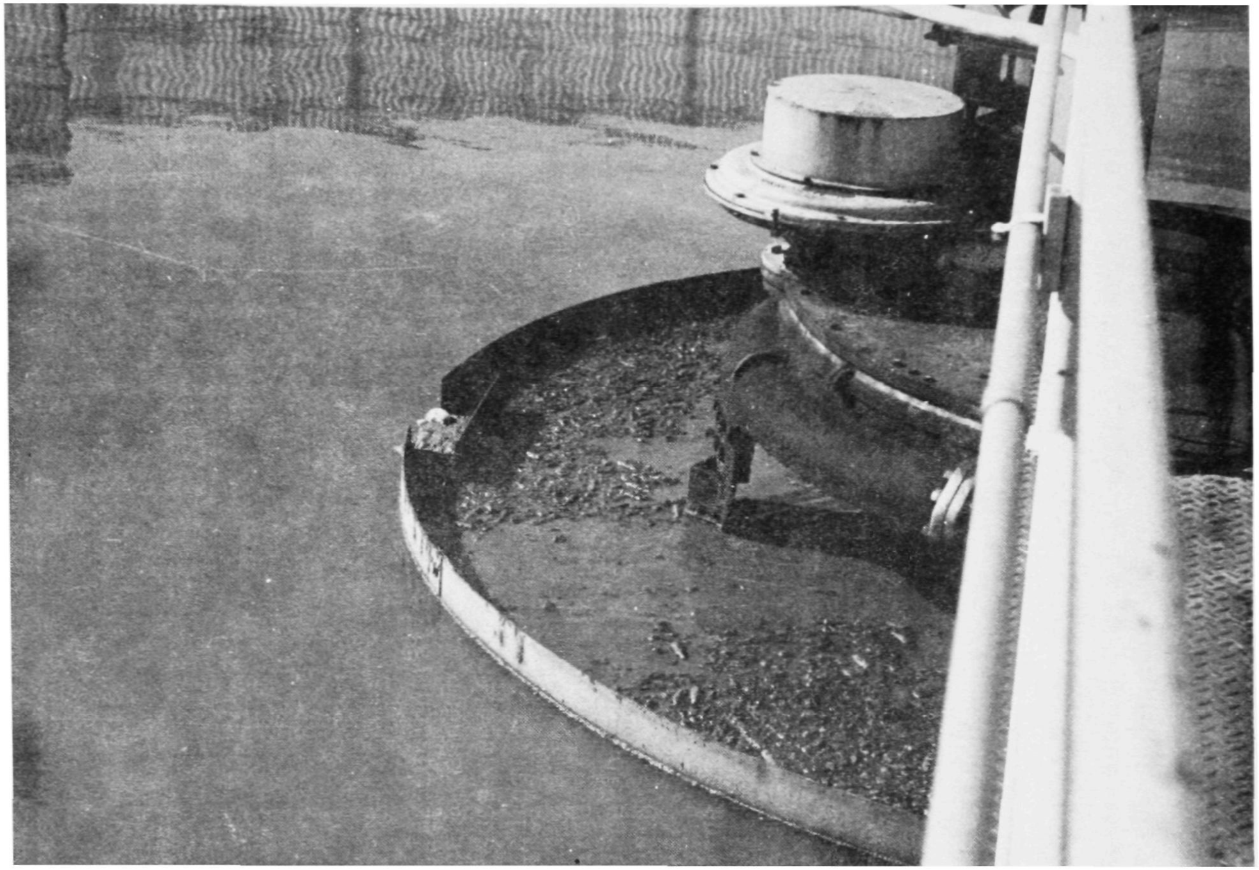

Figure 8. Thicken No. 4 with debris dislodged from influent well.

basin no. 4 at or above 150 gpm. This was required to assure control of the blanket level during periods of high solids loading. On one occasion the no. 4 underflow pump control was found in the manual mode. The operator had switched to MANUAL to adjust the speed and did not return the switch to AUTO.

TEST RUN NO. 4

Basin no. 2 was out of service for two days, October 19 and 20, to conduct scheduled maintenance. The blanket level of basin no. 4 was lowered approximately 4 ft during the evening of October 24 when the operator neglected to return the underflow pump control to the AUTO position. The pump had been switched to manual control to facilitate sample collection.

Both the upper and lower probe of the blanket detector were cleaned at the start of test run no. 3. They were cleaned again one month later at the end of run no. 4. The optical surfaces of the upper probe had become heavily coated. The photocell resistance of both probes was determined. The measurements indicated that the coating on the upper probe had caused the control system to fail and, in turn, caused the underflow pump to run continuously for 3 days.

TEST RUN NO. 5

The inflow totalizer for basin no. 2 was out of service for the last half of this period.

On November 17, 20 days after the previous cleaning, the blanket detector failed due to film accumulation on the probes.

SECTION 8

DISCUSSION OF RESULTS

SLUDGE BLANKET CONTROLLER

Level Control

General--

Two problems were encountered when using the installed hardware to control sludge blankets during normal operation. The speed of the underflow pump was not always sufficient to control the sludge blanket elevation during the periods of high solids loading which were encountered in test runs 1 and 2. As a result the sludge blanket interface rose above the probes for several days despite continuous pump operation. Subsequent instructions to maintain the underflow pumping rate for basin no. 4 at or above 150 gpm, subject to the level of sludge in the holding tank, helped to control this problem during test runs 3 through 5.

Problems with film accumulation on the optical surfaces of the probes were encountered during test runs 4 and 5, and possibly at the conclusion of test run 3. The film coating may have caused the underflow pump to continue running although sludge blanket readings indicated that the blanket was several feet below the probe location. A weekly inspection of the probes should eliminate this problem.

With the exception of the pumping rate and film accumulation problems the sludge blanket control system operated satisfactorily. On several occasions the underflow pump on thickener no. 4 was started manually in order to collect underflow samples. The pump switch was left in the AUTO position during each test run with the exception of the thickener shutdown on September 6 and on three occasions when the underflow pump was placed or inadvertently left in HAND position by the thickener operator (October 7, 12, and 24).

Test Run 1--

The sludge blanket data collected during test run 1 are presented in Figure 9. For the periods August 2-5 and August 9-12 the solids loading was significantly higher than normal. During these periods control of the blanket level was not achieved. The underflow pump for thickener no. 4 operated continuously during the period August 1-11 except for one hour intervals on August 5, 8, 9, and 11. During this period the pumping rate varied in the range of 100 gpm to 175 gpm.

The sludge blanket interface was not well defined during the first ten days of the run, based on the sludge blanket measurements taken during the

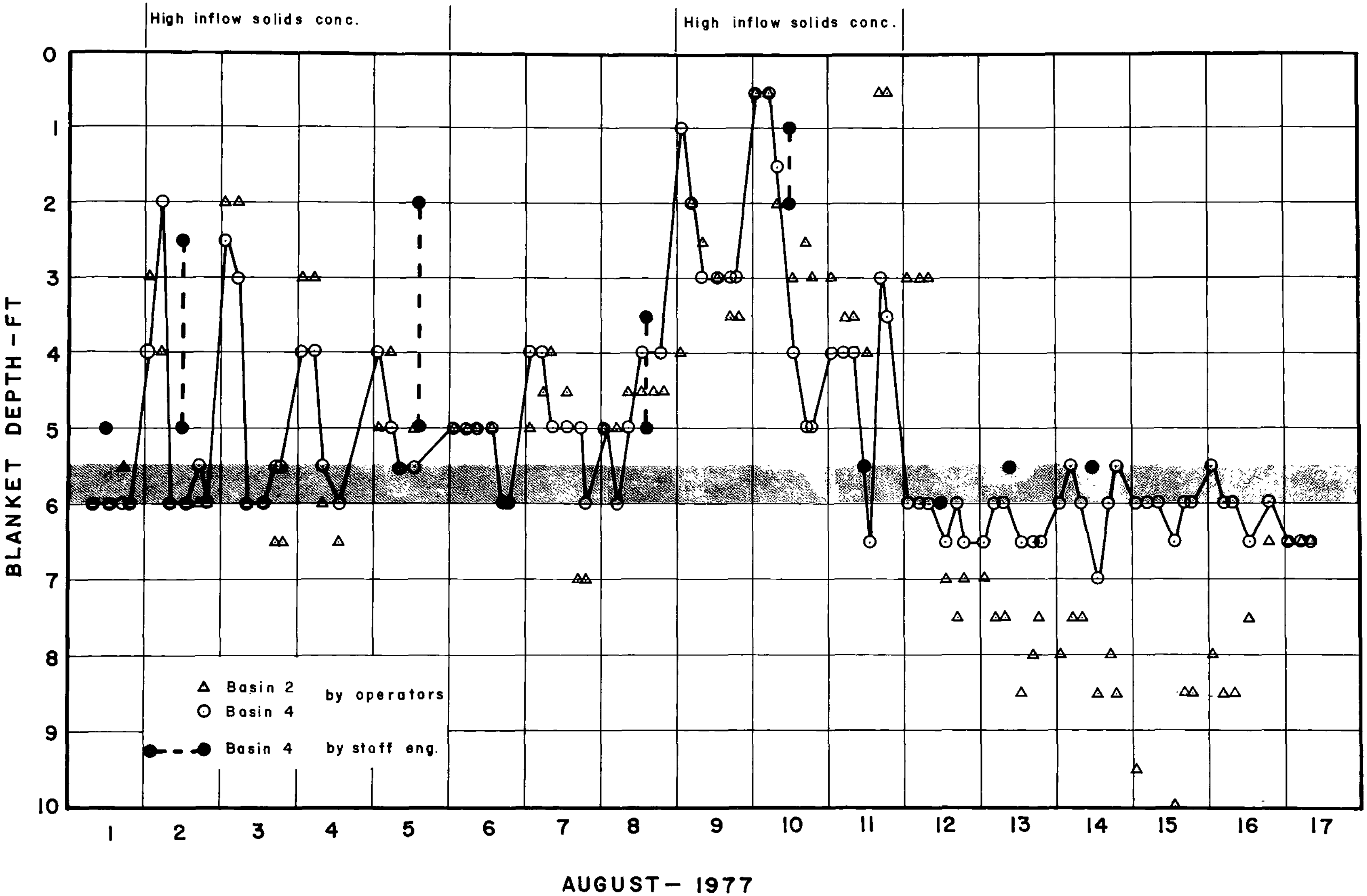

Figure 9. Depth to sludge blankets for basins 2 and 4 during test run No. 1.

inspections conducted over the same time period. On August 5 the staff engineer conducting the study found the precision of the measurement to be particularly poor. A range of 3 ft was observed as illustrated in Figure 9. The absence of a well defined interface may have contributed to the fluctuations observed in the blanket readings.

The underflow pump maintained an on and off operating pattern beginning on August 12 and continuing through August 16 with off times ranging from 7 to 13 hr. During this period the sludge blanket was controlled effectively near the six foot location as illustrated in Figure 9.

Test Run 2--

Thickener no. 4 underflow pump ran on a continuous basis at 50-125 gpm for the period September 1-4. Low pumping rates were used because of high sludge levels in the sludge holding tank. Unfortunately the sludge blanket readings were not available during the first four days of the run. It does appear, however, that the sludge blanket elevation was not controlled during this period based on the continuous pump operation. This lack of control is attributed to the low pumping rates.

The sludge blanket elevation observations made during test run 2 are presented in Figure 10. Blanket elevations well above the control location of 7.5 to 8 ft were recorded for the periods of September 10-12 and 13-16. The rise of the blanket in thickener no. 4 on September 10 and 11 was caused by an increase in inflow suspended solids concentration which remained between 4000 and 5000 mg/l during the period September 7-10, and a decrease in thickener 4 underflow pumping rate to 75-100 gpm on September 10 and 11. Thickener 4 pump operation continued uninterrupted from September 6-16 except for one hr on September 8, during the calibration of the Parshall flume, and 0.5 hr on September 13 when the sludge blanket probes were checked for film accumulation. As indicated in Figure 10, blanket control was not maintained using the low underflow pumping rates.

Test Run 3--

The blanket elevation data collected during test run 3 are presented in Figure 11. The sludge blanket elevation was maintained near the control range of 5 ft to 5.5 ft during most of the run. The underflow pump serving thickener no. 4 maintained an on-off pattern throughout the 15 day period with the off time varying from 1 to 6 hr. The cyclic pattern indicates the blanket controller was functioning and that the underflow pump had sufficient capacity to withdraw solids at a rate $\geq$ the basin solids loading rate.

The irregular blanket elevations recorded by the operators for basin no. 4 on October 6, 11 and 12 were most likely related to the operation of the sludge blanket detector as previously described. Instances of inflow suspended solids concentrations greater than 10,000 mg/l were observed on October 3 and 6. The high loading on October 6 coincided with the high sludge blanket readings recorded on that date. Both high inflow loading periods produced overflow suspended solids concentrations greater than 3000 mg/l in thickener no. 4.

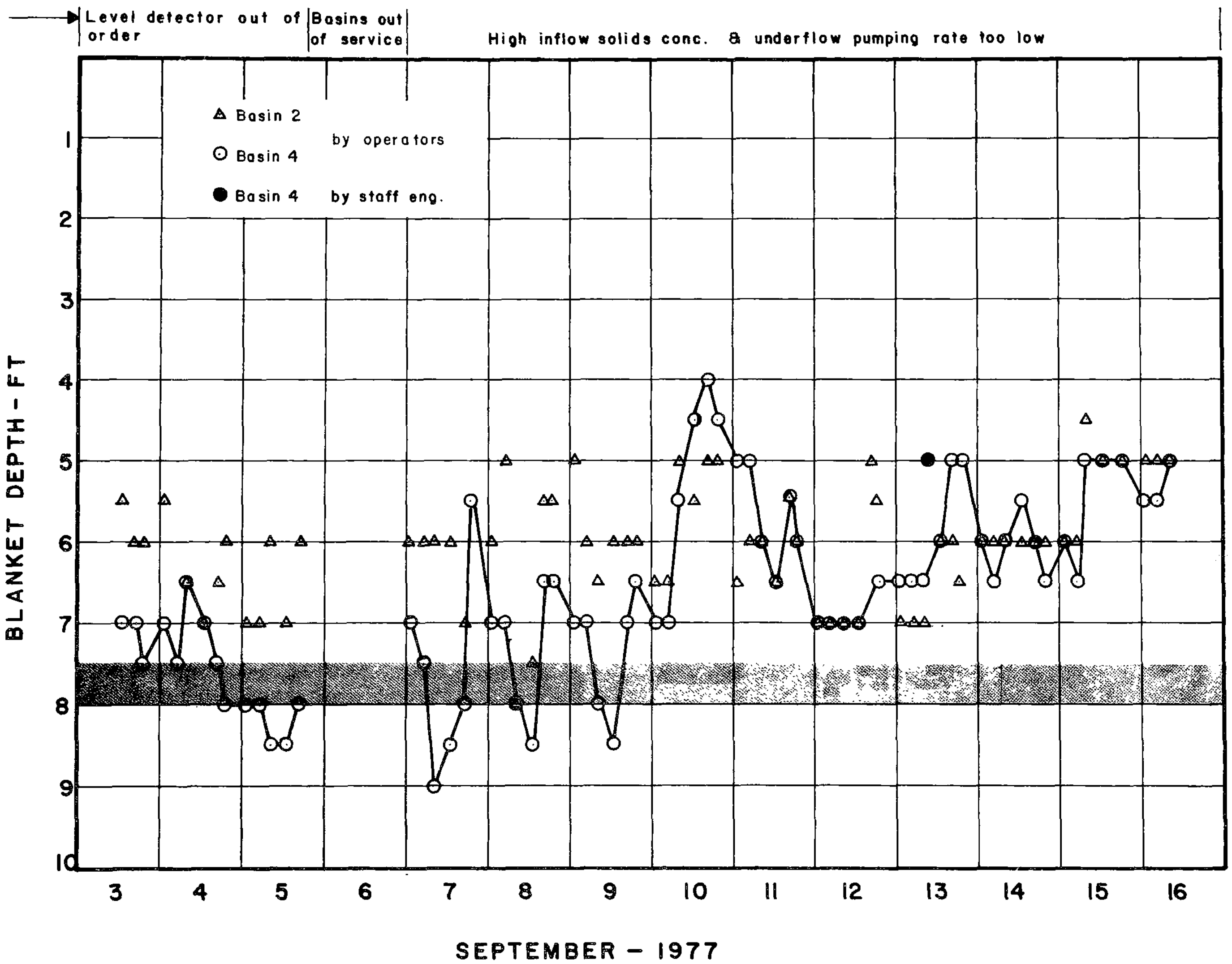

Figure 10. Depth to sludge blankets for basins 2 and 4 during test run No. 2.

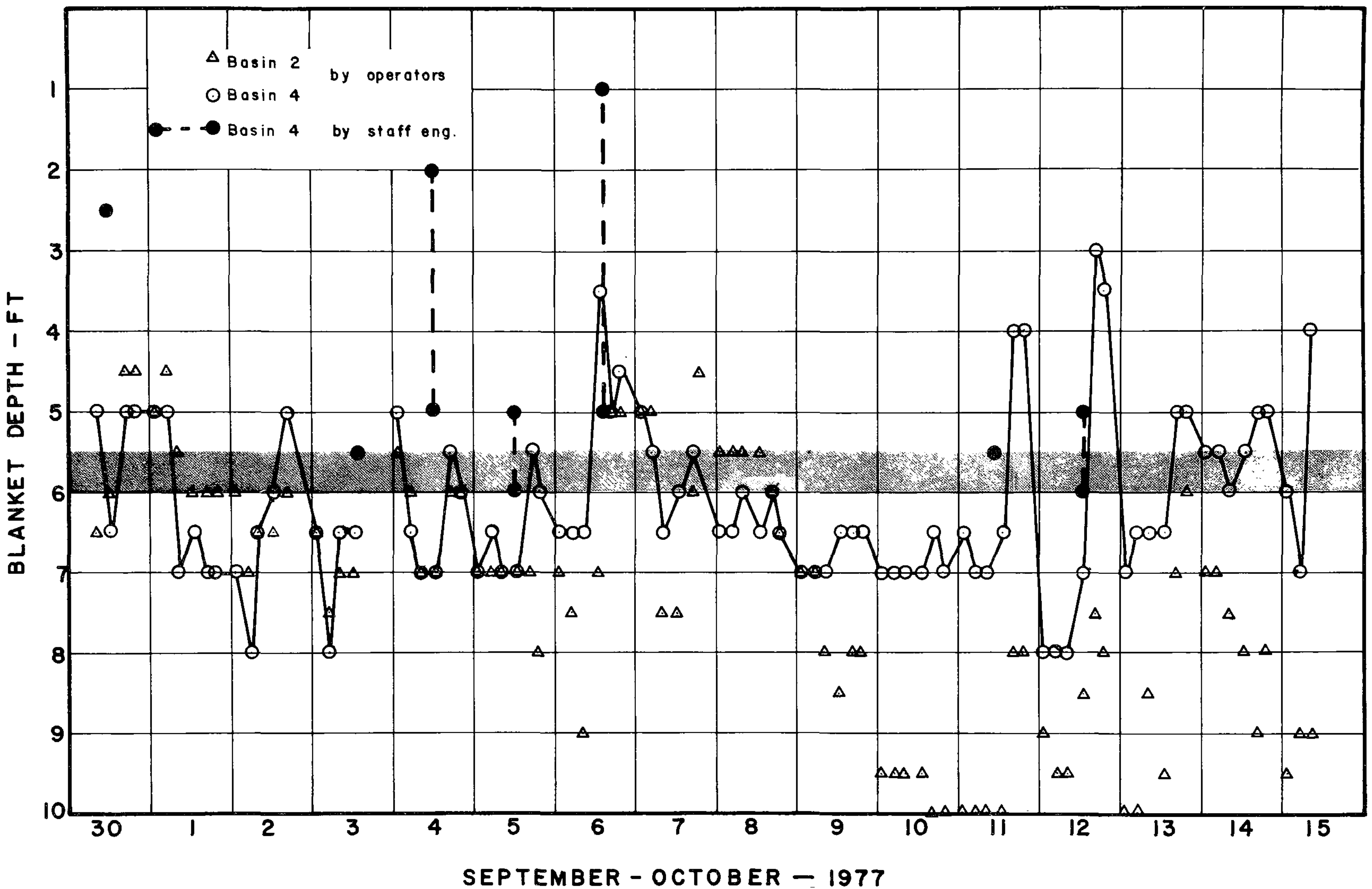

Figure 11. Depth to sludge blankets for basins 2 and 4 during test run No. 3.

Test Run 4--

The sludge blanket elevation data collected during test run 4 are presented in Figure 12. Sludge blanket control was achieved in thickener no. 4 near the probe locations of 3 and 3 1/2 ft from October 19-25. The underflow pump ran continuously from October 17-20 at 100-175 gpm except for a five hr period on October 18. During this period the inflow suspended solids concentrations ranged from 3000 to 5000 mg/l. The solids loading may have been high enough to maintain the sludge blanket above the probe location and call for continuous underflow pumping. During the period October 20-24, the underflow pump operated in an on-off pattern. Inflow suspended solids concentrations decreased to approximately 3000 mg/l over the same time period.

On October 24, the pump control was placed in the manual mode to collect a sludge sample. The pump was inadvertently left in the manual mode by the operator and the sludge blanket was lowered to a level well below the desired location by 1200 hr on October 25. After the pump switch was returned to the AUTO position on October 25, it pumped continuously through October 27 except for one 0.5 hr period. The continuous pumping is attributed to the buildup of film on the optical surfaces of the probes.

Test Run 5--

Sludge blanket elevation data obtained during test run 5 are presented in Figure 13. Sludge blanket control was maintained in thickener no. 4 near the probe locations of 5 and 5 1/2 ft except during the period November 12-13 and on November 17. Thickener no. 4 underflow pump operated in an on-off pattern throughout the test run. Off times ranged from 3 1/2 to 19 hr. On November 16 and 17 the sludge blanket in thickener no. 4 was pumped down from 6 1/2 to 9 1/2 ft when the pump ran continuously for a period of 29 hr. Film accumulation on the optical surfaces of the probes appeared to have caused the problem. The pump remained off for 19 hr after the optical surfaces were cleaned on November 17.

The variation in sludge blanket readings in thickener no. 4 on November 12 and 13 is not readily explained. A lack of sludge blanket control is clearly evident with consecutive blanket readings more than one ft above and below the control location on the same day. The lack of effective blanket level control may have been due to optical surface coating, inaccurate sludge blanket readings or a switch to manual pump control by the operator. It was not evident, however, that any of these problems had occurred. The optical surfaces of the probes had only a slight visible film accumulation during an inspection conducted on November 10. Control of the sludge blanket was achieved on the 13th with blanket readings stabilizing at 5 1/2 to 6 ft.

Maintenance

No mechanical or electrical problems were encountered in the sludge blanket control system from November, 1976 to the conclusion of test run 5 in November, 1977. Maintenance of the system consisted of inspecting the optical surfaces of the probes for visible film and checking the light

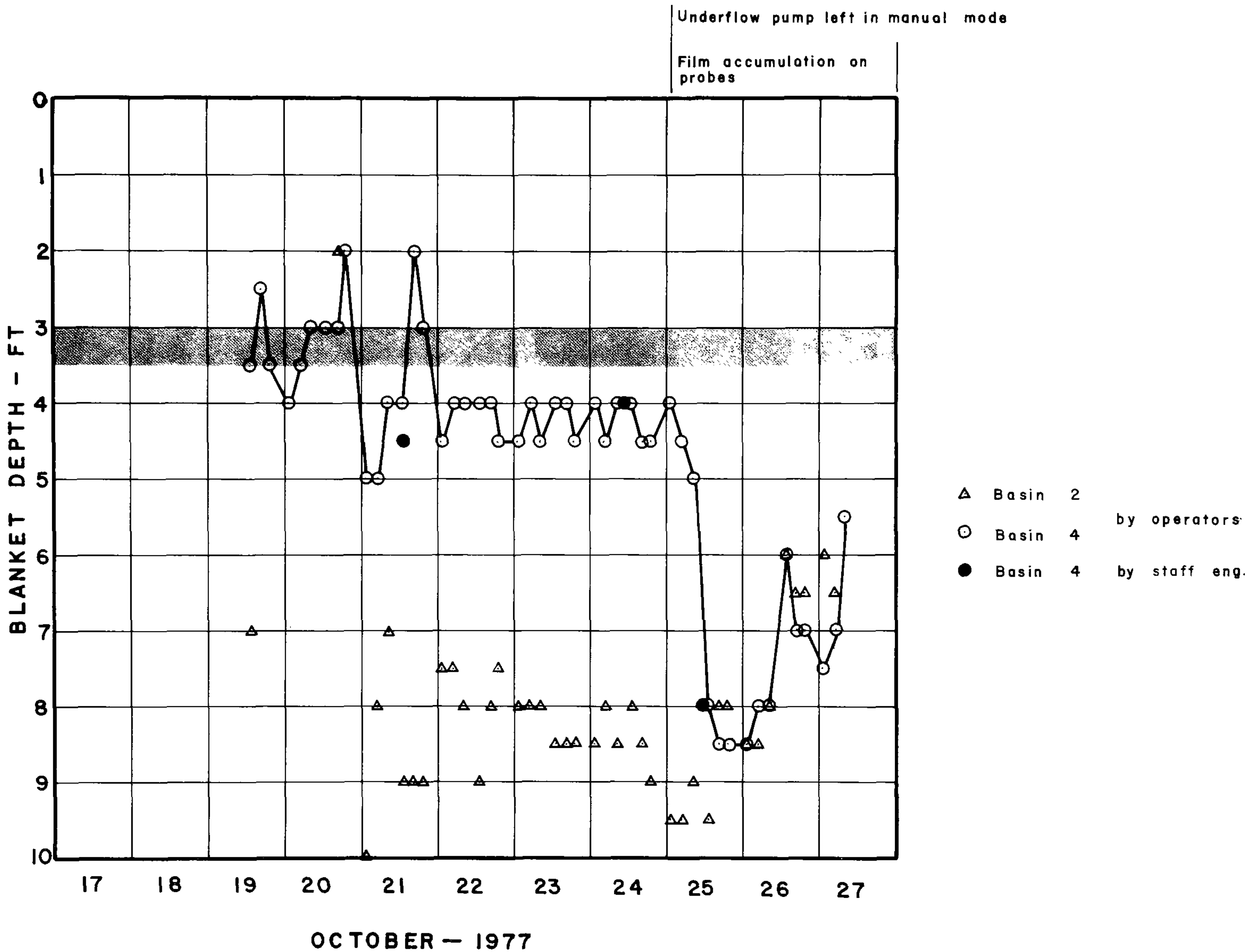

Figure 12. Depth to sludge blankets for basins 2 and 4 during test run No. 4.

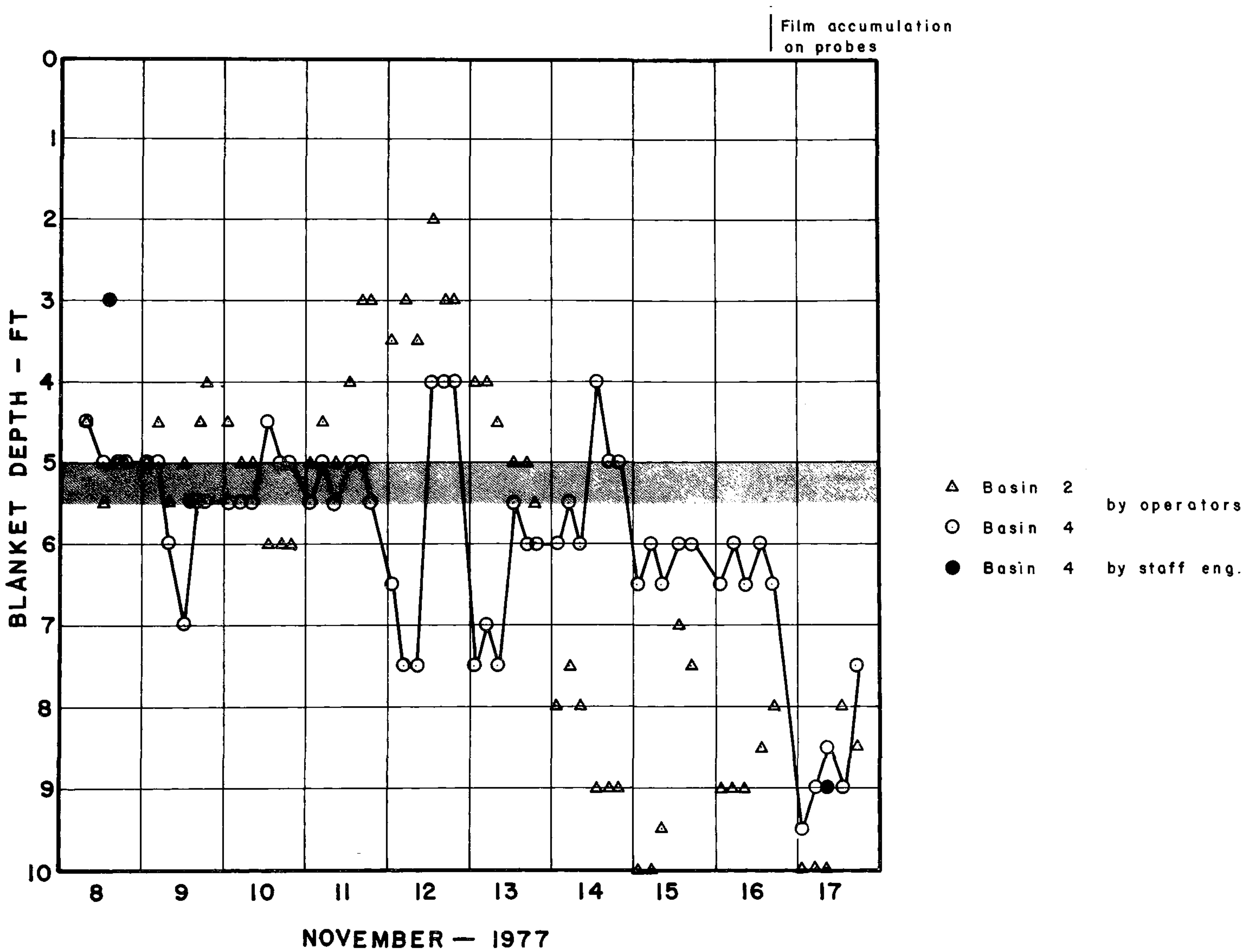

Figure 13. Depth to sludge blankets for basins 2 and 4 during test run No. 5.

sources to verify proper functioning.

The probes were not cleaned during each inspection. This was done to determine the time period the control system could function without maintenance. During test run 4, the probes were left uncleaned for 25 days before problems (continuous pumping) were encountered due to the buildup of film on the optical surfaces of the probes. During test run 5 problems were encountered 20 days after cleaning the probes. No problems were encountered because of film accumulation for a total of 15 days during test run 1, 17 days during test run 2 and at least 12 days during test run 3. The probes were inspected but not cleaned during runs 1 through 3.

The photocell resistance of each probe was determined periodically to monitor the change in output as a function of time and to determine the effect of film accumulation on the output. A comparison was made between the photocell resistance associated with a film coating and that related to a suspended solids suspension which closely matched the suspended solids equivalent of the threshold control setting. The threshold control was maintained at a setting of 4 which is equivalent to 2000 mg/l suspended solids according to the instrument operating manual. Photocell output was determined in clear water and in a thickener inflow sample with a 1900 mg/l suspended solids concentration. This suspension activated the output relay when the lower probe was transferred to it from clear water. Each measurement was conducted in a covered container to eliminate interference from sunlight.

The measured photocell resistance values for the probes are presented in TABLE 2. On one occasion (October 28) the coating on the optical surfaces was sufficient to produce a resistance reading exceeding the resistance recorded for the 1900 mg/l suspension. The 800 kiloohm resistance was evidence that the cause of the continuous underflow pumping observed from October 25 to 27 was due to the coating of the optical surfaces. When inspecting and cleaning the probes it was observed that the upper probe usually had a greater film accumulation than the lower probe. Both photocells exhibited a slow increase in resistance in clear water as a function of time.

Monitoring the photocell resistance was not necessary for operation of the blanket control system and was not considered to be required maintenance. It appears that a weekly inspection and cleaning of the probes would be sufficient to maintain trouble free operation.

SOLIDS ANALYZERS

Inflow and Overflow

Calibration--

The calibration data collected for the inflow suspended solids analyzers are presented in Figures 14 and 15. Two calibration curves are presented for each instrument; one for each setting of the calibration control. The values of the correlation coefficients, r, determined by linear regression analyses, indicate that the solids analyzers did provide reasonably good estimates of the actual suspended solids concentrations. Analyses of the

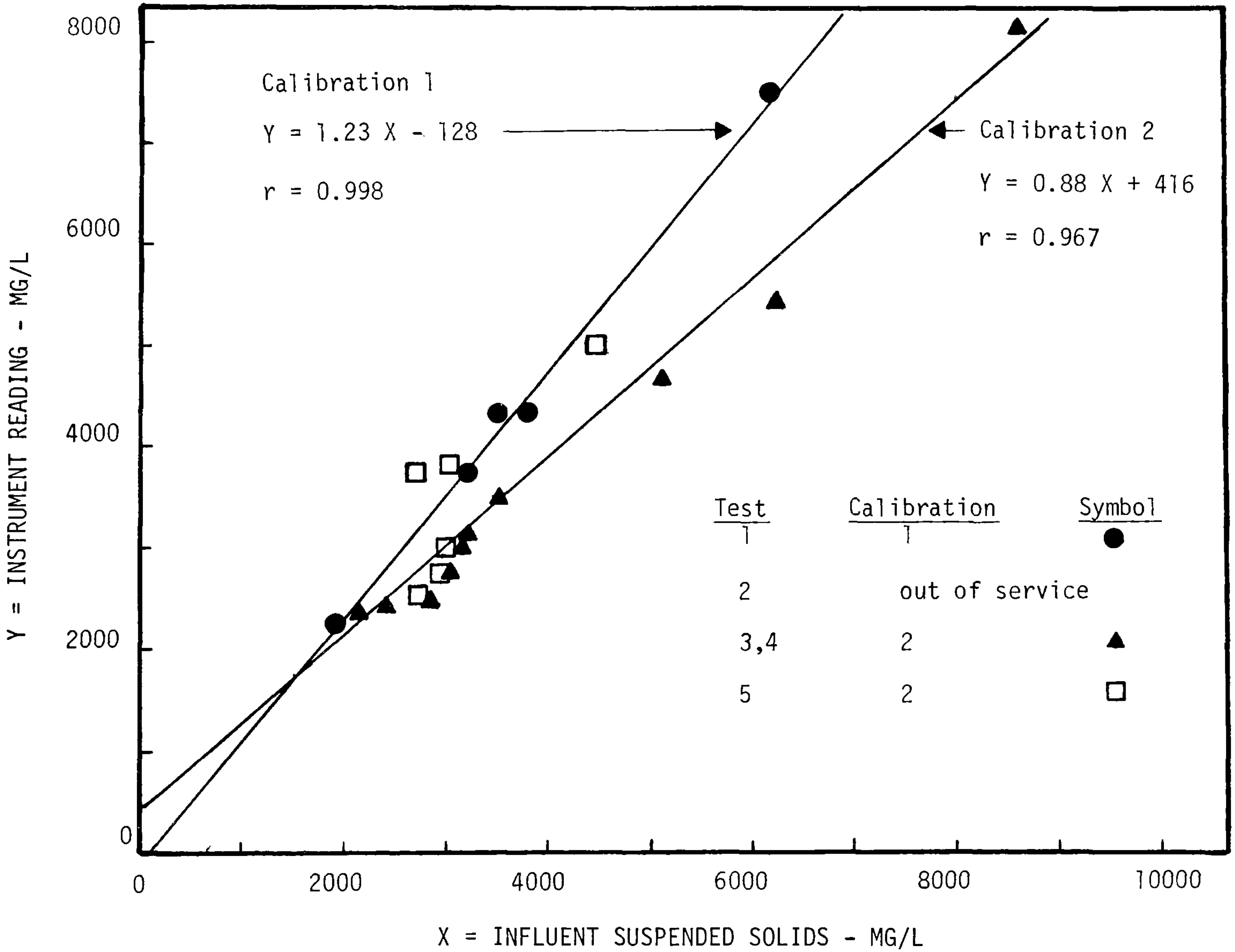

Figure 14. Calibration data for thickener no. 2 influent solids analyzer.

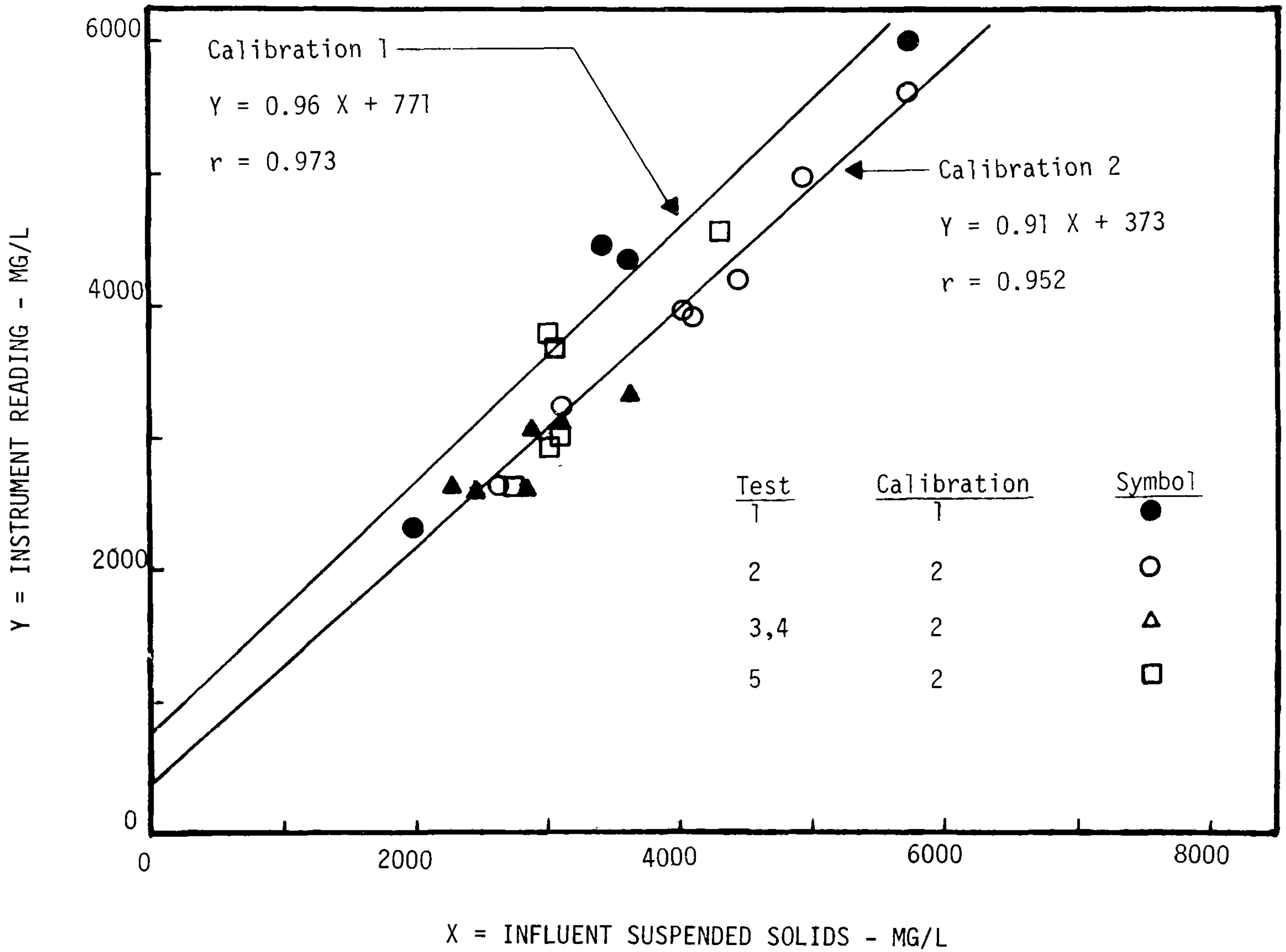

Figure 15. Calibration data for thickener no. 4 influent solids analyzer.

data obtained during each test run did, however, indicate that the values of the correlation coefficient decreased regularly during the 4 month period. This observation may not be significant, however, because of the limited number of calibration points generated during the individual test runs and the limited range of suspended solids encountered.

TABLE 2. PHOTOCELL RESISTANCE MEASUREMENTS

Date	Sample	Probe optical surface condition	Photocell resistance in kiloohms	
			Upper probe	Lower probe
5-26-77	water	clean	16.0	4.95
	1900 mg/l SS suspension	clean	220	65
6- 3-77	water	clean	16.5	5.2
	water	7 day film accumulation under operating conditions	21	8.4
8-16-77	water	15 days under operating conditions	27	8.5
10-28-77	water	clean	21.5	11.5
	water	28 days under operating conditions (upper probe heavily coated)	800	23.5

The calibration curves for the overflow solids analyzers are presented in Figures 16 and 17. The values for the correlation coefficients again indicate that the instruments provided good estimates of the actual suspended solids concentrations.

The instrument readings obtained with test plug are summarized in TABLE 3. According to the manufacturer's literature supplied with the instruments, the test plug readings should be within the 2000 to 6000 mg/l range when the LOW position is used and in the 10,000 to 20,000 mg/l range for the HIGH position. Although the readings remained within the specified ranges some variations were observed. The actual significance of these variations and the effects of control unit drift were not established.

Based on the calibration data collected over the 4 month period the solids analyzers were judged to provide acceptable estimates of suspended solids in the 0 to 10,000 mg/l range. The thickener feed was a mixture of primary sludge, waste activated sludge and dilution water in the ratio

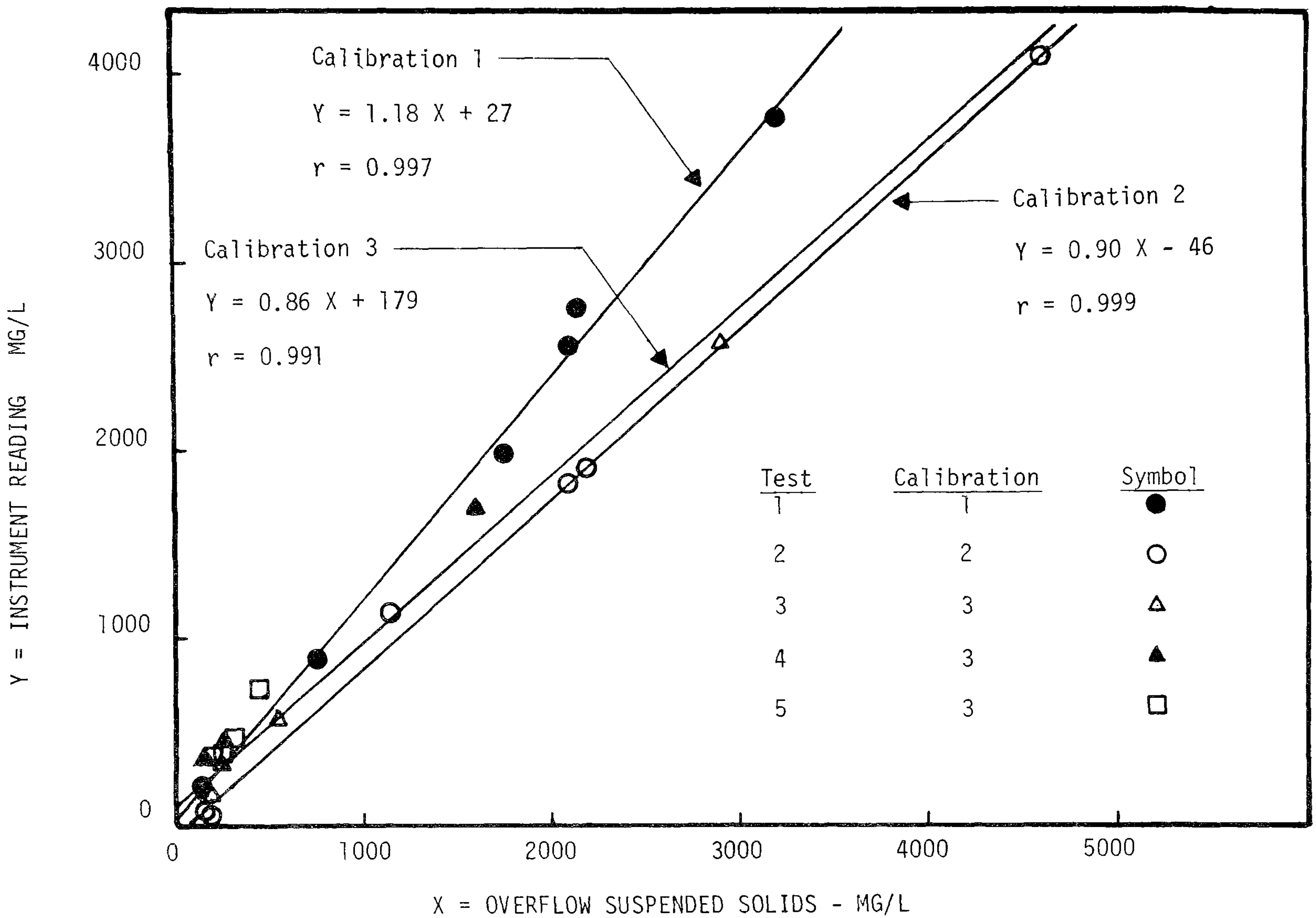

Figure 16. Calibration data for thickener no. 2 overflow solids analyzer.

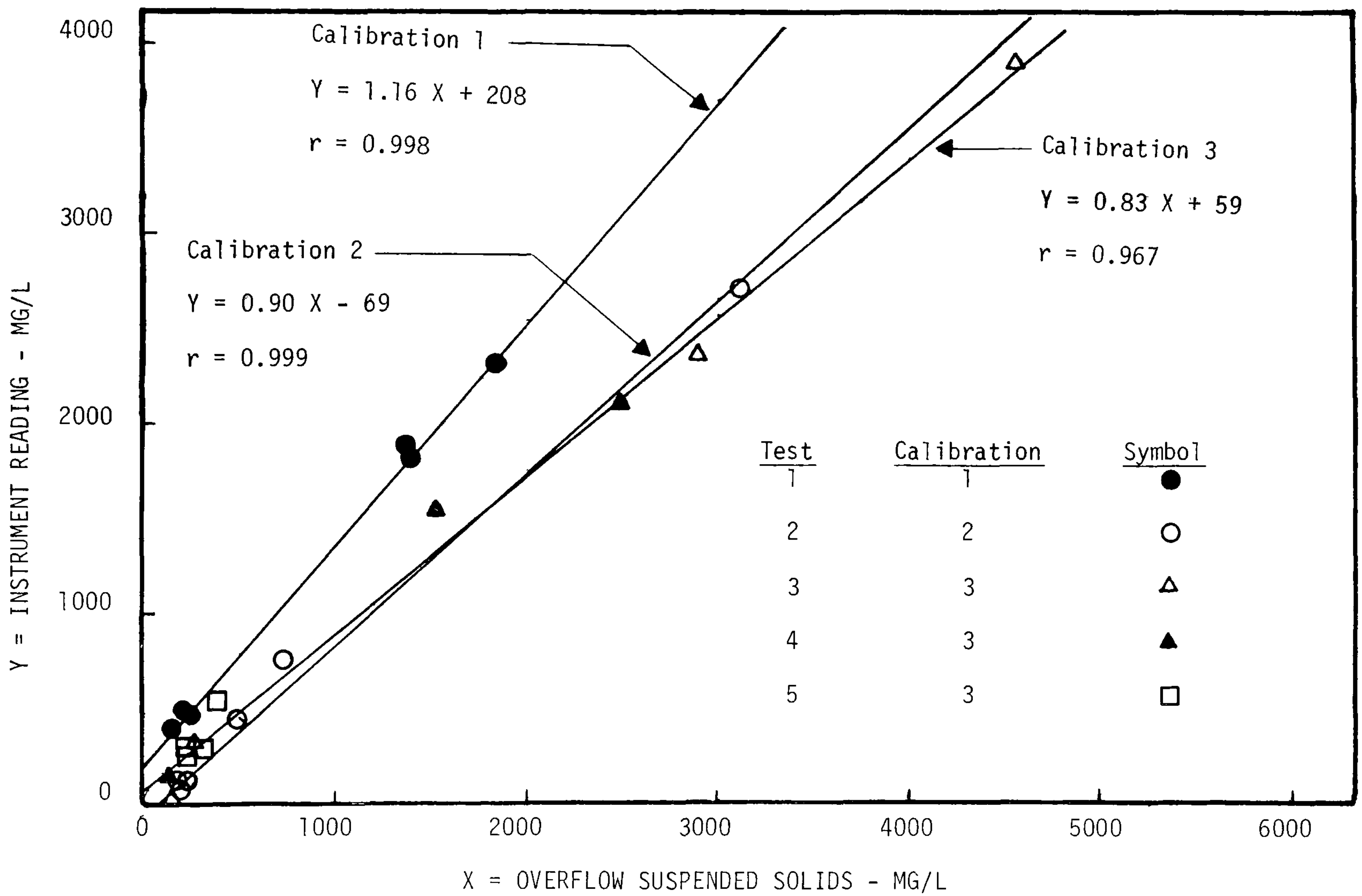

Figure 17. Calibration data for thickener no. 4 overflow solids analyzer.

1:1:2.5 respectively.) In order to insure adequate performance, however, routine calibrations should be performed on a semi-monthly basis and the electronic drift documented on a weekly basis with the test plug.

TABLE 3. TEST PLUG READINGS FOR SUSPENDED SOLIDS ANALYZERS

		Inflow ppm calibration range		Overflow ppm calibration range	
Date	Thickener	Low	High	Low	High
12- 3-76	2	3600a	15,000a	3000a	13,500a
8-31-77	2	3850b	16,900b	3200b	14,000b
11-18-77	2	3950b	17,000b	3400c	14,500c
12- 3-76	4	3900a	16,000a	3100a	13,200a
8-31-77	4	3750b	16,500b	3150b	13,500b
11-18-77	4	3600b	16,100b	3250c	14,000c

a-Prior to calibration, b-Calibration 2, c-Calibration 3

Maintenance--

A motor failure occurred on thickener no. 2 inflow analyzer on August 31, 1977, approximately nine months after installation. A new motor was received on September 26 and installed on September 27. No maintenance was required on thickener 4 inflow analyzer. Both overflow analyzers were routinely checked for overflow debris and slime accumulation during each visit. No other maintenance was conducted on the overflow analyzers.

Underflow

Calibration--

The MWCC conducted evaluations of several types of solids analyzers in 1975 and early 1976. Several instruments on loan from the manufacturers were mounted in the influent and underflow line of thickener no. 2 and calibration data were collected as in this study. The specifications for the monitoring instruments used in the subsequent evaluation of the sludge blanket control scheme were prepared, based on the results of these evaluations-see Figure 18. The technical specifications for all of the instruments used to monitor solids concentrations and control the sludge blanket level are presented in Appendix A.

After the purchased instruments were installed and initially calibrated it became apparent that the span adjustment was not sufficient to bring the meter reading into agreement with the measured total solids concentrations.

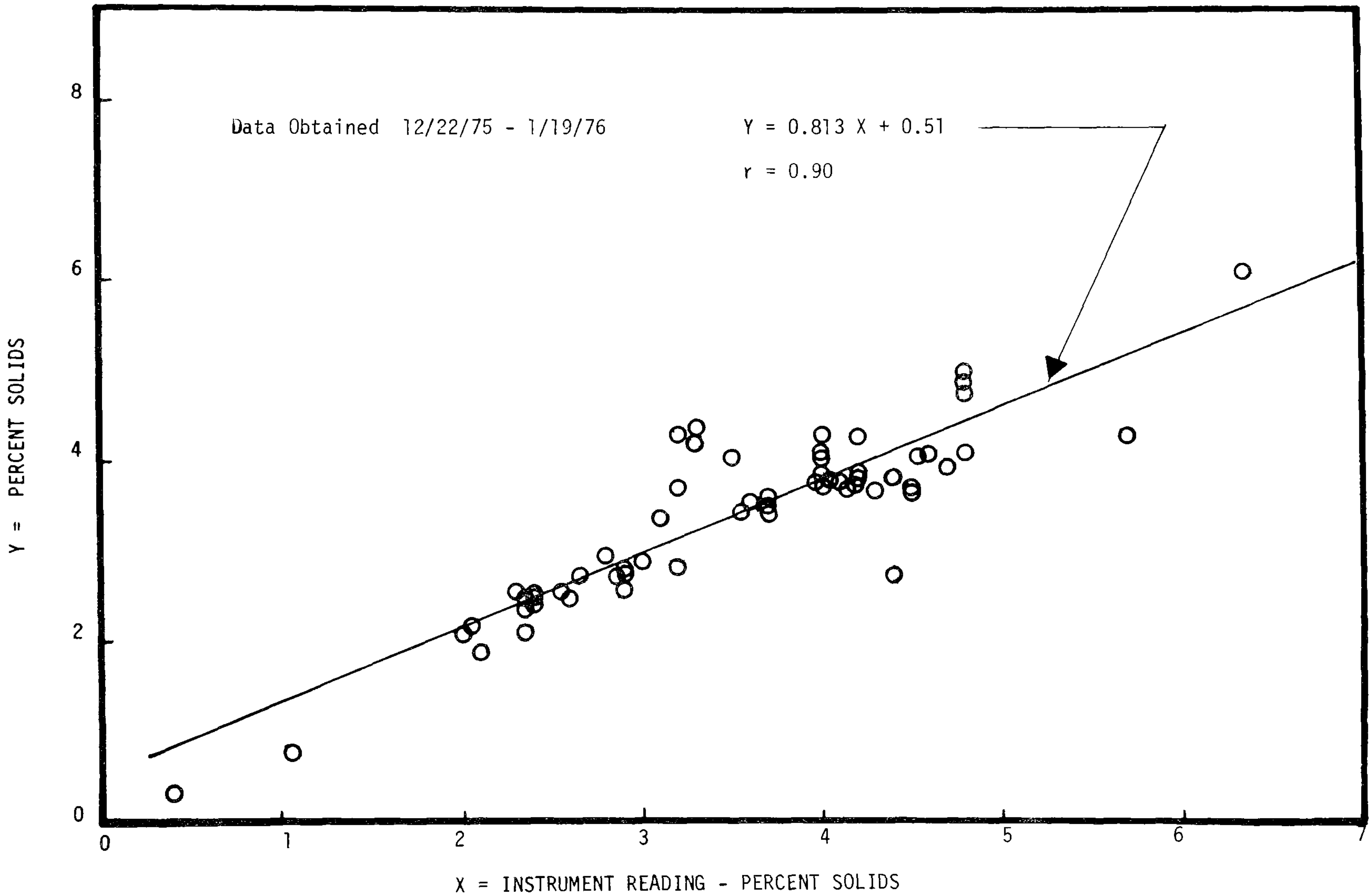

Figure 18. Calibration data for model 52H sludge density analyzer.

The two instruments were returned to the manufacturer late in January 1977. The electronic components were modified and the instruments were returned to MWCC early in March 1977.

The calibration data are summarized in Figures 19 and 20. The origin was included as a calibration point in the linear regression analyses. Because of this, the correlation coefficients are misleading. Although the calibration data are inadequate in terms of the range of solids concentrations it appears that reliable estimates of the sludge solids concentration cannot be obtained with the instruments under the test conditions.

The data presented in TABLE 4 indicate that the scatter observed in Figures 19 and 20 should not be attributed to drift in the electronics modules. The scatter was more likely due to the changing physical properties of the sludge solids and the color of the suspension. Regardless of the cause it is obvious that significant errors can be introduced if the calibration status is not identified at frequent intervals.

TABLE 4. TEST PLUG READINGS FOR SLUDGE DENSITY ANALYZERS

Date	% Solids Thickener 2	% Solids Thickener 4
December 3, 1976	3.0	3.0
August 22, 1977	2.0a	1.4a
August 31, 1977	2.2c	2.6b,c
September 22, 1977	2.3d	2.6d
October 6, 1977	2.2d	2.6d
November 8, 1977	2.3d	e
November 18, 1977	2.2d	e

a - Range adjusted by the manufacturer during February, 1977.

b - Thickener no. 4 underflow analyzer control unit checked by the manufacturer between August 23 and August 29, 1977.

c - Calibration 1

d - Calibration 2

e - Out of Service

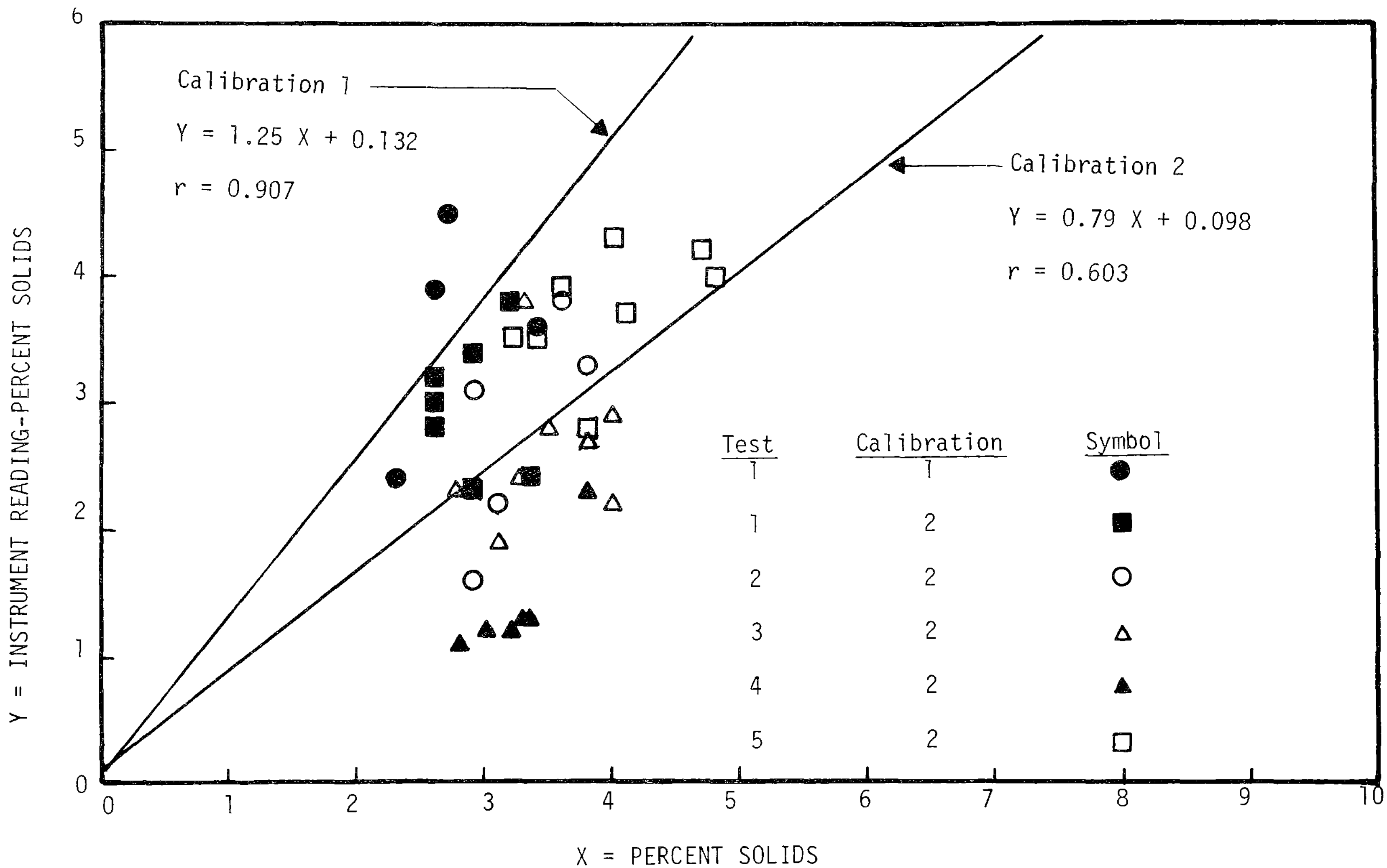

Figure 19. Calibration data for thickener no. 2 underflow solids analyzer.

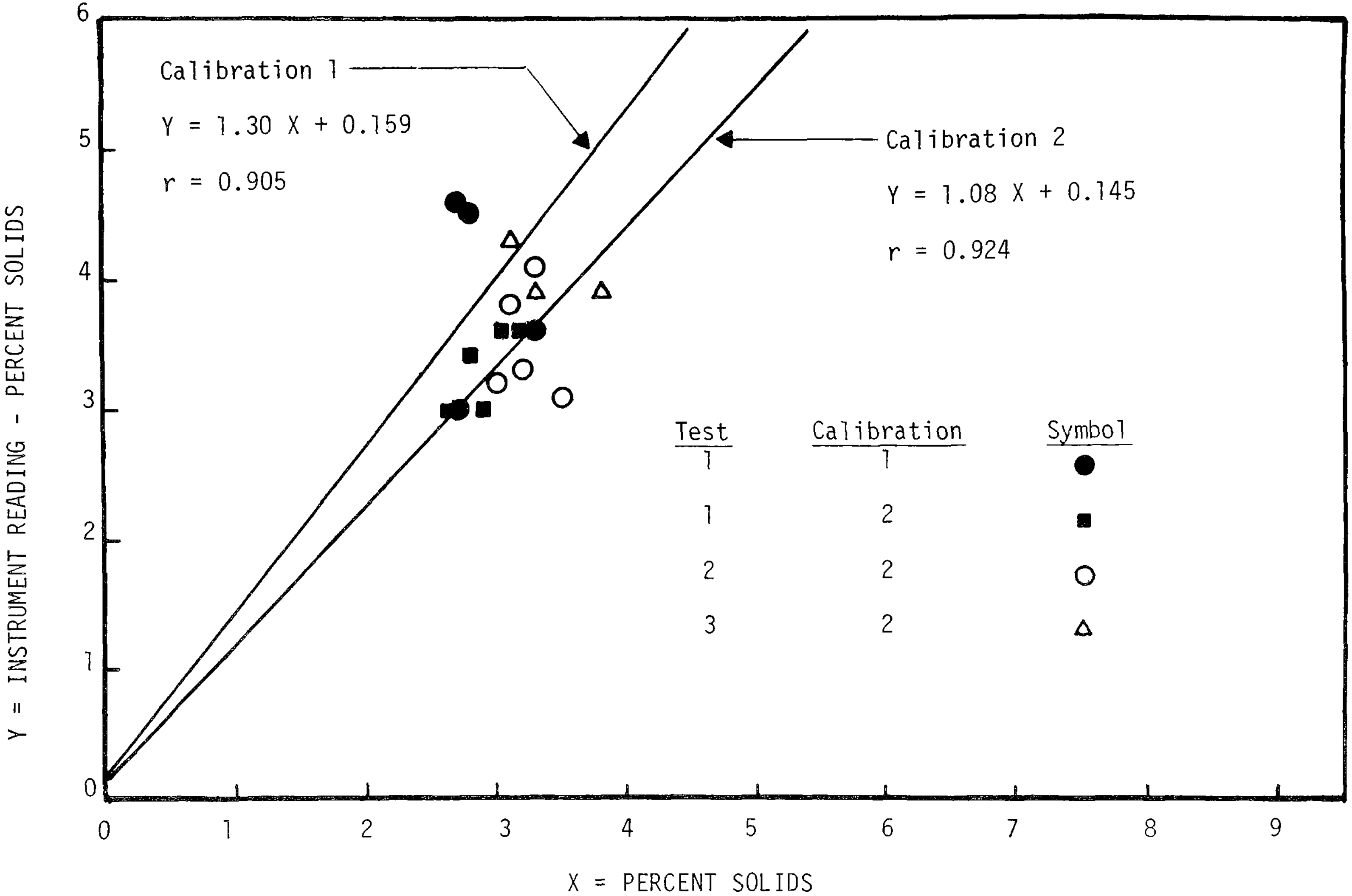

Figure 20. Calibration data for thickener no. 4 underflow solids analyzer.

The underflow solids analyzer serving thickener no. 2 was withdrawn from the sludge line and calibrated using solids suspensions covering a wide range of concentrations. The data obtained are presented in Figure 21 along with the four regression lines for the data collected in test runs 2, 3, 4 and 5 - all at the second calibration setting. These data support the conclusion that optical instruments of this type are not appropriate for all applications.

Maintenance--

Thickener no. 2 analyzer--

The analyzer was removed from its pipe mounting on November 30, 1977 for direct calibration and inspection approximately one year after installation. A thin coating of grease was removed from the analyzer extension tube but the sample port was not plugged. After calibration the analyzer was re-installed in the underflow pipe.

Thickener no. 4 analyzer--

In August 1977 it was observed that the instrument outputs, meter and recorder, were not identical. The control unit was shipped to the manufacturer for service. The unit was returned and installed within a weeks time. On September 21, 1977 the meter was found pegged offscale. The analyzer was removed from the pipe and inspected. The light source, motor and plunger were observed to operate normally; however, a thick coating of grease was removed from the end of the analyzer extension tube. The grease coating was thought to be the cause of the malfunction and the analyzer was installed on the following day. The instrument failed again on October 5, 1977. The control unit was tested and found to be functioning. The analyzer was removed from the underflow pipe on October 5, 1977 and was found to operate normally with both clear water and sludge and subsequently reinstalled. After another failure on the following day it was determined that the light source was failing intermittently - most likely caused by a poor electrical contact and vibration. A replacement light source was ordered but was not delivered until well after test run no. 5 was completed.

FLOW METERS

Overflow

The results of the overflow indicator-totalizer comparisons are presented in TABLE 5. The average difference between the indicator and totalizer values was used to adjust the observed flow indicator readings and, in turn, correct the observed totalized flows as illustrated in TABLE 6. The head on the Parshall flume and the corresponding calculated flow rates are presented in columns 1 and 2 respectively. The flow rates observed at the local indicator are listed in column 3. The values presented in column 4 were obtained by adding the appropriate correction factor (TABLE 5) to the values of column 3. The corrections presented in column 5 were obtained by subtracting the values of column 4 from those of column 2. The calibration data are summarized graphically in Figure 22. In subsequent paragraphs the observed daily overflow volumes for thickners no. 2 and no. 4 were adjusted by +0.48

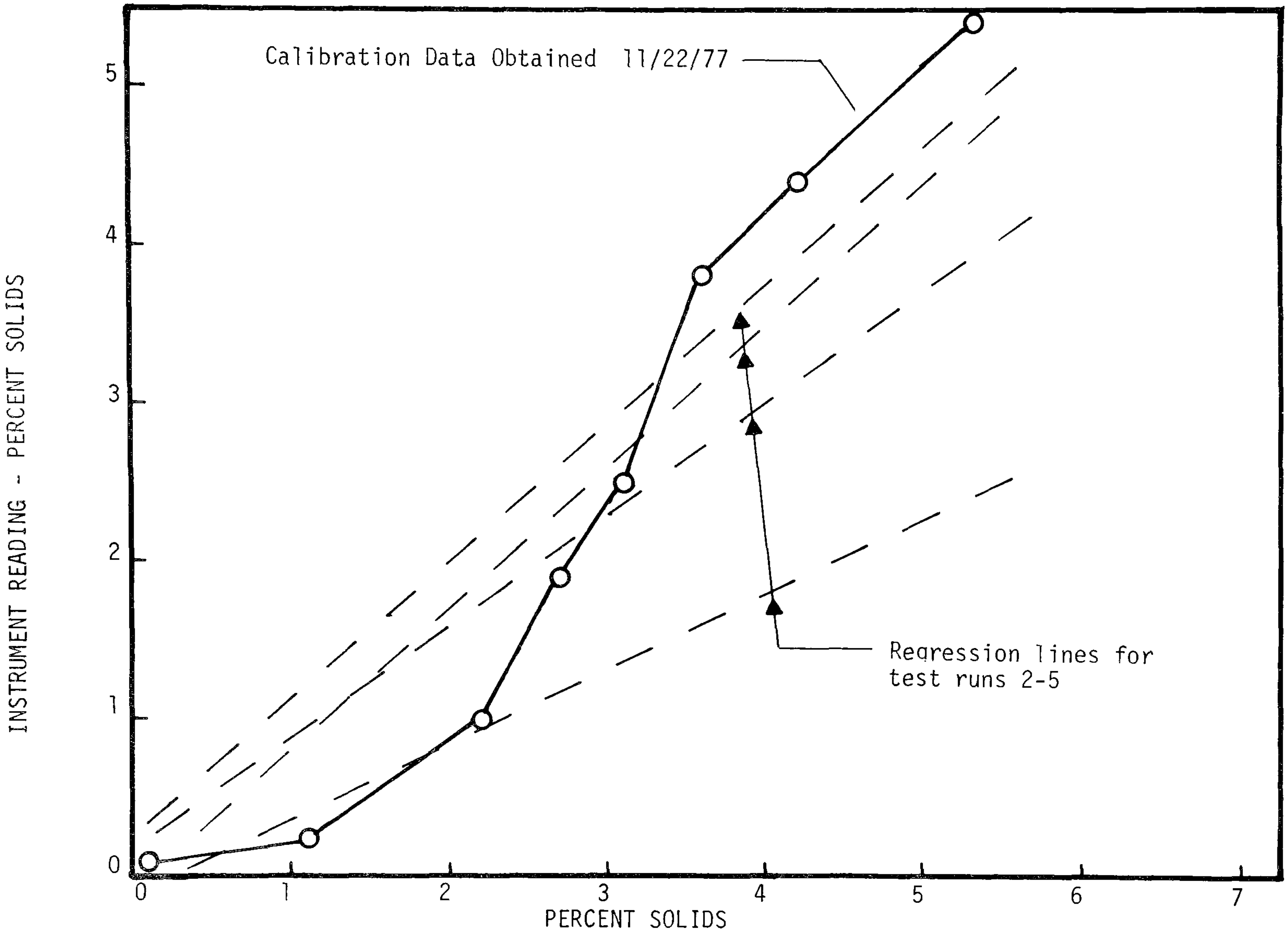

Figure 21. Calibration data for thickener no. 2 underflow solids analyzer.

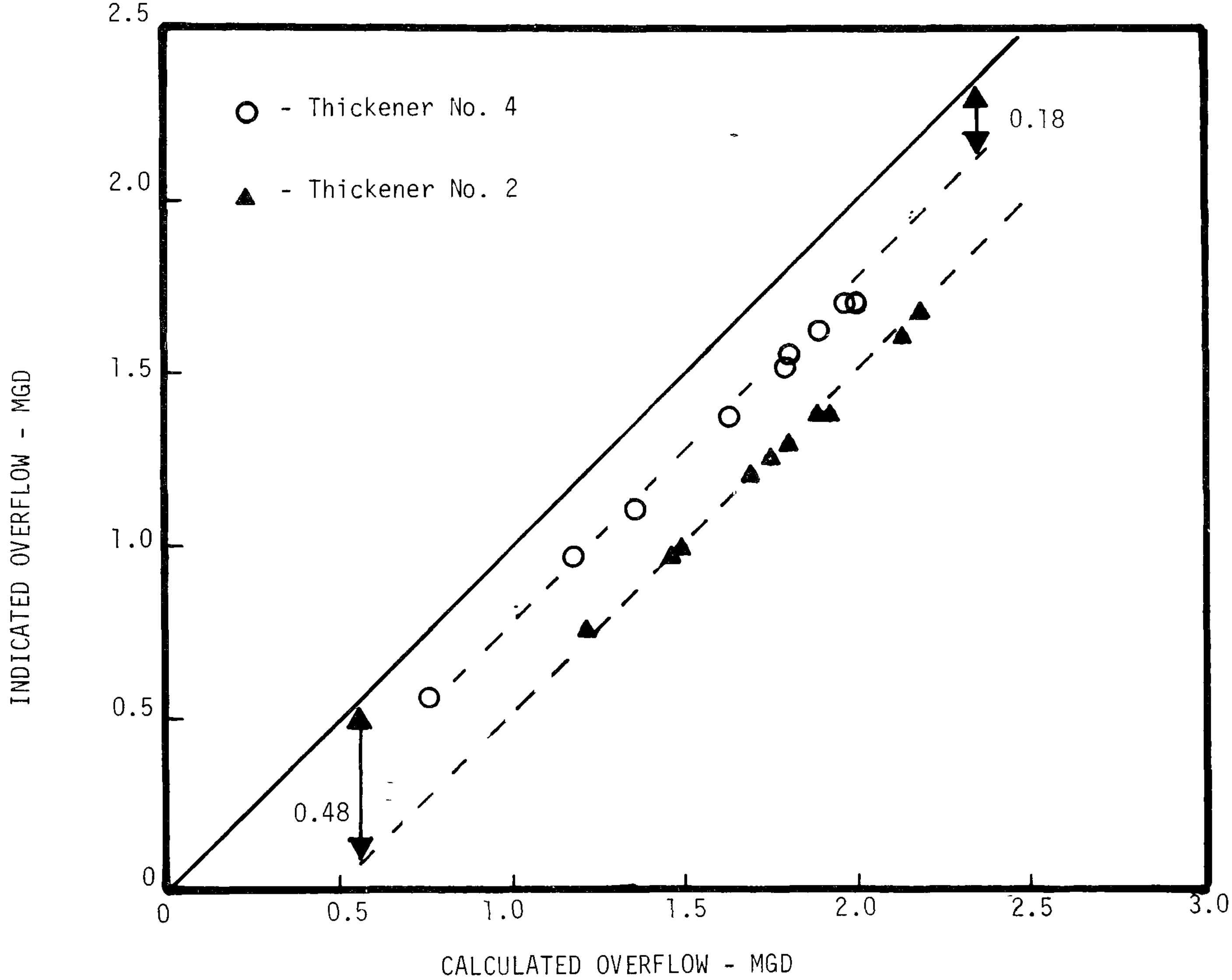

Figure 22. Calibration data for thickener overflow measurement systems.

mil gal and +0.18 mil gal respectively as per TABLE 6 and Figure 22.

TABLE 5. OVERFLOW INDICATOR-TOTALIZER COMPARISON

Date	Time increment (minutes)	Difference in totalizer readings	Flow mgd totalizer	Flow mgd indicator
		Thickener no. 2 overflow		
9-13-77	11.0	1342	1.76	1.72
9-13	11.0	1346	1.76	1.72
9-14	9.75	1436	2.12	2.10
9-14	14.75	2180	2.13	2.10
10-12	6.75	545	1.16	1.15
Correction factor = averaged difference = 0.03				
		Thickener 4 overflow		
9-13-77	11.33	1325	1.68	1.60
9-13	10.67	1258	1.70	1.60
9-14	10.0	1547	2.23	2.15
9-14	14.75	2282	2.23	2.15
10-12	13.0	1870	2.07	1.98
10-13	12.0	1519	1.82	1.73
Correction factor = average difference = 0.09				

TABLE 6. OVERFLOW CALCULATIONS

Date	1 Flume head (feet)	2 Calculated flow(a) (mgd)	3 Indicated flow (mgd)	4 Calculated totalizer (mgd)	5 Correction applied to totalizer (mgd)
Thickener no. 2					
9- 7-77	0.938	1.80	1.29	1.32	+0.48
9- 7	1.068	2.19	1.69	1.72	+0.47
9- 7	0.729	1.22	0.75	0.78	+0.44
9- 8	1.050	2.14	1.61	1.64	+0.50
9- 8	0.921	1.75	1.25	1.28	+0.47
9- 8	0.828	1.49	0.99	1.02	+0.47
9-26	0.978	1.92	1.38	1.41	+0.51
9-28	0.969	1.89	1.37	1.40	+0.49
10-12	0.901	1.69	1.20	1.23	+0.46
10-14	0.819	1.46	0.97	1.00	+0.46
				Average	+0.48
Thickener no. 4					
9- 7-77	0.935	1.79	1.51	1.60	+0.19
9- 7	0.708	1.17(b)	0.96	1.05	+0.12(b)
9- 7	0.528	0.75(b)	0.55	0.64	+0.11(b)
9- 8	0.969	1.89	1.62	1.71	+0.18
9- 8	0.776	1.35	1.10	1.19	+0.16
9- 8	0.529	0.75(b)	0.54	0.63	+0.12(b)
9-26	0.998	1.98	1.70	1.79	+0.19
9-28	0.945	1.82	1.55	1.64	+0.18
10-12	1.001	1.99	1.70	1.79	+0.20
10-14	0.875	1.62	1.37	1.46	+0.16
				Average	+0.18

a $Q = 3.07\ H^{1.53}$ with Q in cfs and H in feet (5)

b Low flows were not used in calculating the average correction because they were not encountered during normal thickener operation.

Underflow

The results of the underflow totalizer calibration are presented in TABLE 7. The correction factors in the last column were used to adjust the observed daily thickened sludge flows.

TABLE 7. UNDERFLOW TOTALIZER CALIBRATION

Date	Thickener No.	Drawdown (feet)	Time increment (minutes)	Totalizer Volume (gal)	Measured Volume (gal)	Volume Ratio Measured/Totalizer
9-15-77	2	0.248	40	6390	6155	0.96 (Avg.)
9-21	2	0.445	106	11590	11044	
9-15	4	0.411	73	9070	10200	1.12

THICKENERS

Underflow

Solids Content--

The solids content of the underflow samples collected during test runs 1 through 5 are summarized in Figure 23. The concentration increased slightly during the 4 month period for both basins; however, the concentrations for the two basins did not appear to be significantly different. The student's t test (6) was used to compare the means of the two sample populations. The hypothesis $u_2 = u_4$ was tested against the alternative $u_2 \neq u_4$. The hypothesis was accepted when the type one error (the probability that $u_2 = u_4$ but rejected) was fixed at 5%.

The temperatures observed during the 5 test runs are presented in Figure 24. The temperature drop was significant as expected for this time of the year. It is possible that the observed increase in underflow solids concentration was related to the decrease in temperature. At lower temperatures the biological activity in the thickened sludge is decreased and the likelihood of gas formation and subsequent expansion of the sludge blanket is also decreased.

Dewatering Characteristics--

General--

The dewatering properties of thickened sludge determine the ease in which

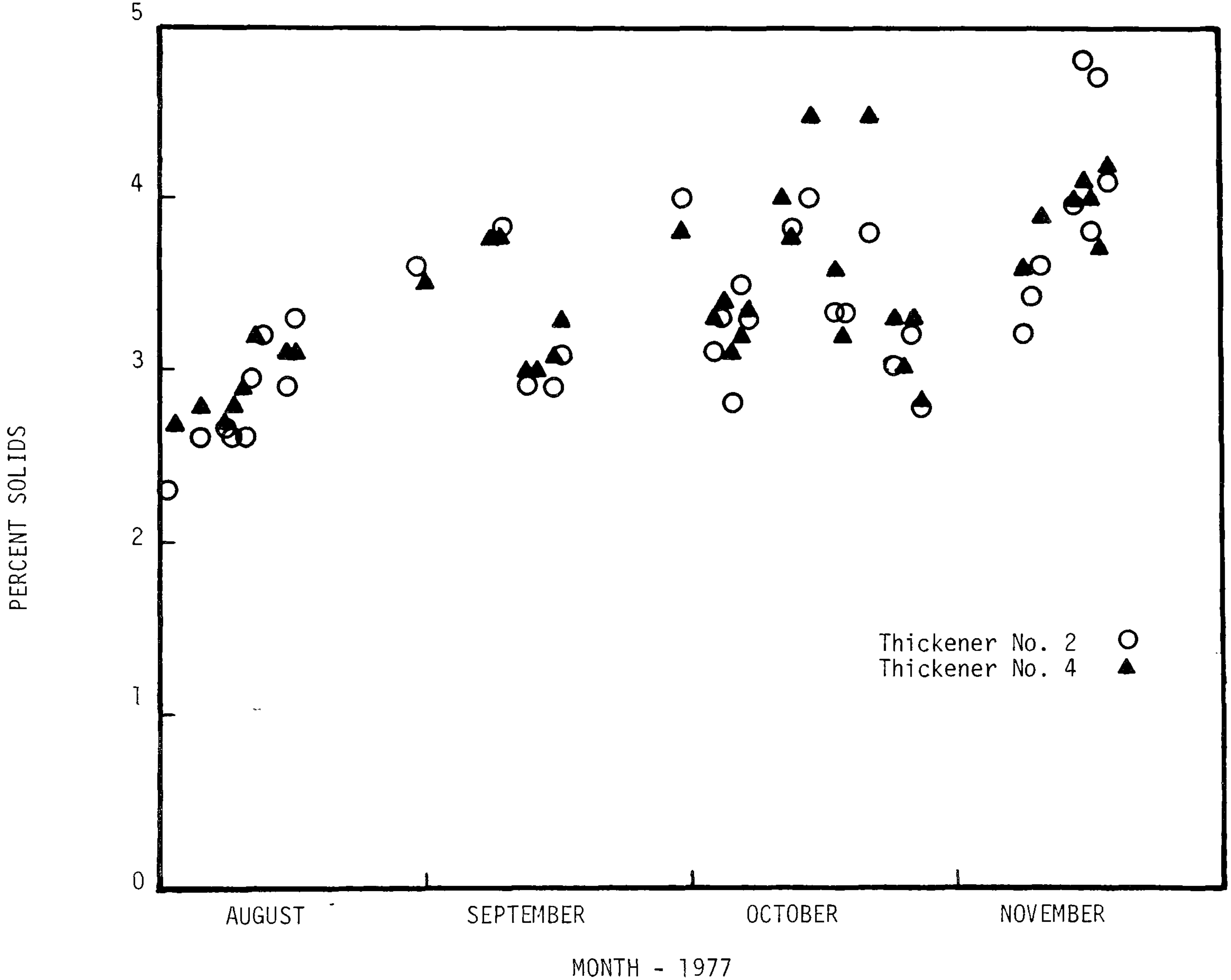

Figure 23. Observed total solids concentration of underflow samples during test runs 1-5.

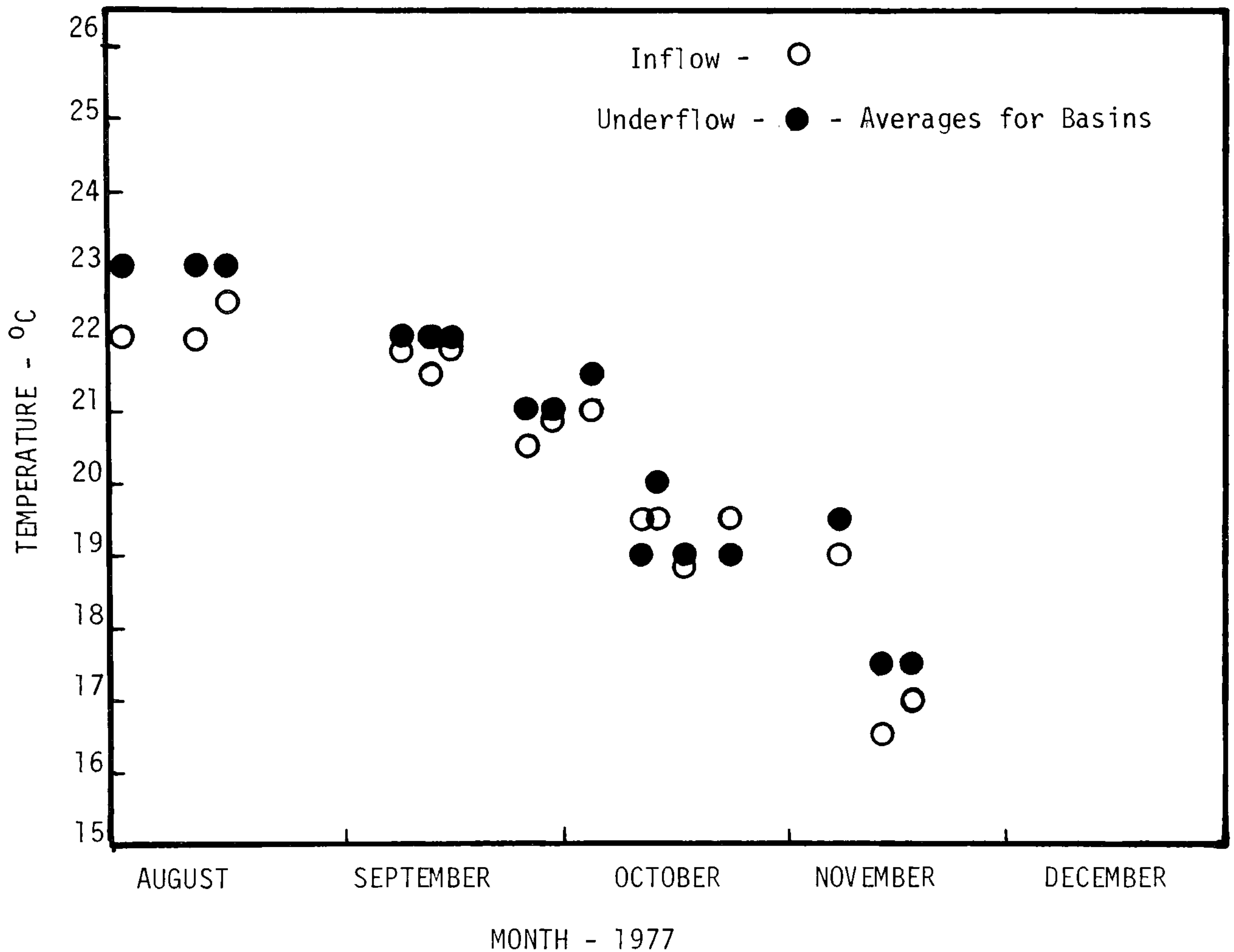

Figure 24. Temperature observations for thickeners no. 2 and 4 during test runs 1-5.

water can be withdrawn by subsequent processes such as vacuum filtration or centrifugation. The dewatering properties have a significant effect on both the size of the dewatering equipment and the quantities of conditioning chemicals required. The dewatering properties also affect the economics of subsequent disposal methods such as incineration or landfilling. CST and filter leaf analyses were employed to characterize the dewaterability of the thickened sludge from basins no. 2 and 4.

Capillary suction time--

Baskerville and Gale (3) have shown that CST can be correlated to the specific resistance for filtration of raw sewage sludges. The CST method is easy to perform and can be conducted in the field at the time of sample collection. CST determinations, however, have been shown to be a function of the absorbent paper used, temperature, the surface tension of the liquid being absorbed, and the suspended solids content of the sample being tested. Differences in surface tension were not considered because of the similarity of the inflow characteristics between thickeners no. 2 and 4. The difference in underflow temperature between thickeners did generally not exceed 0.5 degrees Centigrade and any effects due to differences in temperature were not considered significant in the CST testing procedure. The same batch of absorbent paper was used throughout the testing period, which minimized any effects produced by irregularities in the paper.

The results of the CST determinations conducted during test runs 1 through 5 are summarized in TABLE 8. The CST exhibited a variable correlation with solids concentration; however, in each run the highest CST value was associated with the highest solids concentration. Because of the relatively small differences in solids concentration between thickeners no. 2 and 4, and the lack of a well defined CST-solids relationship, the CST determinations were treated as distinct analytical measurements regardless of the solids content of the underflow samples used for CST determinations.

The student's t test (6) was again used to test the hypothesis, $u_2 = u_4$, where u_2 and u_4 are the average CST values for basins no. 2 and 4 respectively for a single test run. The hypothesis was accepted for test runs 1, 2, 4, and 5 when the type one error was fixed at 5%. The hypothesis was rejected for test run no. 3.

Filter leaf tests--

Filter leaf tests were conducted on underflow samples to obtain a more direct indication of the underflow dewatering characteristics. Filter yields were determined using underflow samples from both thickeners during each test run to demonstrate any significant difference in dewaterability. The results of the filter leaf tests are summarized in TABLE 9.

Differences in yield between thickeners were observed during test runs 1, 4 and 5. In each case individual yields were a function of sludge solids content with the larger filter yield obtained from the underflow sample with the higher solids content. The average solids content for all of the underflow samples taken for filter leaf analysis during the runs was 3.5% for

TABLE 8. CST OF THICKENER UNDERFLOW-SUMMARY

Thickener 2 underflow					
Test run	Average percent solids	CST runs	Average CST	CST standard deviation	CST/solids Correlation coef.
1	2.8	25	320.0	68.4	0.40
2	3.2	15	343.5	61.6	-0.50
3	3.5	22	175.1	37.9	-0.72
4	3.2	17	381.9	141.5	0.27
5	4.1	18	666.4	296.7	0.58
			for all test runs		0.41

Thickener 4 underflow					
Test run	Average percent solids	CST runs	Average CST	CST standard deviation	CST/solids Correlation coef.
1	2.8	28	340.5	84.9	0.70
2	3.3	17	347.7	35.1	0.03
3	3.6	24	210.2	44.3	-0.15
4	3.4	22	396.0	140.6	0.34
5	3.9	16	614.0	178.2	-0.63
			for all test runs		0.25

both thickeners. The corresponding average filter yield for all the test runs was 3.2 psf/hr for both thickeners.

Based on the results of both the CST and filter leaf tests it is concluded that there was no significant difference in the dewatering characteristics of the underflow samples collected from thickeners no. 2 and 4.

Overflow

TABLE 9. FILTER LEAF ANALYSES OF THICKENER UNDERFLOW

Date	Test run	Thickener underflow % Solids Thickener 2	Thickener underflow % Solids Thickener 4	Thickener underflow pH Thickener 2	Thickener underflow pH Thickener 4	Chemical dosage % $FeCl_3$	Chemical dosage % CaO	Filter yield psf/hr Thickener 2 Trial 1	Filter yield psf/hr Thickener 2 Trial 2	Filter yield psf/hr Thickener 4 Trial 1	Filter yield psf/hr Thickener 4 Trial 2
8- 1-77	1	1.8	1.8	6.4	6.6	10	30	2.0	1.7	1.6	1.5
8-16	1	3.3	3.2	6.2	6.0	9	27	4.3	4.1	3.7	3.5
9- 9	2	3.8	3.8	5.9	5.9	10	27	3.6	4.4	4.3	4.1
9-16	2	3.1	3.3	5.7	5.8	12	40	3.2	2.4	2.8	3.0
9-30	3	4.0	3.8	6.0	5.8	8	20	2.7	2.0	2.6	2.5
10-14	3	4.2	4.7	5.9	5.8	7.5	23	4.2	3.9	4.8	3.7
10-18	4	3.5	3.3	6.0	5.7	8	24	4.3	3.2	3.2	3.2
10-21	4	3.6	4.5	6.1	5.9	8	24	2.7	3.0	3.8	4.6
10-27	4	2.7	2.8	6.2	6.2	10	30	2.8	2.3	2.5	2.5
11- 8	5	3.3	3.6	6.1	6.1	8	24	2.8	2.7	2.8	2.8
11-18	5	4.9	4.2	6.1	5.8	6	18	4.1	4.4	3.0	3.4
Average		3.5	3.5	-	-	-	-	3.3	3.1	3.2	3.2

Solids Content--

The overflow suspended solids concentration was highly variable for both thickeners. The values ranged from 100 mg/l to over 3000 mg/l and, during the tests, appeared to be related to the solids loading rates for the basins. Multiple linear regression analyses were conducted to define the overflow suspended solids concentration as a function of: blanket level, hydraulic loading rate, inflow suspended solids concentration and temperature. The least squares procedure yielded the following.

[1] $Y_2 = -1709 - 154\ L + 422\ Q + 0.784\ S + 8.96\ T$

and

[2] $Y_4 = -930 - 186\ L + 479\ Q + 0.432\ S + 14.0\ T$

where: Y_n = average daily overflow suspended solids concentration for basin no. n, mg/l
L = average blanket level for day, ft below surface
Q = basin inflow rate, mgd
S = average daily inflow suspended solids concentration, mg/l
T = temperature of basin inflow, ^{o}C

The standard error of the estimate for equation [1] is 540 mg/l and the multiple correlation coefficient, R, is 0.865. The values of the standard error and R for equation [2] are 466 and 0.758 respectively.

The value R^2, sometime termed the coefficient of multiple determination, is in fact the ratio of the variation in Y explained by the combined influence of the independent variables to the total variation in Y. (7) Thus for equation [1], basin no. 2, 75% of the variability of Y is explained and for equation [2], basin no. 4, 57% is explained.

The significance of each of the four variables, L, Q, S and T, was examined by conducting the regression analysis with one, two, three and all four variables. Based on the results obtained the blanket level, L, and the inflow solids, S, are by far the more significant variables. The regression equations using only L and S are as follows.

[3] $Y_2 = -508 - 159\ L + 0.761\ S$, $R^2 = 0.72$
standard error = 535

[4] $Y_4 = 302 - 200\ L + 0.453\ S$, $R^2 = 0.50$
standard error = 479

The variability not explained by the regression analysis is most likely related to the demonstrated lack of precision in the blanket level determination. In addition, the settling characteristics of the solids, which were not documented, no doubt also affected the quality of the overflow stream.

The regression equations, [3] and [4], are represented by two families of curves in Figure 25. For identical blanket levels the curves indicate that basin no. 4 performed better than basin no. 2 when the inflow solids concentration exceeded approximately 2000 mg/l.

The average hourly inflow and overflow suspended solids concentrations were estimated using the recorded output of the solids analyzers along with

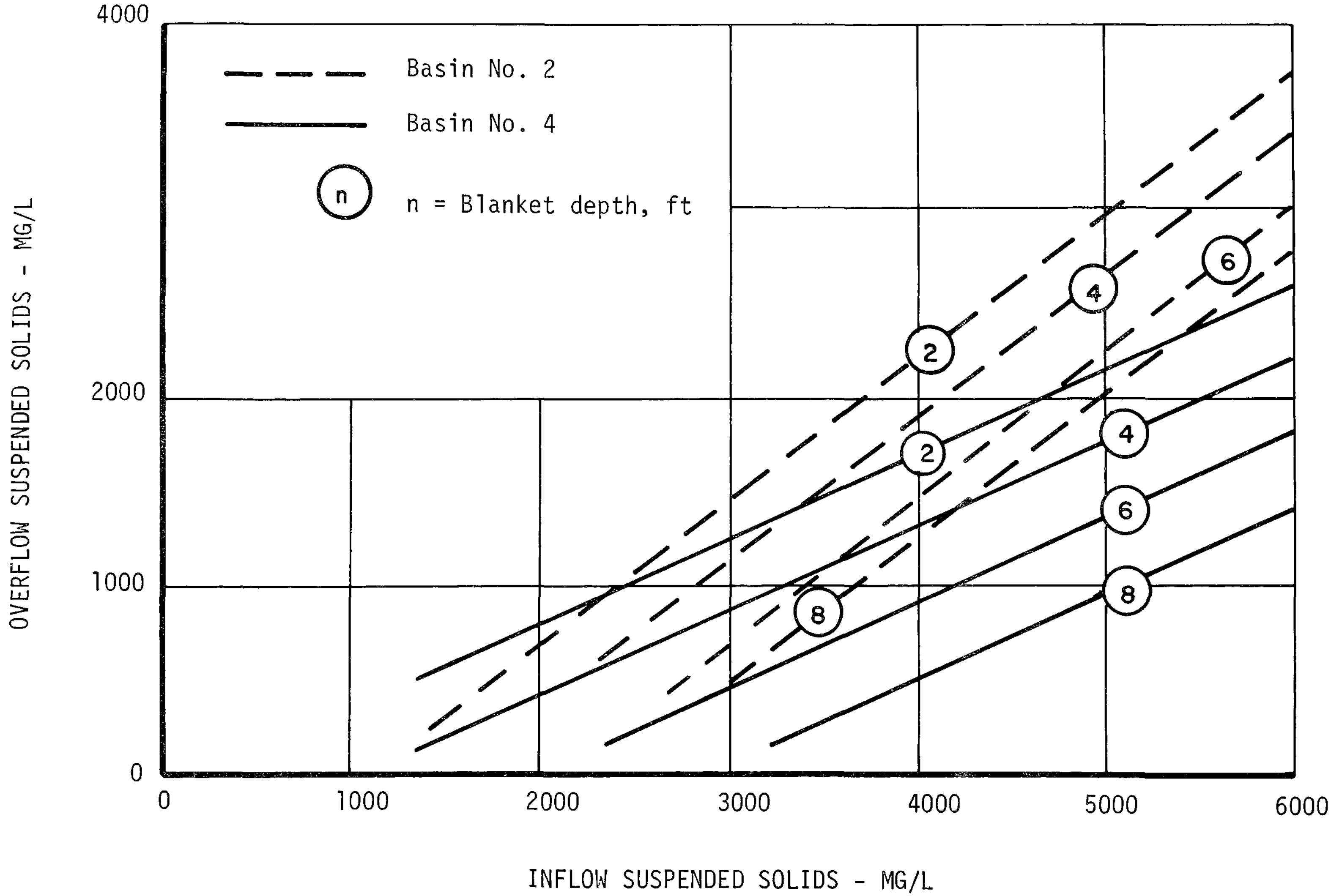

Figure 25. Overflow solids concentration for basins 2 and 4 based on multiple linear regression analyses.

the calibration data (Figures 14, 15, 16, 17). The recorded values for inflow suspended solids were off scale, >10,000 mg/l, on five occasions totaling 13 hrs. A value of 10,000 mg/l was used in subsequent calculations. Likewise, the recorded overflow values were off scale, >3,000 mg/l, on five occasions for basin no. 2, totaling 12 hrs, and on six occasions for basin no. 4, totaling 28 hrs. In these instances a value of 3,000 mg/l was used. The hourly averages were used to construct average daily concentrations.

The daily average suspended solids concentrations for basins no. 2 and 4 are presented in Figure 26 for four ranges of inflow solids concentration. In addition, the average concentrations are plotted for each range of inflow solids concentration. Although the variation of blanket level is not addressed in this plot, the data indicate that basin no. 4 performed significantly better than basin no. 2 when the average daily inflow suspended solids concentration remained over 4000 mg/l.

Organic Content--

The total organic carbon (TOC) concentrations observed in the filtered and unfiltered overflow samples are presented in Figure 27. These data demonstrate that the total TOC of the overflow is directly related to the suspended solids concentration; however, the soluble TOC concentration appears to be independent of the solids concentration. It thus appears that although the quality of the overflow may affect the organic loading of the primary sedimentation basins, the organic loading at the secondary facilities should not vary substantially.

Solids Capture

The solids capture efficiency was determined for each thickener during each of the test runs to establish the significance of blanket level control on overall basin performance. The calculations are described in the following paragraphs.

For the period of time during which the inflow solids analyzer for thickener no. 2 was out of service the average inflow solids concentrations were based on the data collected for thickener no. 4. This substitution was justified because both basins are fed from the same inflow header. The calculated suspended solids content of the underflow was based on the analysis of the underflow samples used to establish the instrument calibration characteristics.

The observed values for basin discharge, overflow and underflow, were adjusted as described in a previous section. The thickener influent flow was assumed to be equal to the sum of the overflow and underflow.

The solids capture calculations are summarized in TABLE 10. During four of the five tests the average solids capture was greater for thickener no. 4 which utilized the sludge blanket control system. Although the differences for the individual tests may not be significant the conclusion that the overall performance of thickener no. 4 was better is substantiated by the data presented in Figure 25.

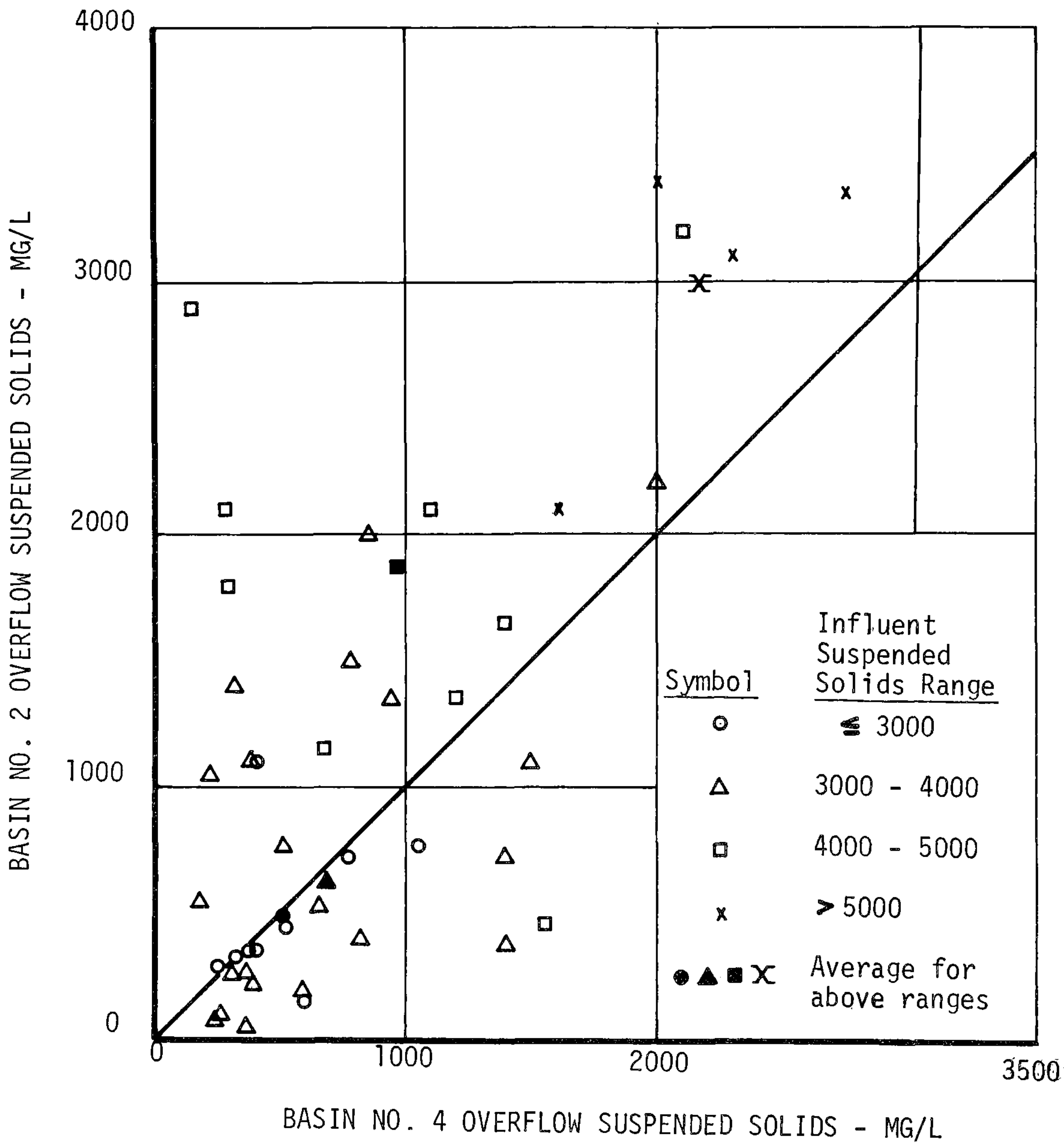

Figure 26. Daily average overflow suspended solids concentration for basins 2 and 4.

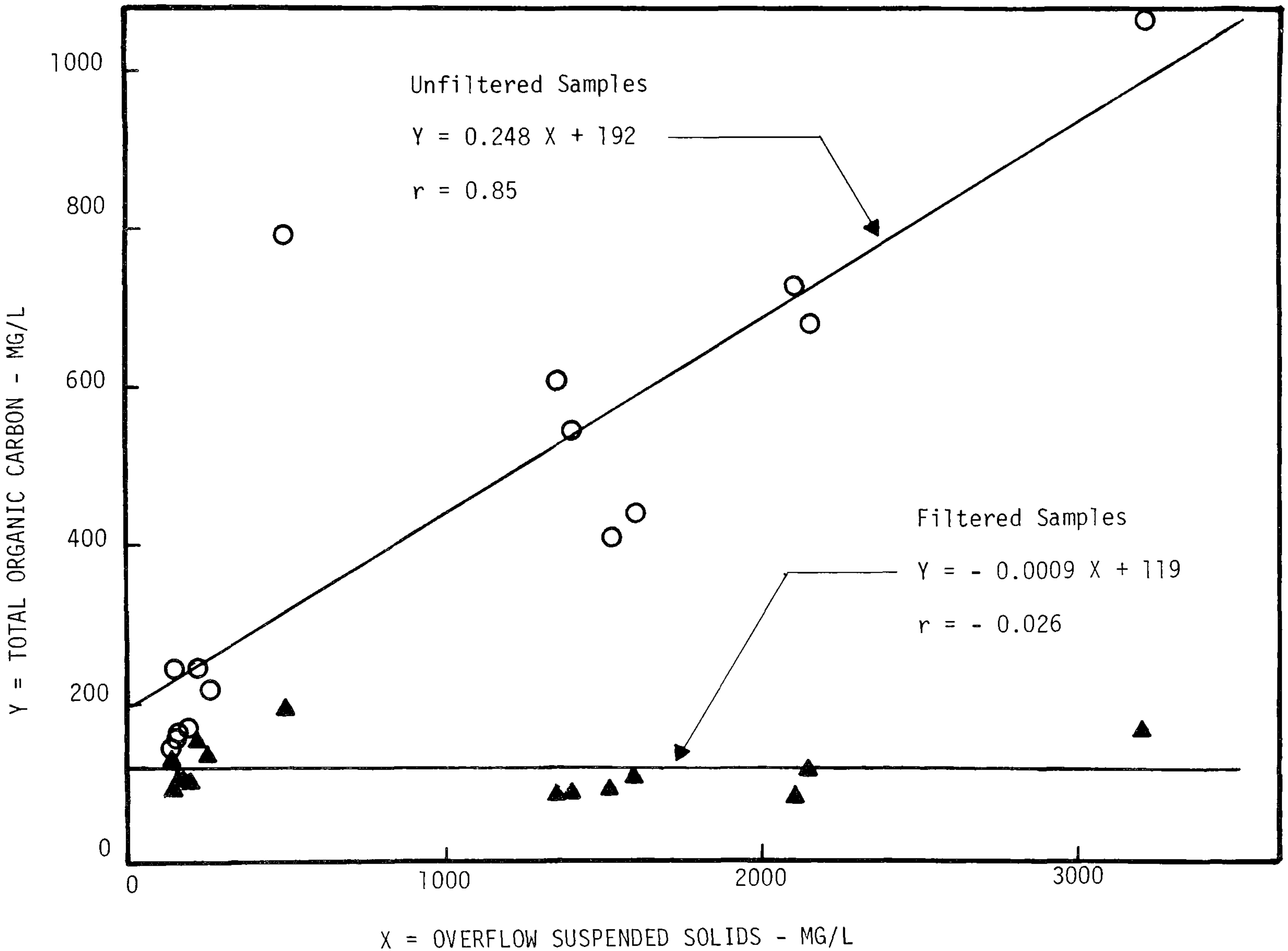

Figure 27. TOC concentration of overflow for thickeners no. 2 and 4.

TABLE 10. SOLIDS CAPTURE-SUMMARY

Test run	Basin no.	Total lbs suspended solids Inflow	Overflow	Underflow	% solids capture (inflow-overflow) (100) / (inflow)
1	2	915,000	311,000	560,000	66
	4	827,000	229,000	578,000	72
2	2	978,000	422,000	532,000	57
	4	998,000	192,000	753,000	81
3	2	852,000	133,000	711,000	84
	4	1,000,000	122,000	746,000	88
4	2	552,000	101,000	395,000	82
	4	706,000	163,000	519,000	77
5	2	570,000	106,000	480,000	81
	4	503,000	58,000	517,000	88

SECTION 9

COST

GENERAL

The decision to utilize a sludge blanket control system on one or more thickeners should be based on estimates of the costs and benefits associated with the control system. The data and discussion presented in the following sections indicate that it would be cost effective to use such a system with one or more thickeners. For any such system, however, it would be advisable to include a high level alarm on the thickened sludge holding tanks as minimum protection against overflows. In the case of the Metro WWTP, however, the use of such a system is presently precluded by the physical constraint of inadequate solids processing capacity downstream of the thickeners.

OPERATING

Based on three separate observations, the thickener operators spent approximately 30 minutes during each eight hour shift monitoring the location of the sludge blanket. The annual labor requirement for this task per basin is approximately 90 hours. The maintenance requirement for the operator's blanket detector averages approximately 10 hours per year according to plant maintenance personnel. Based on these two labor requirements the annual monitoring cost per basin averages approximately $900 per year using current salary and benefit rates.

The data obtained during this study indicate that the two probes of the sludge blanket control system should be inspected and wiped clean once per week. It is estimated that this task would require approximately 20 minutes for the six basins or 3 hours per basin per year. An additional 10 hours per basin per year would be required to determine the location of the blanket level on a daily basis to verify that the control system is functioning. In addition, it is assumed that probe repair and replacement and maintenance of the control modules would require no more than 10 hours per year and no more than $100 for parts and supplies. The total annual cost for operating and maintaining each blanket control system is estimated to be approximately $360 based on current salary scales.

The total installed cost for the sludge blanket control system used on thickener no. 4 was approximately $2000. Based on the above actual and estimated costs approximately four years would be required to recover the cost of the control system. Based on the assumption that the useful life of the entire control system is approximately 10 years its installation is economically justified even though the annual operating cost savings would not be substantial.

TREATMENT

For the entire study period the solids capture efficiencies averaged 74% and 81% for thickeners no. 2 and no. 4 respectively - TABLE 10. The solids loading averaged approximately 61,000 lbs per basin per day. Thus thickener no. 2 returned approximately 4,000 lbs/day more suspended solids to the primary treatment facilities than thickener no. 4. The annual cost of treating these additional solids is substantial.

In June of 1976, the MWCC officially adopted a strength charge system as per a consultant's recommendation. (8) This system is used to calculate strength charges for industrial dischargers containing above average concentrations of COD and suspended solids. Although the system was based on data from all MWCC treatment facilities (22 at the time of analysis) it is believed to accurately describe costs at the Metro plant because approximately 84% of the system flow was treated and 66% of the system O & M budget was expended there.

If the thickener overflows are treated as industrial discharges and current unit costs are employed, the annual strength charges which would be assessed against basins no. 2 and 4 are approximately $96,000 and $58,000 respectively. These values were based on suspended solids concentrations only; because, the soluble organic content of the overflows was essentially constant (Figure 27). It is conservatively estimated that 10% of these strength charges can be directly allocated to the retreatment of these return solids during their passage through the treatment plant.

An annual saving of $3,800 per basin can thus be attributed to improved blanket level control. This value is indeed conservative because the average solids capture efficiencies obtained during this study were used. A review of Figures 9-13 illustrates that the performance of the automated blanket level control system was better than the average obtained here once equipment maintenance was standardized.

Based on the above conservative assumption, the payback period for the blanket level control system as described is approximately six months. Additional costs, however, would be incurred to construct an integrated control system for six basins and two holding tanks.

Based on experience at Metro, the performance of the entire treatment plant can be affected by the thickener overflow characteristics. The overflow is discharged to one of the six primary settling basins. The overflow suspended solids are not effectively removed by sedimentation and discharge to the aeration tanks thus increasing the quantity of waste activated sludge. When the overflow suspended solids concentration remains over 1000 mg/l for several days solids cycling within the plant increases and eventually these solids appear in the final effluent. It has also been observed that the dewatering characteristics of the primary sludge processes in F & I No. 1 are adversely affected by the overflow suspended solids. Although no attempt was made to identify the direct costs associated with those operating problems, they are assumed to be significant because the ability of the facility to meet its' discharge permit is affected.

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APPENDIX A

TECHNICAL PROVISIONS OF SPECIFICATIONS FOR HARDWARE ITEMS

BID ITEM A SLUDGE DENSITY ANALYZER

The sludge density analyzer shall consist of a photoelectric sensor and a remotely located control unit.

The sensor shall be of the self cleaning type. The sensing head shall contain a pyrex glass sampling chamber with a piston, a light source and photocells. The sensing head shall be mounted at the wet end of a one foot long tube which connects it with the drive mechanism located at the dry end of the tube. The drive mechanism operating the piston shall periodically draw the sample slurry into the sampling chamber and wipe its optical surfaces at the same time. The sensor shall be supplied with a pipe insertion adapter for attachment through a 2 inch NPT threaded hole to the process pipe. The pipe insertion adapter shall be constructed so as to allow removal of the sensor from the process pipe without dewatering the process pipe. A 100 foot long multiconductor cable shall be attached to the sensor for connection to the control unit.

The control unit shall have a meter graduated from 0 to 10 percent suspended solids, a power switch, and a calibration control. The photo cell output shall be conditioned and/or converted through internal circuitry to yield a 4-20 ma DC output. The output shall be directly proportional to the suspended solids content of the sample over the specified concentration range. The control unit shall be designed for both bench and panel mounting and all necessary hardware shall be provided. A terminal block shall be provided for connection to 120V AC power and for connection of an output recorder. The sludge density analyzer shall be designed to operate in an ambient temperature range of $5^{o}C$ to $50^{o}C$.

BID ITEM B SUSPENDED SOLIDS ANALYZER - PIPE MOUNT

The suspended solids analyzer shall consist of a photoelectric sensor and a remotely located control unit.

The photoelectric sensor shall be designed such that the optical surfaces are continually cleaned by the process flow stream or by a mechanical wiper. The sensor shall be supplied with a pipe insertion adapter for attachment through a 2 inch NPT threaded hole to the process pipe. The pipe insertion adapter shall be constructed so as to allow removal of the sensor from the process pipe without dewatering the process pipe. A 100 foot long multiconductor cable shall be attached to the sensor for connection to the control unit.

The control unit shall have a meter scale graduated in ppm suspended solids, a power switch, and a calibration control. The instrument shall have a full scale range of 0 to 20,000 ppm. The photocell output shall be conditioned and/or converted through internal circuitry to yield a 4-20 ma DC output. The output shall be directly proportional to the suspended solids content of the sample over the specified concentration range. A terminal block shall be provided for connection to 120V AC power and for connection of an output recorder. The control unit shall be designed for both bench and panel mounting and all necessary hardware shall be supplied. The suspended solids analyzer shall be designed to operate in an ambient temperature range of 5°C to 50°C.

BID ITEM C SUSPENDED SOLIDS ANALYZER - CLAMP MOUNT

The suspended solids analyzer shall consist of a photoelectric sensor and a remotely located control unit.

The photoelectric sensor shall be designed such that the optical surfaces are continually cleaned by the sample flow stream or by a mechanical wiper. The sensor shall be designed to operate in the vertical position. The sensor shall be supplied with a clamp for attachment to a one inch pipe. The clamp shall be located approximately 24 inches above the sensor face to allow for positioning in a sample sink. A 100 foot long multiconductor cable shall be attached to the sensor for connection to the control unit.

The control unit shall have a meter scale graduated in ppm suspended solids, a power switch, and a calibration control. The instrument shall have a full scale range of 0 to 2500 ppm. The photocell output shall be conditioned and/or converted through internal circuitry to yield a 4-20 ma DC output. The output shall be directly proportional to the suspended solids content of the sample over the specified concentration ranges. A terminal block shall be provided for connection to 120V AC power and for connection of an output recorder. The control unit shall be designed for both bench and panel mounting and all necessary hardware shall be supplied. The suspended solids analyzer shall be designed to operate in an ambient temperature range of 5°C to 50°C.

BID ITEM D SLUDGE BLANKET CONTROLLER

The sludge blanket detector shall consist of two submersible probes suspended, by individual waterproof cables, from a control box.

The probes shall be constructed of non-corrosive materials. Each probe shall consist of a light source and photocell separated by an optical gap. The radiant energy emitted from each light source shall be limited to those wave lengths that do not promote algae growth. Each probe shall be attached to a 25 foot waterproof cable by means of a waterproof connection made by the contractor.

The control box shall be a weatherproof NEMA 4 enclosure equipped with mounting lugs and clamps for attachment to a wall, handrail or vertical post. Space shall be provided inside the control box for storage of the unused lengths of the two 25 foot long probe cables. The control box shall contain the required solid state electronic circuits, power supplies and output relays. The output relays shall be rated for 10 amps at 120 VAC. A two position response switch shall be incorporated in the electronic circuitry to provide fast or delay response to sludge level changes. Three indicating lights labeled, LOW, MEDIUM, HIGH, shall be mounted on the enclosure to indicate the sludge blanket position as below, between or above the two probes. A terminal block shall be provided for connection to 120 VAC, 60 Hz power and for connection of relay contacts to external pump controls. When probe 'A' is located above probe 'B' in a sedimentation basin the controller shall function as follows. The energy source in the probe shall emit radiation through an optical sensing gap to the photocell which senses the amount of energy transmitted through the liquid and produces an electronic signal related to the suspended solids concentration of the liquid in the gap. This signal is compared in the control circuit to an adjustable density threshold setting. When the signal representing the concentration of solids in the liquid at probe 'A' exceeds the threshold setting an electronic integration is initiated. If the sludge level remains at or above probe 'A' at the expiration of the integration interval the output relay is energized and the HIGH lamp on the control box illuminates. When the sludge level drops below probe 'A' the photocell signal drops below the threshold setting and in turn the HIGH lamp is extinguished and the MEDIUM lamp illuminates. When the sludge level drops to probe 'B' and the signal representing the concentration of solids in the liquid is less than the threshold setting an electronic integration is initiated. If the sludge level remains below probe 'B' at the expiration of the integration interval the output relay is deenergized and the MEDIUM lamp is extinguished and the LOW lamp illuminated. When the sludge level increases to probe 'B' the photocell signal increases above the threshold setting and in turn the LOW lamp is extinguished and the MEDIUM lamp illuminated. The above cycle is repeated.

The sludge blanket controller shall be designed to operate at ambient air temperatures in the range of -30°F to 110°F. The wetted portions of the sludge blanket controller shall be designed to operate at ambient water temperatures in the range of 32°F to 85°F.

APPENDIX B

DETAILED CHRONOLOGY - FIELD NOTES

TEST RUN NO. 1

August 1

The sludge blanket probes were adjusted to levels of 5 1/2 and 6 ft below the surface of thickener 4. The optical surfaces of both probes were cleaned prior to measuring their photocell resistance in water.

Both initial sludge blanket levels were measured at 5 feet using the operator's portable sludge blanket detector.

The CST values for the underflow sludges were low, approximately 200 sec because of their low solids content.

August 2

Debris was removed from no. 4 overflow sample container. The debris consisted of fibrous clumps of sludge solids which were observed floating on the thickener surface. The material somehow was transported under the scum baffle and discharged to the launder and eventually to the overflow sample line. The material appeared to be associated with the primary sludge because of its size and appearance.

Both optical surfaces of both probes were visually checked and found to be free of film accumulation. The sludge blanket levels of both thickeners were determined with the operators blanket detector. Both basins exhibited diffuse interfaces ranging from 2 to 5 ft from the surface.

The recorded value for underflow analyzer no. 4 was approximately 0.5% solids lower than the corresponding meter reading. Both underflow analyzers yielded high readings based on sample analyses.

August 8

Clumps of solids were again removed from both overflow sample containers. The overflow analyzer readout increased by approximately 50 to 100 mg/l after removing the material.

Because both underflow solids analyzers gave very high readings twice in succession, their calibration settings were adjusted downward.

Both sludge blanket interfaces were found to be diffuse; thickener no. 2 interface was located 1 to 4 ft from the surface; thickener no. 4 interface was 3 1/2 to 5 ft from the surface.

The optical surfaces of both probes were found free of film accumulation.

August 9

Both sludge blankets were located at 1 to 2 ft below the surface.

Clumps of solids were again removed from both overflow sample containers. Analyzer output increased by 25 to 50 mg/l when solids removed.

The recorded value for underflow analyzer 4 was approximately 0.8% solids lower than the corresponding meter reading.

August 10

Solids were again removed from both overflow sample containers however no changes were observed in the overflow analyzer readings.

Both sludge blanket interfaces were measured at 1 to 2 ft from the surface.

August 12

Both sludge blankets were located at approximately 6 ft below the surface.

The recorded value for underflow analyzer no. 4 was approximately 1.5% solids lower than the corresponding meter reading.

August 15

Both blankets had well defined interfaces - no. 2 at 8.5 ft and no. 4 at 5.5 ft.

The recorded output of no. 4 underflow analyzer continued to read 1.5% solids lower than instrument meter. CST values for underflow increased substantially compared to previous values.

No. 4 underflow was black and no. 2 was brown. The pH values were 5.8 and 6.3 respectively.

August 16

Test run 1 was terminated. Both probes were checked for film accumulation and photocell resistance. After 15 days of operation, the upper probe had a noticeable accumulation on the optical surfaces however the light source and detector were visible.

The head on the overflow weirs of thickener 4 was found to be much lower than the other thickeners. Although no. 4 overflow totalizer had been indicating low flow rates since August 11, no. 4 inflow totalizer had not shown a corresponding decrease and continued to indicate flow rates in excess of 2 mgd. Based on the observations made on the overflow head on thickener 4, it appeared that the inflow meter was generating an erroneous flow signal for several days.

INTERIM

August 22

No. 4 underflow analyzer was examined and it was found that the 4 to 20 ma output did not correspond to meter readings. The control unit was packaged and shipped to the manufacturer for repair.

August 29

Debris which was found to be lodged in thickener 4 influent well was flushed out by closing the inflow valves to thickeners 2 and 6 and increasing the flow to thickener 4. After the influent well had been cleared of the obstructions the head on the overflow weirs of thickener 4 increased to levels similar to those observed on thickeners 2 and 6.

August 30

The optical surfaces of the probes were wiped clean and placed 7 1/2 and 8 ft below the surface of thickener no. 4.

No. 4 underflow analyzer control unit was returned from the manufacturer and installed in the control panel. After installation of the unit, the meter reading matched the recorder reading and the analyzer appeared to be working properly. The calibration adjustment was not changed from the previous setting.

The sludge blanket detector used by the operators was out of service and thus sludge blanket levels were not determined.

TEST RUN NO. 2

August 31

No. 2 inflow analyzer failed during a test plug check. A work order was issued for inspection and repair.

September 5

Inflow to all thickeners was terminated because the vacuum filters were shutdown.

September 7

Thickeners in service for full day. Calibration of overflow flumes started.

September 8

Solids removed from overflow sample containers; however, the analyzer output was not affected.

September 9

Both probes were visually inspected and the optical surfaces were found to be free of film accumulation. Both underflow streams sampled for filter leaf tests. No. 2 inflow local indicator and totalizer out of service.

September 12

The overflow sample containers were cleaned. No effect observed on instrument outputs.

September 13

The optical surfaces of both probes were found to be free of film accumulation based on visual inspection.

No. 2 influent metering system was back in service. Both blankets located at 5 ft.

September 15

No. 2 underflow totalizer calibrated.

September 16

Both no. 2 and 4 underflow totalizers calibrated. Test run 2 terminated.

INTERIM

September 19

Failure of no. 2 inflow analyzer identified as motor failure - motor drives plunger. New motor ordered from manufacturer.

September 21

No. 4 underflow analyzer output off scale (upper end) with motor and plunger operating normally.

September 22

No. 4 underflow analyzer output remained off scale.

September 26

Replacement motor for no. 2 inflow analyzer received. Instrument maintenance crew removed no. 4 underflow analyzer from underflow pipe and a grease accumulation at the sample entrance was removed. The analyzer was tested in the laboratory with sludge samples and found to operate properly.

September 27

Both no. 2 inflow and no. 4 underflow analyzers installed in respective process lines and placed into service.

TEST RUN NO. 3

September 30

The optical surfaces of both probes were wiped clean. The probes were positioned at 5 and 5.5 ft below the surface. The blanket levels were located at 4 ft and 2.5 ft for basins 2 and 4 respectively.

The CST values were lower than normal and the sludge appeared to have a high fiber content.

No. 2 underflow analyzer output was low based on sample analysis.

October 3

No. 4 underflow analyzer output off scale as previously observed on September 21.

No. 2 underflow analyzer output again low based on sample analysis.

CST values lower than normal, <200 sec.

October 4

Diffuse blanket interfaces observed in both basins (2 to 5 ft) at 1200 hr. The operator reported values of 7 ft for both basins at 1300 hr.

The operators were notified to maintain underflow pumping rate for basin no. 4 $\geq$150 gpm to assure control of blanket level during periods of high influent solids loading.

October 5

Both probes were found to be free of film accumulation based on visual inspection.

No. 4 underflow analyzer was removed from the underflow pipe after it was determined the control unit was functioning. The analyzer was operated in clean water and sludge samples and operated normally. The analyzer was installed in the underflow pipe of basin 4.

October 6

Diffuse interfaces were observed in both thickeners - 3 to 6.5 ft in basin 2 and 1 to 5 ft in basin 4. No. 4 underflow failed off scale again.

October 7

No. 4 underflow analyzer was removed from the underflow pipe and the light source did not appear to be functioning. When the unit was later installed it functioned properly. All underflow pumps turned off at 1030 hr because of flooded gallery. No. 4 pump turned on AUTO at 1245 hr.

No. 4 underflow analyzer failed late in day based on recorder chart.

October 11

No. 4 underflow analyzer removed from underflow pipe. It was determined that the light source had failed and had caused problems in previous days.

Both blanket interfaces were well defined - no. 2 at 9 ft and no 4 at 5.5 ft.

October 12

No. 4 underflow pump was found in MANUAL at 1250 hr. At 1200 hr operator switched to MANUAL while adjusting speed and did not return to AUTO. Pump returned to AUTO at 1300 hr.

The optical surfaces of the upper probe had a visible film accumulation however the lower probe was clean. The blanket levels were observed at 7.5 to 8.5 ft for no. 2 and 5 to 6 ft for no. 4 at 1245 hr. The operator reported a level of 7 ft for no. 4 at 1300 hr.

October 14

No. 2 underflow analyzer yielded low reading based on sample analysis.

The film accumulation was readily visible on the optical surfaces of the upper probe but the light source and detector were visible.

The blanket level detector used by the operators was taken out of service at 0800 hr for repair.

TEST RUN NO. 4

October 17

The probes were placed at the 3 and 3 1/2 ft levels, with the upper probe retaining the film coating formed during test run 3.

No. 2 underflow analyzer yielded low reading based on sample analysis.

October 18

No. 2 underflow analyzer continued to yield low values. The pH of basin 2 sludge was 6.0 and lighter in color than basin 4 sludge which had a pH of 5.7.

October 19

Thickener 2 was pumped down several feet by the operator to facilitate an oil change in the sludge collector mechanism. All of the thickeners were scheduled to be lubricated during the following week. The test run was terminated until October 21 when thickener 2 would be returned to operational status. Thickener 4 would be oiled after the next test was terminated.

The operator's sludge blanket detector was returned from the instrument maintenance department.

October 21

The blanket levels were observed at 8.5 ft and 4.5 ft for basins 2 and 4 respectively.

October 24

A moderate film was visible on the optical surfaces of the upper probe. The film on the lower probe was somewhat lighter. The control system functioned properly despite the coatings. The optical surfaces were not cleaned since September 30.

Both blanket interfaces were well defined - no. 2 at 7.5 ft and no. 4 at 4 ft.

No. 2 underflow analyzer continued to yield low values based on sample analysis.

No. 4 underflow pump was switched to MANUAL to facilitate sample collection.

October 25

The no. 4 underflow pump was not returned to AUTO on the previous day and operated through the night. The blanket level of basin no. 4 was dropped to 8 ft before the pump was returned to AUTO.

October 26

Solids were removed from the overflow sample containers. The analyzer outputs were not affected.

No. 2 underflow analyzer continued to yield low values.

October 27

Test run 4 terminated.

October 28

The optical surfaces of the upper probe were heavily coated. The photocell resistance of both probes was determined before and after the optical surfaces were wiped clean.

TEST RUN NO. 5

November 8

The probes were located at 5 and 5.5 ft depths. Both probes had visible film accumulation on the optical surfaces.

No. 2 underflow analyzer yielded values higher than in previous days for same solids concentrations.

Blanket levels observed at 5 ft and 3 ft for basins 2 and 4 respectively.

CST values were extremely high.

November 9

No. 2 underflow analyzer again yielded higher values.

November 10

Both probes had slight film accumulation on optical surfaces.

No. 2 inflow totalizer out of service.

November 14

Basin temperatures dropped 2^{o}C since November 8.

November 16

No. 2 underflow analyzer yielded low values based on sample analysis.

November 17

The blanket level detector failed due to film accumulation. The pump was operating when the blanket level was observed 3.5 ft below the lower probe. Both probes were wiped clean.

November 18

Test run 5 terminated.

CST value for basin 2 underflow extremely high, $>$1200 sec.

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

Project Officer: Irwin J. Kugelman (513) 684-7633

16. ABSTRACT

The purposes of this study were to evaluate some of the hardware required to monitor and control the operation of a gravity thickener and to identify any benefits associated with improved sludge blanket level control.

An automatic sludge blanket level control system was installed in one of the six gravity thickeners at the Metropolitan WWTP. In addition, optical type solids analyzers were installed to monitor the inflow, overflow, and underflow streams of two basins - one with automated blanket level control and one with manual control The performance characteristics of the instruments were documented during a series of five tests each lasting approximately two weeks.

The performance of the two basins is characterized in terms of underflow solids concentration and dewatering characteristics along with solids capture. The cost savings associated with automated blanket level control are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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