Fisheries and Environment Canada
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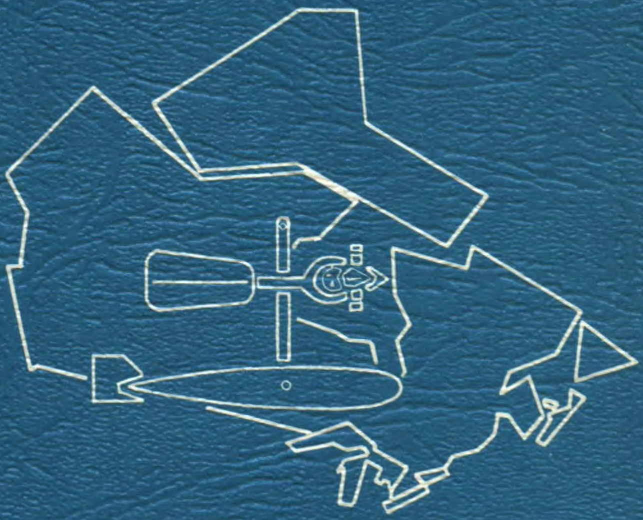
Hydrometric Field Manual – Measurement of Stage

L.P. COOPER - HEAD, S. AREA
WATER RESOURCES



INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1976.

(Résumé en français)

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Foreword

The *Hydrometric Field Manual* was prepared to assist Water Survey of Canada personnel in the collection of hydrometric data that meet national standards. During use of the manual the need for revisions or additions will become apparent. Any suggestions for these changes are welcome.

Both SI units and yard-pound units are used in this section. The next edition will contain only SI units, and illustrations of yard-pound unit equipment will be replaced by metric equipment.

This section of the manual was compiled and edited by R.A. Halliday and R.A. Terzi. The contributions by many individuals and organizations are gratefully acknowledged.

Abstract

This section of the *Hydrometric Field Manual* discusses the types of water level gauges and telemetering devices used in the collection of stage data at Water Survey of Canada gauging stations. The installation, maintenance and trouble-shooting of standard instrumentation are covered in considerable detail. Other stage instrumentation not often used at Water Survey of Canada stations is outlined briefly. Also, the theory of float-actuated and pressure-actuated water stage recorders is reviewed.

Résumé

Le présent guide traite des types de limnimètres et d'instruments de télémétrie utilisés dans les stations de jaugeage de la Division des relevés hydrologiques du Canada, lors de la collecte des données sur les niveaux des eaux. L'installation, l'entretien et la réparation des instruments normalisés sont étudiés d'une façon très détaillée. Les autres instruments de mesure peu utilisés dans les stations de la Division des relevés hydrologiques sont brièvement décrits. On y examine également le principe de fonctionnement des limnigraphes à flotteur et à pression.

Definitions

Backwater (BW) — a rise in stage produced by an obstruction in the stream channel caused by ice, weeds, control structure, etc. The difference between the observed stage for a certain discharge and the stage as indicated by the stage-discharge relation for the same discharge is reported as the backwater at the station.

Bank, right or left — the margin of a channel as viewed facing downstream. The expression "right" or "left" applies similarly to structures on the right or left, such as abutments and cableway towers.

Bubble gauge — a term commonly applied to a water level recording system that uses a gas purge technique.

Control — the condition downstream from a gauging station that determines the stage-discharge relation. It may be a stretch of rapids, a weir or other artificial structure. In the absence of such features, the control may be a less obvious condition, such as a convergence of the channel or even simply the resistance to flow through a downstream reach. A shifting control exists where the stage-discharge relation tends to change because of impermanent bed or banks.

Crest stage gauge — a manual gauge that records the peak stage that has occurred since previous setting.

Discharge (Q) — it is expressed in terms of volume, with either a stated or implied reference to time. The term "discharge" is herein considered synonymous with "streamflow."

Discharge measurement — the determination of the discharge at a gauging station on a stream; an observation of no flow is classed as a discharge measurement.

Float gauge — a manual gauge consisting of a float that rides on the water surface, rising and falling with the surface. The float's movements are transmitted to an indicating device.

Flume — a specially shaped open channel flow section that may be installed in a channel to measure discharge. Depending on the shape of the section, flumes may be termed Parshall, H-flume, Cutthroat, etc.

Gauge correction — any correction that must be applied to the gauge observation or gauge reading to obtain the correct gauge height.

Gauge datum — the permanent horizontal plane to which gauge heights are referred. This plane is in turn referred to a Geodetic Survey of Canada bench mark or to a bench mark having an assumed elevation.

Gauge height — the height of the water surface above the "gauge datum"; it is used interchangeably with the terms "stage" and "water level."

Gauge observation or gauge reading — an actual notation of the height of the water surface as indicated by a gauge; it is the same as a "gauge height" only when the 0.000 mark of the gauge is set at the "gauge datum."

Gauging station — a location where systematic records of stage or stage and discharge are obtained. This is also referred to as a "hydrometric station."

Inclined gauge — a manual gauge made by setting a staff gauge on an incline.

Manual gauge — a non-recording type of gauge from which observations of stage are obtained.

Painting — this refers to the wide ink trace on water level recorder charts that is caused by short-term water level fluctuations or by a malfunction in a recorder having a gas purge system.

Pressure water level recorder — this term is commonly used to designate the pressure recording attachment to the Stevens Type A recorder that was developed for use by the Water Survey of Canada.

Reference gauge — the gauge to which a water stage recorder is set.

Reference mark — a point of known elevation from which measurements may be made to a water surface. It is also known as a "measuring point."

Shift — a change in the stream control which alters the stage-discharge relationship. This change can be either temporary or permanent.

Slope-area measurement — a method of computing peak flow at a gauging station by determining the water surface profile and channel dimensions over a short reach of a stream.

Staff gauge — see "vertical gauge."

Stage — a general term used to describe the height of a water surface and, in a particular application, may be either a gauge height or a water elevation.

Stage-discharge relation — the relation between the stage and the discharge at a gauging station.

Stilling well — a well installed in a riverbank and connected by intake pipes or an open trench to the stream. Water levels in the well are sensed by a float and recorded on a water stage recorder in an instrument shelter on top of the well.

Streamflow — the actual flow in a stream. The term "streamflow" is herein considered synonymous with "discharge."

Vertical gauge — a manual gauge consisting of a graduated plate or rod which is set vertically in a streambed or attached to a solid structure. It is also known as a "staff gauge."

Water elevation — the height of the water surface as referred to Geodetic Survey of Canada or other standard datum.

Water level — see "gauge height."

Water level recorder — an instrument that records water levels in analog or digital form. The recorder may be actuated by a float or by any one of several pressure systems.

Water stage servomanometer — a type of water level sensor that converts pressure in a gas purge system to a shaft rotation using a servo-operated mercury manometer.

Weir — an overflow structure built across an open channel to measure the discharge in the channel. Depending on the shape of the opening, weirs may be termed rectangular, trapezoidal, triangular, etc.

Wire weight gauge — a manual gauge that is used to obtain gauge readings by lowering a weighted cable to the water surface.

Metric Conversion Factors

LENGTH

1 inch	= 0.025 40 m
1 foot	= 0.304 80 m
1 statute mile	= 1.609 3 km
1 nautical mile	= 1.852 0 km

AREA

1 square foot	= 0.092 903 m^2
1 square mile	= 2.590 0 km^2
1 acre	= 4046.9 m^2

VOLUME

1 cubic inch	= 16 387 mm^3
1 cubic foot	= 0.028 317 m^3
1 acre-foot	= 1.233 5 dam^3

VOLUME FLOW RATE

1 cubic foot per second	= 0.028 317 m^3/s (1 m^3/s = 35.315 cfs)

MASS

1 avoirdupois ounce	= 28.350 g
1 avoirdupois pound	= 0.453 59 kg

FORCE

1 ounce force	= 0.278 01 N
1 pound force	= 4.448 2 N

PRESSURE

1 pound force per square inch	= 6.894 8 kPa
1 pound force per square foot	= 47.880 Pa

ENERGY

1 watt hour	= 3600 J
1 British thermal unit (International)	= 1055.1 J

TEMPERATURE

$°C = 5/9(F + 40) - 40$

$°F = 9/5(C + 40) - 40$

Hydrometric Field Manual—Measurement of Stage

INTRODUCTION

The main purpose of a gauging station is to provide a means of systematically gathering hydrometric data. Discharge measurements are related to stage observations at the time of measurement and used to produce a stage-discharge relation. Once this relation has been determined, it may be used together with daily stage data to produce a daily record of discharge. The measurement and recording of stage are important, as the stage record provides the means by which daily discharge computations are made. In addition, some gauging stations are operated exclusively for the collection of stage data for such purposes as navigation and computation of reservoir contents.

This section of the *Hydrometric Field Manual* covers the techniques of stage measurement that are in general use in the Water Survey of Canada and the operation of equipment used for stage measurement. Maintenance of gauge datum is covered in the Levelling Section[1] and details of Telemark operation are discussed in the *Telemark Manual.*[2] Design and construction of gauging stations will be covered in the Construction Handbook. Daily discharge computation procedures are described in the *Manual of Hydrometric Data Computation and Publication Procedures.*[3]

MANUAL GAUGES

Stage readings may be obtained either by observing the water level using a permanently installed manual gauge or by direct measurement at the time of a visit to a gauging station.

A manual gauge is a non-recording gauge used to obtain gauge heights. The gauge may be operated independently or used as a reference gauge for a water stage recorder. All manual gauges installed at a site are set to read elevation above gauge datum (0.000).

[1] *Hydrometric Field Manual — Levelling,* R.A. Terzi, Ottawa, 1973.

[2] *Telemark Manual,* K.F. Davies and R.A. Terzi, Ottawa, 1971.

[3] *Manual of Hydrometric Data Computation and Publication Procedures,* W.J. Ozga, Ottawa, 1975.

Vertical (Staff) Gauge

The most commonly used manual gauge is the vertical or staff gauge. This gauge (Fig. 1) is made of 1-m sections of enamelled steel plate that are accurately graduated to 0.002 m, with a clear indication of each 0.01 m and 0.10 m. (Yard-pound unit gauge plates are 3 ft long and are graduated to 0.01 ft.) The gauge plates are fastened to a backing board, and the entire unit is firmly attached to a bridge abutment, pier, wharf piling or to the inside of a stilling well. Another method of installation is that of driving a length of heavy pipe, angle iron or metal flange into the streambed, and then attaching the backing board to this support. The backing board should have slots at the point of attachment to permit vertical adjustment of the gauge. Backing boards should be pressure treated and/or painted to prevent deterioration.

Install staff gauges so that they are protected from damage by floating ice and debris and are not affected by local drawdown or pile-up of water. Small local effects may be reduced by mounting the gauge so that the face of the plate is parallel to the current and by streamlining the backing board by attaching commercially available wood mouldings. When the gauge is used as an outside gauge for a water stage recorder, install it as close as is practicable to the end of the inlet pipe or to the orifice of a gas purge system. In most cases, it will be necessary to install the gauge near the water's edge.

Where it is necessary to use more than one outside vertical gauge, install them so that they are on a line perpendicular to the direction of flow. Set the gauges to the same datum and ensure continuity. Also number the gauges, reference them to fixed objects and record this information in the station description.

Clean the gauge regularly so that it will be clearly legible. Read the gauge from near the water surface to avoid parallax errors. When the observer can approach the gauge so closely as to see the meniscus of water, the bottom of the meniscus should be read. When the water level is surging, observe it for a few minutes and record the mean of the fluctuations.

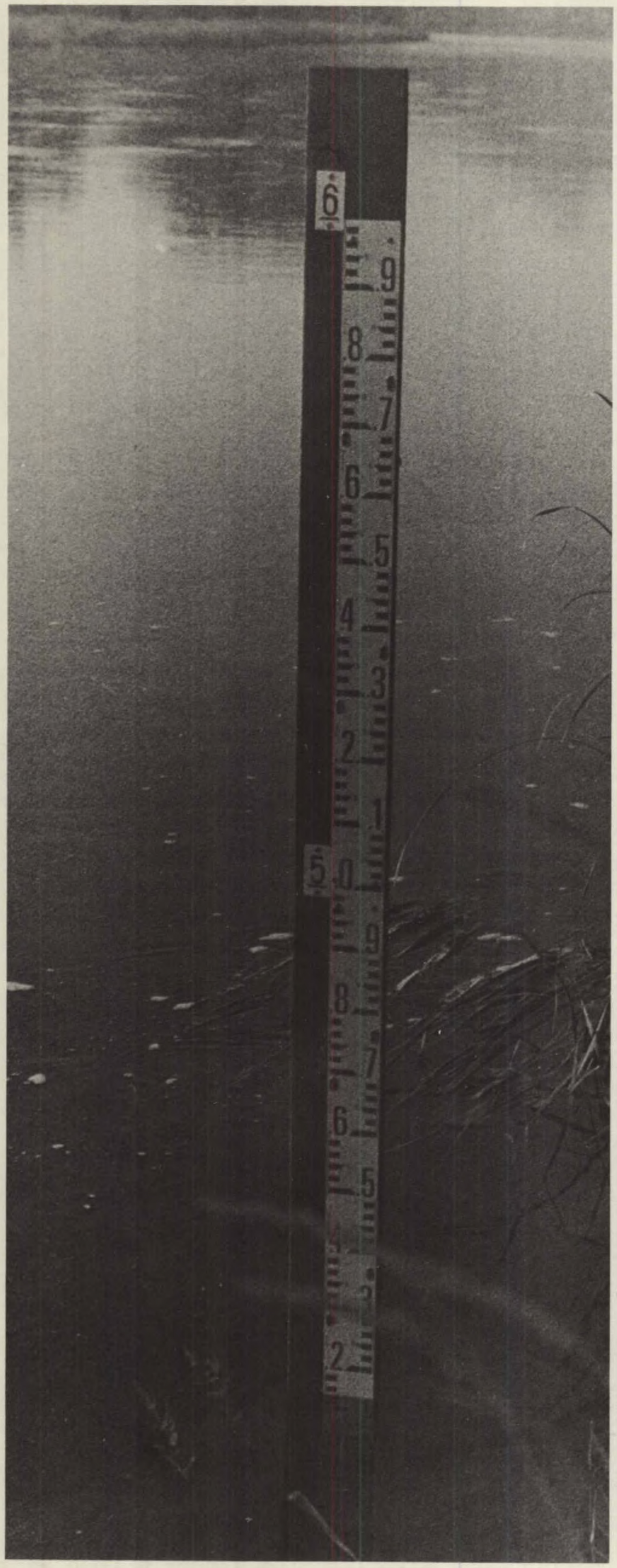


Figure 1. Vertical gauge.

Inclined Gauge

An inclined gauge is essentially a vertical gauge placed on an incline. The use of this gauge may be considered where gently sloping riverbanks make it impractical to install a vertical gauge and where a vertical gauge would be endangered by floating debris during periods of high flow. A conversion table produced by levelling at various points along the entire length of the inclined gauge must be used to convert the gauge observations to stage data. Inclined gauges are seldom used, as they are subject to movement from frost action, can be damaged by ice and often become unserviceable on account of scour or deposition of sediment.

Wire Weight Gauge

These gauges are generally housed in a compact metal case and are of two basic styles. One type (Fig. 2) uses a reel solely as storage for a wire that is marked with numbered brass tags at intervals for the required range of stage and has a weight attached to the free end. A plate equal in length to the tagging interval and graduated in 2-mm (0.01-ft) increments is located alongside the storage reel. When the weight on the end of the wire is lowered to the water surface, the tagged wire passes along the face of the gauge plate and the number read from the tag and the fraction of the metre (or foot) read from the plate. The gauge is designed so that the graduated plate may be either vertical or horizontal. Both types of plates are in common use.

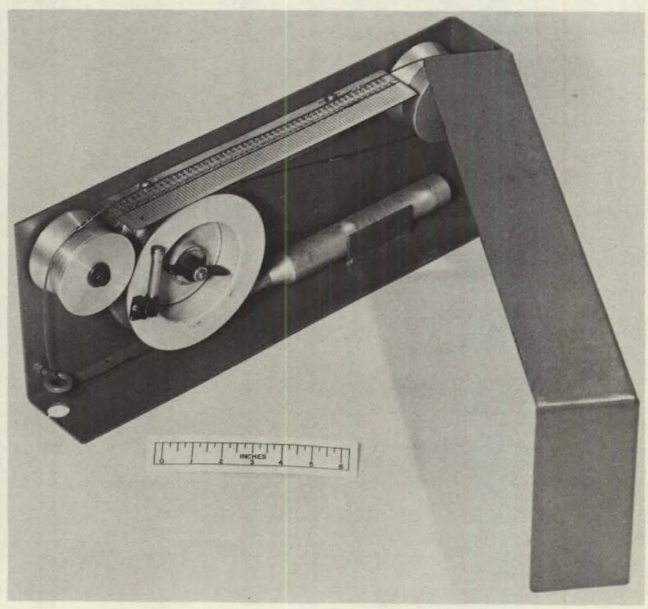


Figure 2. Wire weight gauge (tagged wire).

The other style of wire weight gauge (Fig. 3) uses a precision drum wound with one layer of cable which has a weight attached to the free end. The drum diameter is such that when it is turned one complete revolution, the weight is raised or lowered 0.3 m. A revolution counter attached to the drum reads in metres and centimetres, whereas graduations on the flange of the drum adjacent to the counter are in even millimetres. (Yard-pound unit gauges have a drum 1 ft in circumference and may be read to 0.01 ft.)

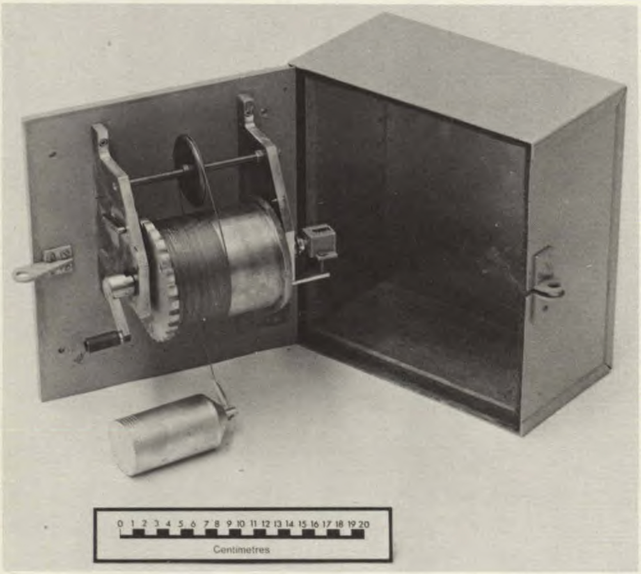


Figure 3. Wire weight gauge (counter type).

A wire weight gauge is used as an outside gauge when conditions at a gauging station make it difficult to read or to maintain a staff gauge. It can be readily mounted over the water surface from bridges and piers or the weighted cable can be suspended from the end of a rigid beam cantilevered out over the water surface. In the latter case, the gauge box is attached to the cantilever base on shore, and the gauge is usually referred to as a ''cantilever'' gauge.

The point on the water surface at which the wire weight gauge readings are observed should have minimal local turbulence or drawdown. A wire weight gauge must be read as it touches the water surface when being lowered; because of surface tension, once contact with the water surface has been made the weight can be raised as much as 6 mm (0.02 ft) without breaking the contact. It may be necessary to take several observations and average the results to obtain a good gauge reading. During periods of high wind, the accuracy of reading will be degraded by wind drag on the wire.

Some counter type wire weight gauges are equipped with a check bar. The gauge reading on this check bar should be verified on each visit to ensure that it has not changed. If the reading has changed, this is an indication that slippage has occurred between the drum and the counter.

Wire weight gauges are equipped with a weight having 2-mm (0.01-ft) grooves cut in the bottom portion of the weight. These grooves are used when levelling the gauge. Wire weight gauges require very little maintenance other than removal of dust from the gauge and in some cases, lubrication. Care should be taken when using the gauge to ensure that the cable does not become kinked.

Hook Gauge

Hook gauges (Fig. 4) are used at gauging stations equipped with weirs or flumes to determine the pen setting for a water stage recorder that has a very accurate gauge scale (1:1 in metric units or 10:12 in yard-pound units). Although hook gauges are very accurate, their measuring range is small, usually 1 m or less.

The hook gauge consists of a hook, the tip of which approaches the water surface from below. The tip is tapered to a point having an included angle of about 60°, and the point is rounded to a radius of about 0.25 mm. The position of the hook is read on a graduated scale and vernier.

The gauge is read by moving the hook up until the tip just touches the water surface, and then reading the scale at that position. The water surface should be free from all turbulence or surges at the point of observation otherwise the value of a hook gauge will be negated. The water surface should also be well lighted at the time of observation to permit accurate setting of the hook.

The gauge must be kept clean so that moving parts do not bind, and should be levelled frequently to ensure continuity of gauge datum.

Electric Tape (Contact) Gauge

The electric tape gauge (Fig. 5) is used to provide gauge readings in a stilling well that is either too small in cross section or too deep to permit the field officer to climb down to read a staff gauge safely. The gauge consists of a stainless steel tape graduated in 1-mm (or 0.01-ft) increments to which a cylindrical weight is fastened, as well as a reel for the tape, an electrical power source

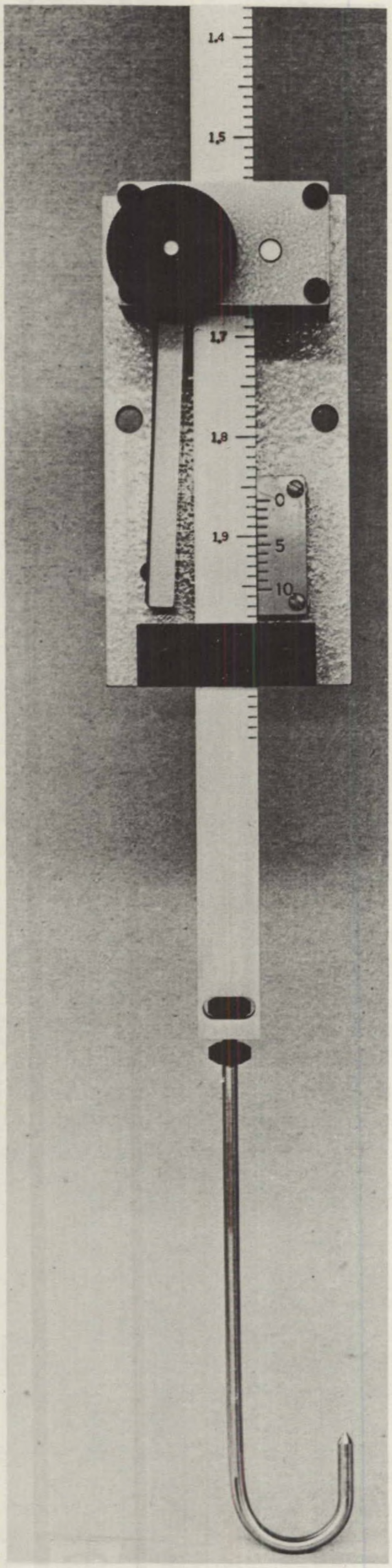


Figure 4. Hook gauge (Courtesy of Leupold & Stevens Inc.).

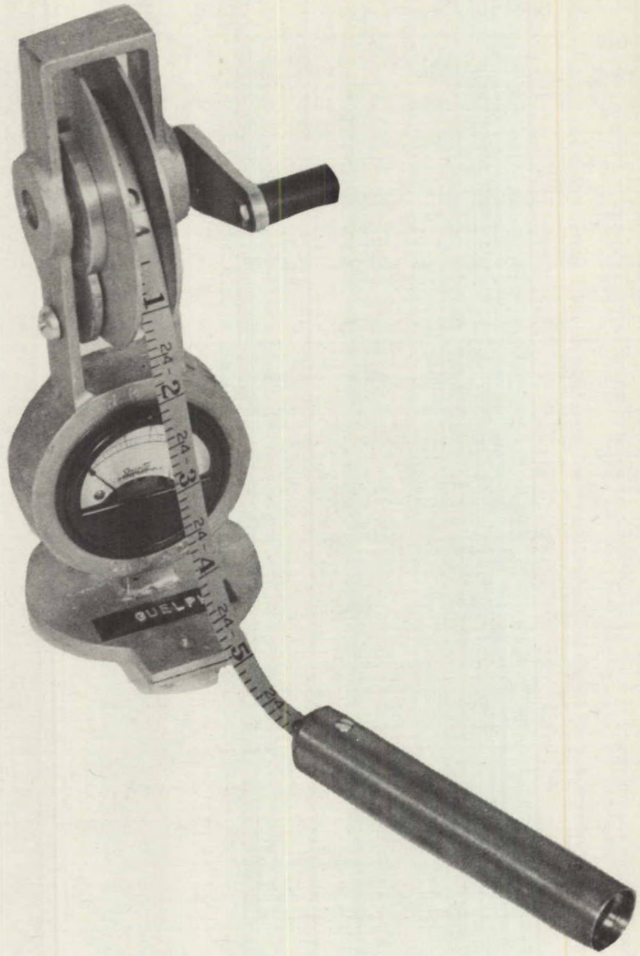


Figure 5. Electric tape gauge.

(usually a battery) and a device to indicate when an electric circuit is complete (usually a voltmeter). All parts are supported by an electrically insulated bracket. The contact surface of the weight is reduced by making the bottom concave to prevent observation errors because of water droplets on the weight bottom.

In determining water levels, the weight is lowered until it contacts the water surface, thus completing an electric circuit and producing a deflection of the voltmeter. With the weight held in the position of contact, the tape reading is observed at the index mark provided on the reel mounting. Several readings should be taken, in each case lowering the weight to the water surface to avoid errors caused by surface tension.

The gauge should be inspected often to ensure that no corrosion occurs on the bottom of the weight or elsewhere in the electric circuit. The battery should be replaced annually.

Float Gauge

Like the tape gauge, the float gauge (Fig. 6) is used as an inside gauge for setting a water stage recorder. The gauge consists of a float, a pulley mounted on a standard and a counterweight. The reading on a graduated tape is observed on an adjustable index. The tape may also be adjusted at the connection to the float when adjustments larger than those that the index adjustment can handle are required.

The float used should be as large as the recorder float to ensure sufficient accuracy and should travel freely through the entire range in stage. The index must be adjusted only at the time of level checks to ensure continuity of gauge datum. The use of a graduated tape and index on the standard of a recorder as an inside gauge usually does not provide a sufficiently independent check of water level recorder operation.

When observing the readings on a float gauge, care must be taken to eliminate parallax errors. If the water level in the well is pulsating, make several observations and average the results.

Inspect the float periodically to ensure that it is floating properly and is free from corrosion. Clean and lubricate the bearing of the float pulley as required.

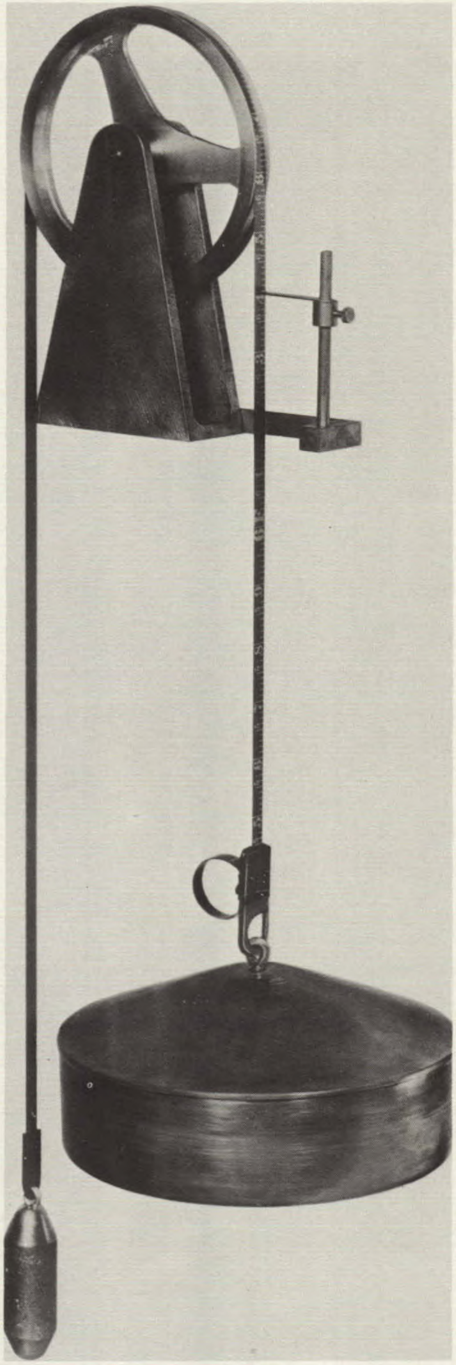


Figure 6. Float gauge (Courtesy of Leupold & Stevens Inc.).

Crest Gauge

A crest stage gauge is used to provide a means of obtaining the peak stage that may have occurred between visits to the gauge. There are two basic types: one contains cork dust in a steel tube (Fig. 7), the other has an Ethafoam rider in a plastic tube (Fig. 8).

In the first case, a galvanized pipe, 50 mm in diameter and capped at both ends, is used. A number of holes are drilled in the bottom cap to permit entry of water while keeping surge effects to a minimum. A vent hole is drilled in the top cap. A wooden rod having a small container for cork dust attached at the lower end is placed inside the pipe so that it cannot float. As the water rises in the pipe, the cork dust floats free of the container and adheres to the rod at the point to which the water has risen. The entire crest gauge assembly is firmly fixed to a bridge or pier and levelled to gauge datum. The gauge is read by measuring from the top or bottom of the rod to the cork dust line. The wooden rod must be cleaned and the cork dust container refilled before the rod is replaced in the pipe.

The second type of crest stage gauge consists of a length of Plexiglas tubing attached to a backing board, usually alongside a staff gauge. Inside the tube there is a cylindrical Ethafoam rider; the bottom and top of the tube have been drilled to permit entry of water and venting of air. In operation, as the water level rises inside the tube, the rider floats upward following the rise in stage. The cohesive properties of the foam rider and the tube prevent

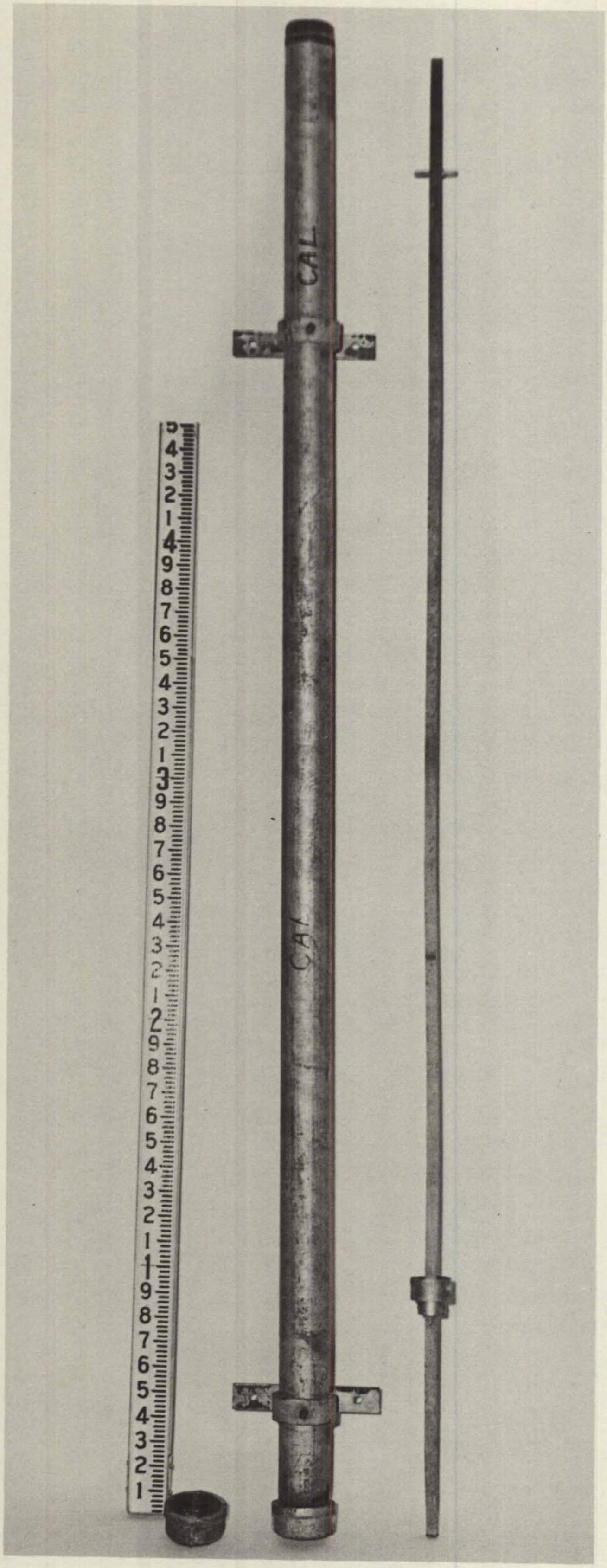


Figure 7. Crest stage gauge (USGS type).

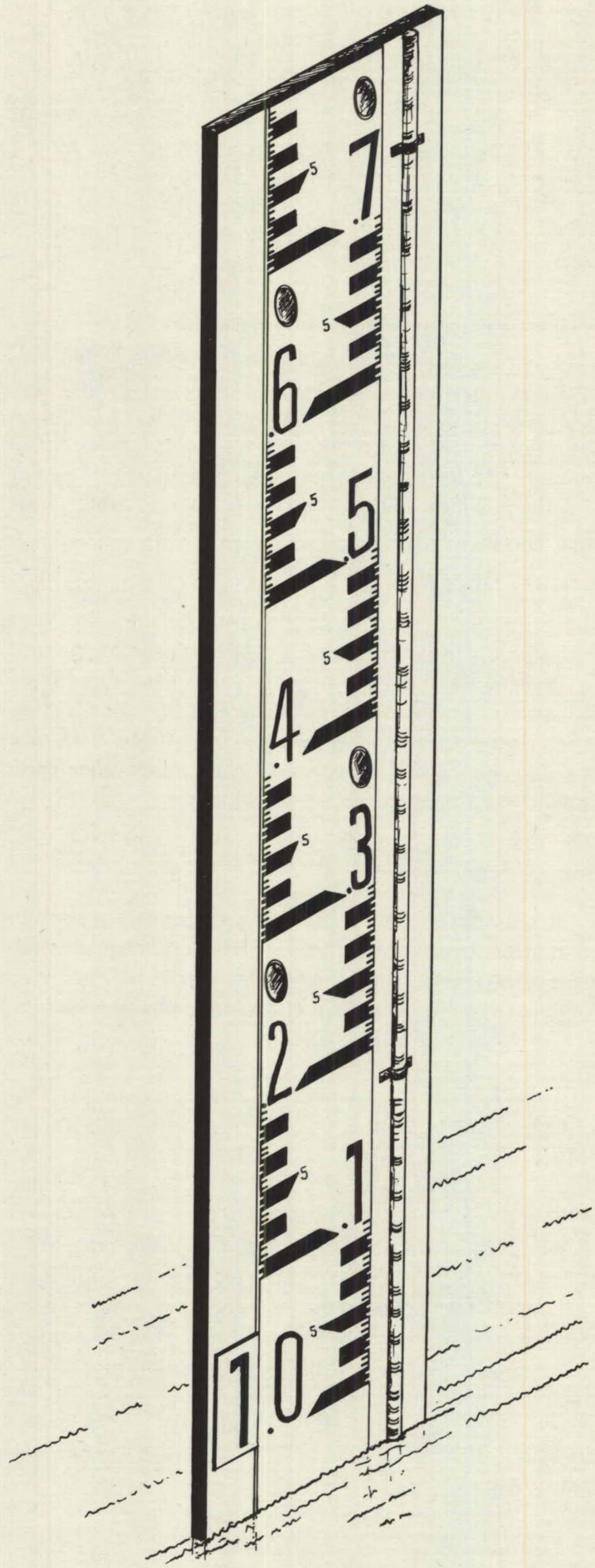


Figure 8. Crest stage gauge.

the rider from dropping when the water recedes from maximum stage. (Cases of non-adherence of the rider have occurred when the gauge is subject to vibration or to very low humidities.) The height of the midpoint of the rider is read on an adjacent staff gauge or determined by levelling from a bench mark. The gauge is easily reset by removing the top plug from the tube and lowering a weighted cord to dislodge the rider. This places it at the existing water level ready to follow the next rise in stage.

Alternative Manual Stage Observations

At some gauging stations it is not feasible to install or maintain a manual gauge because of channel conditions or vandalism. In other cases, records are required only for a short period of time or data are needed to reconstruct a stage hydrograph after a flood event. There are several methods of making these observations, some of which may be used by a local observer to ensure collection of stage data that may otherwise be lost.

Direct Water Level

Stage observations may be made by direct levelling to the water surface from a bench mark using an engineers' level. This procedure is frequently employed to determine the pen setting for a pressure-actuated recorder or to verify that inlets to a stilling well are clear.

Care should be taken to ensure that direct water levels are taken at the same location each time, otherwise there is a danger that inaccuracies in the stage record will be introduced because of slope in the water surface. The location at which the levels are taken should be referenced to known objects and shown in the station description.

Reference (Measuring) Point

A reference point is a stable, accessible point on a bridge, pier, abutment or stilling well from which the distance to the surface of the water may be measured using a weighted tape similar to that shown in Figure 9. A reference point often is established when a conventional gauge has been destroyed or damaged beyond repair. As in other cases, the point on the water surface beneath the reference point should be free from turbulence and other local effects. The distance from the reference point to the surface should be read when the weight contacts the water surface as it is lowered to avoid surface tension effects. The weighted tape should be checked occasionally to verify that the bottom of the weight is at the zero of the tape.

Another type of reference point system involves setting a series of stable rods or bench marks down the riverbank on a line perpendicular to the current direction. The bench marks are then levelled to the station datum. As the stage rises and water covers the reference points, the observer must wade out to the last point covered and place a level rod or staff gauge plate on top of the reference point. The stage is then determined by reading the rod or gauge plate as a staff gauge would be read. This system is not often used because of the inconvenience involved and the possibility of having unstable reference points.

Figure 9. Weighted tape.

High Water Marks

There are occasions when streams overflow their banks at a gauging station, and for some reason no daily stage data are available. When this situation occurs, information on the maximum stage may be obtained by means of high water marks. It may be possible then to make an estimate of peak flow using indirect methods of computation.

High water marks must be selected with care. A misinterpretation because of water pile-up or drawdown can produce a serious error in computation. Normally it is necessary to search carefully along each bank at least 150 m upstream and downstream from the gauge for evidence of high water marks. Often a good mark is left inside a gauge house or other buildings in the vicinity of the gauging station. Select sufficient points to define the water surface profile at the time of the peak so that the peak stage at the gauge may be computed algebraically. Identify additional points if it seems likely that it will be necessary to compute peak discharge by an indirect technique such as the slope-area method.

Water Level by Stakes

At times when regular gauging facilities are inoperable due to inundation by floodwater, or the recorder or gauge has been damaged and other means of referring water levels to fixed points are not available, a local observer should be requested to drive a stake at the water's edge when visiting the station and to write the date and time of observation on the stake. These stakes may then be referenced to station datum by levelling to produce stage data.

Photographs

Unusual conditions are, at best, difficult to describe adequately and what may be a commonly used phrase today may be difficult to interpret in a few years. Photographs accompanied by descriptions of the events may prove valuable in interpreting the hydrometric data. In all cases, the photographs should be dated and the point from which they are taken referenced to permanent objects such as bridges, gauge houses or rock cairns. The distance to the water's edge is also useful.

Recording of Manual Observations

Gauge observations are usually recorded in one of two places, namely, on the cover sheet of the Hydrometric Survey Notes (R21-A) or in the booklet *Gauge Height Observations* (R2 or R6). The Hydrometric Survey Notes form (Fig. 10) is used by the field officer at the time of a visit to a gauging station. The form has a space to record level notes at a gauging station, an area for sketches and a block on the cover for gauge readings. In recording gauge readings, the gauge must be described by type, number or location so that persons examining the record at a later date will be certain of the gauge used. The abbreviation IG is frequently used to designate the inside staff gauge in a stilling well and is generally unambiguous. The abbreviation OG for an outside gauge, however, may present problems. It is preferable to designate these gauges as WWG (wire weight gauge), MP (measuring point), STAFF No. 2, etc. All times recorded should specify the time zone and whether the time is standard time or daylight time, for example, 14:30 EDT or 09:00 PST. It is preferable to record standard time rather than daylight time.

Some gauging stations are not equipped with water stage recorders. Therefore stage data must be obtained by hiring a local observer to read a manual gauge and to mail the record of gauge readings to a Water Survey of Canada office. The data provided by these local observers are extremely important, since without these gauge readings

HYDROMETRIC SURVEY NOTES

Station . . . . Sta. No. . . . .

Date . . . . 197 . . . . Party . . . .

Width . . . . Area . . . . Mean vel. . . . . . . CORR. M.G.H. . . . . . .

Temp. A . . . . . ° . . W . . . . ° . . . DISCHARGE . . . . cfs

Measurement began at . . . . ended at . . . .

Levels obtained . . . .

Gauge Readings				
Time	Station	Pen	Inside	Outside
Weighted M.G.R.				
Correction				
Correct M.G.H.				

Meter No. . . . .

Date rated . . . .

Meter . . . . ft.

above . . . . lb. weight.

Method . . . .

Coeff . . . .

No. of vert. sect. . . . .

Angle of flow . . . .

Obs. seen . . . .

Book insp. . . . .

RECORDER: Chart removed . . . . Supply roll . . . . days remaining

Weather conditions . . . . Wind . . . .

MEASUREMENT: Wading, cableway, boat, ice cover, upstream, downstream side of

bridge . . . . ft., mile, above, below gauge . . . .

REMARKS: Include condition of station equipment: . . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Computed by . . . . Checked by . . . .

Figure 10. Hydrometric Survey Notes form (cover sheet).

the annual record for a gauging station would consist only of miscellaneous measurements obtained by the field officer.

Any time spent in training an observer to take accurate gauge readings is worthwhile. If the observer is visited regularly and the importance of the work stressed, better data will result. The observer should be advised to read and follow the "Instructions to Gauge Observers" (Fig. 11) contained in the *Gauge Height Observations* booklet, and not to guess at readings if for some reason it is not possible to read the gauge on a certain day. In areas where observers have difficulty using this booklet, the person may be supplied with a full-size diagram of the staff gauge and asked to draw a line on the diagram at the correct water level. These lines can be identified in some way (dated or numbered) so that the field officer can determine correct daily gauge readings.

INSTRUCTIONS TO GAUGE OBSERVERS

1. Always take this book to the gauge and, on reading the gauge, immediately record in the book the time of observation and gauge height. Do not keep your records on the gauge height card, on slips of paper or in any book of your own. This book should contain original records.
2. Be sure you record your observations and time correctly, and opposite the proper date.
3. Do not fill in column under "Corrected height".

UNDER REMARKS

State any occurrences or conditions that affect the height of the stream or lake at the gauge, such as:—

1. Weather Conditions:—Rain (heavy or light), snow, cold weather (freezing), mild weather (thawing); or extremely warm weather (evaporation); direction of wind (strong or light).
2. Ice Conditions:—Ice along edges of channel, slush ice running, stream completely frozen over, formation or breaking up of ice jams above or below gauge; formation or presence of ice on riffle (rapids) below gauge, either on surface of water or on bed of stream, snow melting or running into stream or lake, ice broken up in channel ice completely gone out of stream or lake.
3. Open-water Conditions:—Formation or breaking of log jams, collection of debris on riffle below gauge, formation of sand or gravel bars, growth of grass in channel or on riffle below gauge.
4. Always try to explain sudden rises or falls in water level. Your opinion as to the cause of such changes is of value.

(Continued on inside back cover)

5. If the stream stops flowing, note this fact. Also note if water is standing in pools, or the stream is dry. Send cards even when stream is dry.
6. If you have some one else read the gauge for you, be sure you instruct your substitute fully, and note substitute's name under remarks.
7. When you are unable to read the gauge, fully record weather conditions. Never record gauge heights which have not been observed. No records are better than incorrect ones.

WRITE OR TELEGRAPH DISTRICT ENGINEER

1. If the gauge is destroyed or the water goes above or below it. Also set a temporary gauge, or place stakes at water's edge marking height of water with date each day.
2. If you leave the district and do not get any one to read the gauge, or find that you cannot read the gauge, please notify this office.
3. If you do not understand these instructions, or any feature of this work, please write to this office.

FLOOD CONDITIONS

During floods you can be of very valuable service by noting the rate at which the water rises in one or more hours; also the extreme height to which water rises, and the time when extreme height is reached.

GAUGE HEIGHT CARDS

Copy observations and remarks from this book on to cards supplied for this purpose, each Saturday, and mail as promptly as possible.

Figure 11. Instructions to gauge observers.

RECORDING GAUGES

Water stage recorders are installed at gauging stations when local observers are not available or when water levels vary so frequently that daily manual gauge readings do not adequately define the stage hydrograph. Ideally, all gauging stations should have a recording gauge.

A water stage recording system consists of two main components: a sensor that detects the water level and an instrument that records the water levels. Water levels may be sensed by a float or by pressure-actuated systems which use the principle that the pressure at a fixed point below the water surface is proportional to the depth of water. The water stage recorder used at Water Survey of Canada gauging stations is the Stevens Type A.

Operation of a float-actuated system requires that a stilling well be constructed in the riverbank or attached to a permanent structure such as a bridge abutment. If properly constructed, the water level in a stilling well should accurately follow that in the stream, but with short duration oscillations damped out. The stilling well should be long enough to cover all ranges in stage, be equipped with a flushing system to remove sediment deposits from the intake pipes, have a means of removing sediment from the well itself and, in high velocity streams, have intakes equipped with static tubes to reduce velocity effects. The well should be capable of being operated through the winter period, if necessary.

Stilling wells tend to be installed at permanent gauging sites where the river channel is not subject to scour or deposition, the presence of bedrock does not present an installation problem and winter temperatures do not create an operational problem. When installation or operation of a stilling well is difficult or at temporary gauging stations, it is usually advisable to install a pressure-actuated system.

Table I is a trouble-shooting check list for recording gauges.

Float-Actuated Systems

All float-actuated instruments operate on the principle that a float rests on the water surface and rises and falls as the water level changes. A flexible wire or tape attached to the float runs over a pulley without slipping and is kept taut by a counterweight. The pulley driven by the float is used to move the pen carriage mechanism of the recorder.

The basic requirements for a satisfactory float are that the sides in contact with the water surface be vertical, the float be stable in the water, and if hollow, the float be watertight but vented to prevent implosion owing to atmospheric pressure change. The float and its hardware should be constructed of non-corrodible and non-fouling materials.

The sensitivity of a float to water level fluctuations is directly dependent on its cross-sectional area. For most applications, a float 200 mm or 250 mm (8 in. or 10 in.) in diameter is sufficiently sensitive.

The line connecting the float to its counterweight should be as light as possible to minimize errors produced as the line passes from one side of the float pulley to the other. (For this reason, beaded cable is more satisfactory than steel tape.) The counterweight should be as light as possible, yet keep the float line taut. Increasing the weight of the counterweight will decrease sensitivity by augmenting friction at the pulley standard. An error is introduced when the counterweight becomes submerged, although this error tends to compensate errors caused by line shift. Another source of error is the effect of temperature variations on the float line and the stilling well. This effect need only be considered for deep wells, as in most cases the temperature effect on the float line will compensate that on the stilling well. More information concerning float-operated systems is contained in Appendix A.

Winter operation is a problem common to all float installations. Floats can be operated in the winter if stilling wells are equipped with insulated sub-floors or oil cylinders. Where commercial power is available, an immersion heater may be installed in a float or heat lamps used to heat a stilling well to prevent freezing. If heat lamps are used, they should be positioned high enough above the water surface that water vapour is not produced. This vapour may condense as frost at holes where the float line passes through the floor of the gauge house and could impede the movement of the float. When power is available and frost is a problem, a low wattage bulb suspended near the holes will keep them clear. This problem may also be reduced by lining the holes with absorbent material and soaking the material with antifreeze, by venting the stilling well or by insulating the gauge house.

Stevens Type A Recorder

The Stevens Type A recorder (Fig. 12) is a continuous strip chart recorder that produces a record of stage through two interdependent systems, one for stage and the other for time.

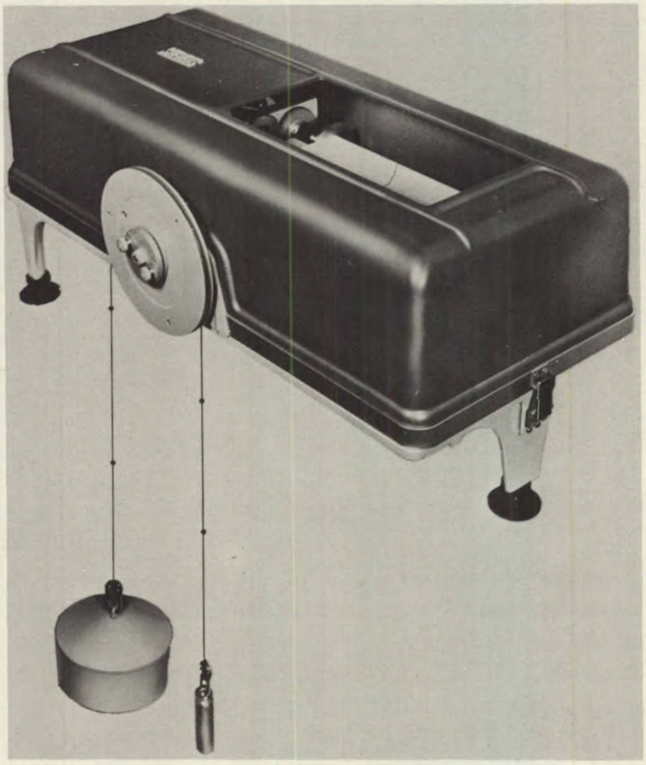


Figure 12. Stevens Type A recorder (Courtesy of Leupold & Stevens Inc.).

The movement of the pen across the chart paper, which depicts changes in water level, is caused by rotation of the shaft mounted in the pulley standard at the front of

I

Table I. Trouble-Shooting of Water Stage Instruments

Part 1. Float-Actuated, Including Type A Recorder

Symptom	Possible cause	Action
Pen not inking or pen skipping	Dirty pen or ink supply exhausted	Clean pen using cleaner wires or fill reservoir
	Pen tip not flat on chart paper	Adjust
	Lucite reservoir held too tightly in stylus carriage	Adjust
Flat spot in trace at high water	Float jammed against floor	Cut hole in floor to allow float to rise to shelf level
	Counterweight resting on bottom of well	Shorten float line
	Beaded float wire caught on shelf or floor	Enlarge holes
Flat spot in trace at low water	Bottom intake blocked or frozen	Flush pipe or thaw
	Bottom intake not low enough	Reinstall bottom intake
	Silt in well	Remove silt
	Counterweight caught on floor or shelf	Lengthen float line
	Beaded float wire caught on shelf or floor	Enlarge holes
Discontinuity in trace on rise or fall in stage	Float or counterweight caught on obstruction or each other	Check path of float and counterweight through range in stage
	Layer of thin ice forming on water surface in the well	Check heating system
	Sticking reversal mechanism	Check for smooth operation; clean
	Beaded float wire caught on shelf or floor	Enlarge holes
Water level in well is usually higher than that in stream	If well is not sealed, could be caused by groundwater inflow to well	Open valves on intake pipes to maximum temporarily; seal well eventually
Water level is different from that in the stream (if intakes are clear, most records will show signs of slight "pen action")	Float pulley is loose	Tighten
	Beaded cable or float tape disengaged	Re-engage; check for possible reason, dirt in tape hole, etc.
	Intakes blocked by sediment deposition	Remove sediment

Part 1. Continued

Symptom	Possible cause	Action
Painting, particularly at high water	Intakes are too large	Close intake valves slightly
	Velocity effects on intakes	Install static tubes on end of pipes
Recorder clock stopped (if no apparent cause of failure, replace the clock)	Negator spring-pawl engaged, or spring overwound, or completely unwound	Release pawl, carefully unwind spring, or wind as required
	Weight drive—weight spring drawn up into hole in floor or shelf, or weight dropped to its full extent	Remove weight and unwind a little cable, or wind cable as required
	Electric clock—power failure (may be noted as a step in the trace)	Check circuit breaker, supply voltage
	Extreme cold temperatures	Lubricate using arctic lubricant or heat the recorder
	Incorrect torque input from negator spring or drop weight	Check torque, should be 300-380 mN•m (42-54 oz-in.)
Clock runs extremely fast	Drive roll not engaged, take-up roll is pulling paper through	Check if the rubber rollers that engage drive roller are in contact

Part 2. Pressure-Actuated Systems

Symptom	Possible cause	Action
No change in stage	Gas supply exhausted	Replace nitrogen cylinder
	Dead battery	Replace battery
	Battery leads reversed	Check polarity
	Failure in servocontrol unit	Check or replace servo
	Electric motor failure	Check brushes and motor drive train
	Mercury frozen in extreme cold	Heat installation
Uniform painting	Water in line	Purge line, try slightly higher bubble rate; may be necessary to reinstall line to eliminate low spot
	Silicone oil in line	Purge line with white gas; check oil level in sight-feed, may be too high
Erratic painting	Silt deposits on orifice	Remove silt or reinstall orifice

Part 2. Continued

Symptom	Possible cause	Action
	Float switch jewel screws too loose or too tight	Adjust
	Water velocity effects on orifice	Check velocity at orifice with current meter; lower orifice or use well point
Narrow painting band "hunting"	Servomanometer float switch or servo-beam-balance contacts set too close together	Increase gap between contacts
	Air trapped in servomanometer mercury-transfer tube	Tap the tube to dislodge bubbles
	Float-switch jewel screws too loose or too tight	Adjust
Poor sensitivity "stepping"	Servomanometer or servo-beam-balance contacts too far apart	Adjust
	Contacts dirty or fouled with silicone oil	Scrape contacts carefully or replace
	Float-switch jewel screws too tight	Loosen slightly
	Drive motor brushes are worn	Check/replace brushes
	Pressure water level recorder—pen pressure too heavy	Adjust pen counterweight
Apparent drop and recovery in water level—"false troughs" (may be confused with legitimate diurnal fluctuations)	Intermittent leaks—usually caused by temperature changes	Close valve to sensor, disconnect battery lead, close valve to bubble tube, allow pressure to build up and check fittings with leak detector
Erratic bubble rate	Metal particles or oil in needle valve assembly of Conoflow regulator	Increase feed pressure, observe if bubble rate increases; replace Conoflow or dismantle carefully and clean
	Particles caught in needle valve tip	See if any particles are in the bottom of the sight-feed glass; replace Conoflow or dismantle carefully and clean
Drive motor labours	Low battery	Check/replace
	Motor gear train damage	Disengage motor and operate; replace if it does not sound normal
	Friction in instrument drive train	Disengage motor and operate the instrument drive train by hand, check for binding

Part 2. Concluded

Symptom	Possible cause	Action
Instrument at maximum full-scale reading	Orifice completely blocked by silt or orifice frozen	Install new line
No mercury in servomanometer float-switch reservoir, pressure side too full	Fitting in bottom of float-switch reservoir not screwed in far enough to retain a mercury droplet or contact screw in float not adjusted correctly	Check and adjust
Servomanometer mercury blown out, pressure reservoir at top limit switch	Intermittent blockage of orifice, usually by ice	Replace mercury, lower feed pressure
Servomanometer operates in one direction only	Failure in servocontrol unit	Check using test switch; replace if necessary

the recorder which in turn is actuated by the water level sensor. The pen carriage is driven by an endless chain and is equipped with a reversal mechanism that automatically changes the direction of travel of the pen when the assembly reaches either margin of the paper. Thus this reversal mechanism enables the pen to continue producing a record when the pen reaches the paper margin during a rising or falling stage.

The paper is advanced in the recorder by the chart drive mechanism which is regulated by a clock which in turn may be powered by electricity, a drop weight or negator (constant torque) spring. Use of the negator spring is preferable, as it is not dependent on commercial power supplies that may fail during storms or floods, nor is it dependent on the availability of deep wells as is the drop weight drive.

The Type A recorder now being produced is the A-71, although there are over 1200 of the earlier A-35 instruments in service in Canada. The A-71 is readily identifiable because of its removable, rather than hinged, cover. The A-71 also has Teflon bearings that improve its performance.

The gauge height ratio and time scales commonly used are 1:5 (1 mm on the chart equals 5 mm of water level change) and a time scale of 2.5 mm/hr, respectively. (In yard-pound units, the gauge height ratio is 1:6 and the chart speed 0.1 in./hr). A height ratio of 1:10 (1:12) may be used at some lake stations, and a ratio of 1:1 (10:12) used at some small streams that have weirs. Faster time scales are employed in some special cases, for example, in recording seiche effects or tidal fluctuations.

If the recorder is operating in severe temperatures, the clock should be lubricated with a special lubricant (Moebius Syntalube Arctic) and non-freeze ink should be used in the pen. This will enable functioning in temperatures as low as -50°C.

Installation — Installation of a Type A recorder requires the following steps:

1) Take the instrument from its shipping carton, cut and remove all twine and packing. The float, float pulley, float lines, ink and oil are packed separately.
2) Drill holes in the recorder shelf and shelter floor through which the float line (and clock weight line, if used) can pass. The recorder manufacturer provides a template for locating the correct hole positions.
3) Position the recorder on the shelf, level it using the adjustable legs, and screw the legs to the shelf so that the recorder cannot move.
4) Install the float pulley by removing the hex nut on the front of the standard, unscrewing the retaining clamp and removing the washer. The float pulley (or sprocket if the recorder will be actuated by a pressure sensor) is placed on the shaft so that the flat side is to the recorder, the washer replaced, then the retaining clamp screwed on and the hex nut tightened securely.
5) Pass the beaded cable through the holes in the shelf and floor, then attach the end hook for the float.

Normally the float is on the left side of the pulley standard. It is useful to label the holes in the shelf "float" and "counterweight." If beaded cable is used as a float line one bead should be positioned so that it bears on the end hook clamp; this will ensure that no slippage takes place.

6) Lower the float to the water surface, place the float line over the pulley, and determine the correct length of line before attaching the counterweight. Any excess cable may be rolled up at the float and tied securely. The length of line should be such that the counterweight will not touch the bottom of the well until the float is at its maximum possible height. The float and counterweight should pass each other and neither should touch any obstructions in the well. To achieve this, it may be necessary to install guide sheaves. As an example, guide sheaves must be used when a 250-mm (10-in.) float is installed on a recorder having a scale ratio of 1:5, the usual metric scale.
7) Fill the recorder pen reservoir carefully using the eyedropper provided. Do not fill completely as ink expands in hot weather. Ink splashed on the rails on which the pen carriage travels may cause sticking; ink falling on the carriage itself may foul the reversal mechanism or the idler wheels on which the carriage rides. If the pen will not ink immediately, cover the small breather hole with a finger and "pump" on the fill hole with another finger. If this does not work, blow carefully on the fill hole until a small drop of ink appears at the end of the pen. The bore of the pen may be cleaned using the fine wire provided for this purpose.
8) Check that the pen reversal mechanism is operating properly by rotating the float pulley. Adjust the pen position using the knurled nut on the pen holder so that the reversal points fall on the margins of the paper. Read the inside gauge and set the pen so that it is in direct drive, that is, a rising stage will move the pen to the right. When the pen is set correctly, the float pulley is clamped to the shaft by turning the two knurled nuts on the clamp in opposite directions simultaneously. It is useful to write the gauge reading of each margin of the paper on the metal writing table and to set the left margin of the paper at an exact metre or foot reading.
9) Start the recorder clock by removing the dust cover in the recorder case and screwing the crank handle into the end of the winding shaft and winding. Note that the crank is wound clockwise for weight drive clocks and counterclockwise for negator spring drives. For weight drive recorders, guide the weight cable onto the drum so that it does not overlap. The weight should be wound up to the floor of the gauge house so that the suspension spring does not stick in the hole in the floor. In the case of negator spring drives, the crank must be pushed in to engage the winding mechanism and the spring wound until the warning mark on the spring appears. If the spring is wound to its entire extent it will not operate. **After winding the negator spring clock, ensure that the pawl is disengaged from the ratchet.** The winding shaft should be pushed out by a spring so that the pawl rides on the second and uncut ratchet. **Never attempt to wind a negator spring when the clock has been removed.** An electric clock is started simply by plugging it into a supply of 115 V, 60 Hz.
10) In the case of weight-driven recorders, normally used only in deeper wells, remove the clock and unwind enough cable to pass through the hole in the floor. Reinstall the clock carefully to ensure that the wide flange of the rear clock hold-down nut depresses the locking level, then attach the weight to the clock cable using the spring provided between the cable and the weight.
11) To set the time, remove the tension on the paper take-up roller by pulling and rotating the knurled disc at the right side of the recorder away from the recorder. Roll the chart to a time just short of the correct setting, push the disc back in, and roll the chart to the correct time setting, thus taking up the tension in the paper.
12) Rotate the float pulley enough to make an identifiable mark, for example, 10 mm in length. Draw a line from the pen trace to a position over the small metal writing table under the chart and make the following notations on the chart:
    station name (do not use ambiguous abbreviations),
    date, (if all numeric dates are used follow ISO Standard, e.g., 1975-08-24),
    inside gauge reading,
    outside gauge reading,
    pen setting,
    time of the readings,
    whether pen is plotting direct or reverse, and
    name or initials of person making the inspection.

Maintenance — The recorder should be serviced on each visit to the gauging station and the chart removed at intervals of four to six weeks. Service the recorder immediately on arriving at a site, then inspect it again before leaving to ensure that the instrument is operating and that no mistakes were made. The steps in servicing follow:

1) Inspect the recorder installation to determine if any malfunction or damage has occurred. If the recorder clock has stopped, roll the chart forward before doing anything else. The vertical line at the end of the trace

will show the range in stage during the stoppage.

2) Read the manual gauges and annotate the chart as described in step 12 in the previous section on "Installation." Observe the left side of the take-up roll to see if any "coning" of the paper has taken place. Do not reset the pen or advance the chart unless the record will be reduced manually.
3) Flush the intake system by closing the appropriate valve(s) and by filling the flush tank using water from the well. Observe the change in water level and the recovery rate when the valve(s) are re-opened. If the water level in the well is slow to recover more flushing may be required or repairs to the intake may be necessary. The frequency of flushing depends on the site. The intakes to a silty stream may need flushing on every visit, whereas those on other streams may require annual or even less frequent flushing.
4) Check the performance of any accessories in use, such as the reversal indicator, event marker, rain gauge or thermograph.
5) If the chart is to be removed, remove tension from the paper take-up roller by pulling and rotating the knurled disc at the right side of the recorder. Roll the chart forward so that there is about 100 mm of blank chart paper between the end of the record and the closest edge of the metal writing table. Cut off the chart paper at the front of the writing table. This should be done using a pencil point or similar blunt object, as knife marks on the painted metal writing table soon rust and may cause the chart to stick.
6) Remove the chart from the take-up roller by unwinding it while the take-up roller is still in its receptacle. Unwinding has two advantages over the sliding-twist method of removing the chart. It prevents binding of the chart on the take-up roller and allows the field officer to inspect the entire record obtained since the chart was last removed. Defects in the record, such as a sticking float or pressure system malfunctions, are thus apparent and corrective action may be taken before leaving the site.
7) Determine if a sufficient supply of chart paper remains for use until the next planned visit to the station, plus a good safety margin for exigencies. Each small division (2 mm or 0.1 in.) between the warning line and the edge of the chart indicates a one-day supply at the conventional chart speed.
8) If it is necessary to install a new chart roll, remove the writing table and lift out the supply roll. Remove the knurled washernut from the end opposite the flange and remove the old core. Put the new chart on the supply cylinder with the flush end against the flange, tighten the washernut so that the roll cannot slip and put the supply roll in its bearings, flange to the left. Make a right-angle crease in the paper about 20 mm from the end and feed the end of the paper underneath the drive roller so that it will pass between the drive roller and the friction rollers.
9) Attach the end of the chart to the take-up roller using the spring clamp and roll some chart paper onto the take-up roller, making sure that the paper is tracking squarely by holding it taut.
10) Check that the reversal mechanism is operating and that the margins are correct.
11) If the clock has gained or lost more than two hours a month since the last time the chart was removed, it should be adjusted. Unscrew the cover and move the adjusting indicator toward F to make the clock run faster and toward S to make it slower. If a record of these adjustments is kept in the gauge house, clock malfunctions may be detected and corrected.
12) On arriving at the gauge house if the recorder clock has stopped, it is best to replace it and have the clock checked by a clock repairer. **Make sure that the pawl on a negator spring recorder is engaged before removing the clock.** It may be necessary to wind the spring slightly to engage the drive holes of the new clock. This should be done by holding the clock near its correct position and turning the spring take-up spool carefully by hand until the clock engages. **Do not use the crank.** When replacing the clock of a weight-driven recorder, remove the clock weight so that if the locking lever is accidentally pressed, the clock weight cable will not unwind. Remember to re-attach the weight.
13) Fill the recorder pen as required, lubricate the recorder annually using the oil provided, and clean the pen using the cleaning wire provided. If the ink in the pen dries out, a liquid cleaner such as Iosol can be used to clean it. Note that some solvents, such as alcohol, will dissolve the acrylic plastic reservoir.
14) Read the inside and outside gauges, set the pen correctly and make the required notations on the chart as described in step 12 on page 15.
15) Check the position of the pawl on a negator spring clock, close the dust cover at the crank hole, and close the recorder lid before leaving the shelter.

Pressure-Actuated Systems

As stated previously, pressure-actuated water level sensors are generally used where construction and operation of a stilling well would be costly and difficult. This would apply to streams having high banks, rocky banks or a channel that is subject to scour or deposition of bed material. Also, it is easier to operate a pressure system rather than a float system in areas that are subject to severe freezing conditions.

Gas Purge Technique

The method generally used to transmit pressure from a fixed point in the streambed to a sensor is the gas purge technique. The advantages of this technique over use of pressure transducers installed in the stream are that the need to place relatively expensive components in the stream is eliminated and the flow of gas in the purge system has a cleaning effect on the orifice and may prevent silt from plugging the orifice.

Appendix B contains a more detailed discussion of the gas purge system. The system consists of a gas supply, a pressure-reducing valve, a gas flow control valve with visual indicator, a length of tubing, an orifice in the water, and a pressure take-off to the pressure sensor.

Gas is usually obtained from a cylinder of compressed nitrogen having a capacity of 6.8 m^3 (240 ft^3) or 3.4 m^3 (120 ft^3). As the purge system is frequently operated under freezing conditions, the nitrogen must be either oil-pumped or water-pumped and labelled "extra-dry" or "super-dry." Under normal conditions, a large cylinder of nitrogen is sufficient for many years of operation.

Pressure reduction is provided by a single stage cylinder regulator which has a pressure gauge that reads up to 28 000 kPa (4000 psi) and a feed pressure gauge that reads up to 400 kPa (60 psi). The regulator must have a female counterclockwise thread to match the thread on the cylinder valve. A satisfactory cylinder regulator is usually provided by the supplier of the pressure sensor.

A Conoflow DH21-1086 constant-differential pressure regulator (Fig. 13) is used to control and to indicate the gas flow visually. A pressure drop of 20 kPa (3 psi) is maintained across a needle valve by means of a diaphragm acting on a soft-seated plug. This constant pressure differential ensures that the gas flow does not vary with stage. A visual indication of gas flow is provided by means of a glass sight-feed containing oil. The viscosity of the oil in the sight-feed must remain almost constant despite temperature variations so that a constant volume of gas is maintained in each bubble. Silicone oil, such as Dow-Corning 200, with a viscosity of 500 m^2/s at 25°C is normally used.

The gas is fed to the orifice through black polyethylene tubing with an inside diameter of 3 mm (0.125 in.) and an outside diameter of 9.5 mm (0.375 in.). Black polyethylene is not affected by ultraviolet light or by chemicals in soil and thus can be buried without protection. In those cases where the tubing would be subject to damage by ice, debris, rodents or vandals, it should be encased in conduit; where severe scour is expected, it should be used in place of the core cable in manufacturing a wire rope.

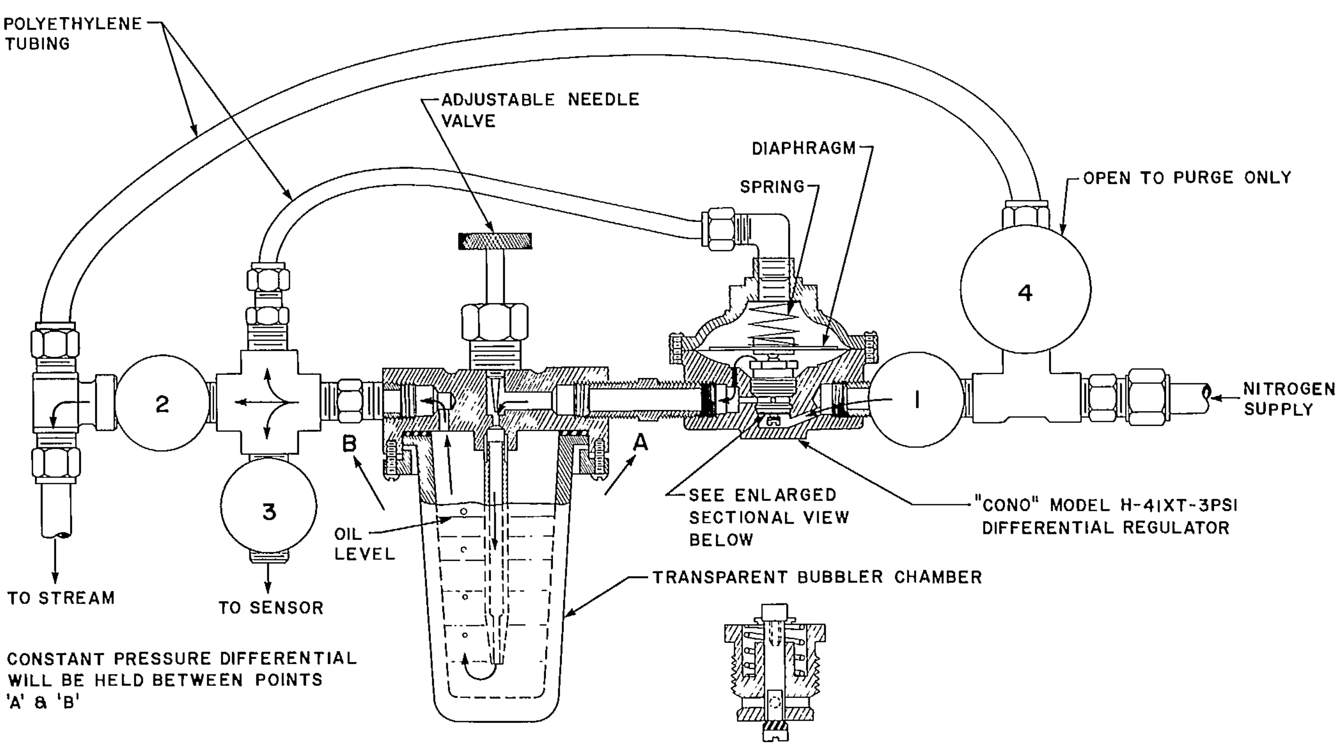


Figure 13. Details of Conoflow differential pressure regulator.

The bubble tubing may terminate at either of two basic types of orifice. One type (Fig. 14) is made from pipe fittings and is anchored to a concrete block that is placed on the streambed. The other uses a standard well point that is buried in a sand or gravel bubble in the streambed (Fig. 15) or attached to a weight and placed on the streambed. The well point should be used in the following cases: where there is a high stream velocity past the orifice; where there is a danger of the standard orifice becoming frozen into the winter ice cover; or where streams are silt-laden. There is a risk in using buried orifices that silt deposits over the orifice will cause the recorded water level to lag behind the true water level.

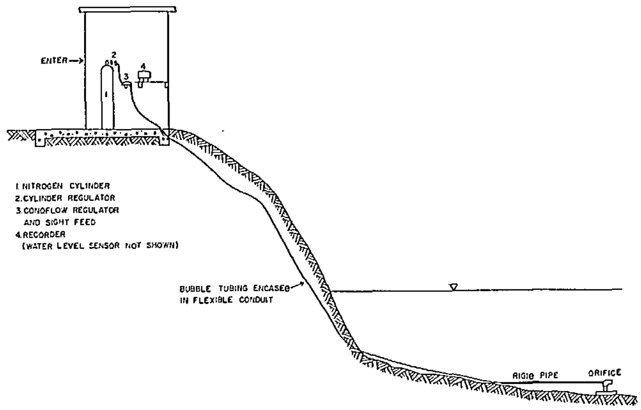


Figure 14. Typical gas purge system installation.

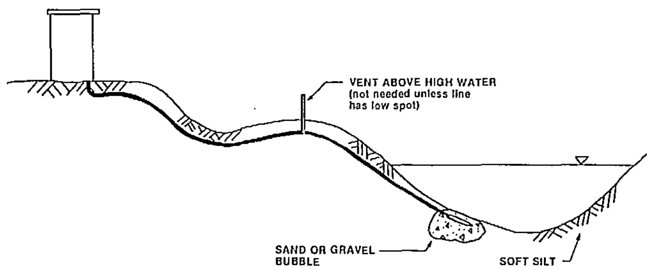


Figure 15. Well point orifice.

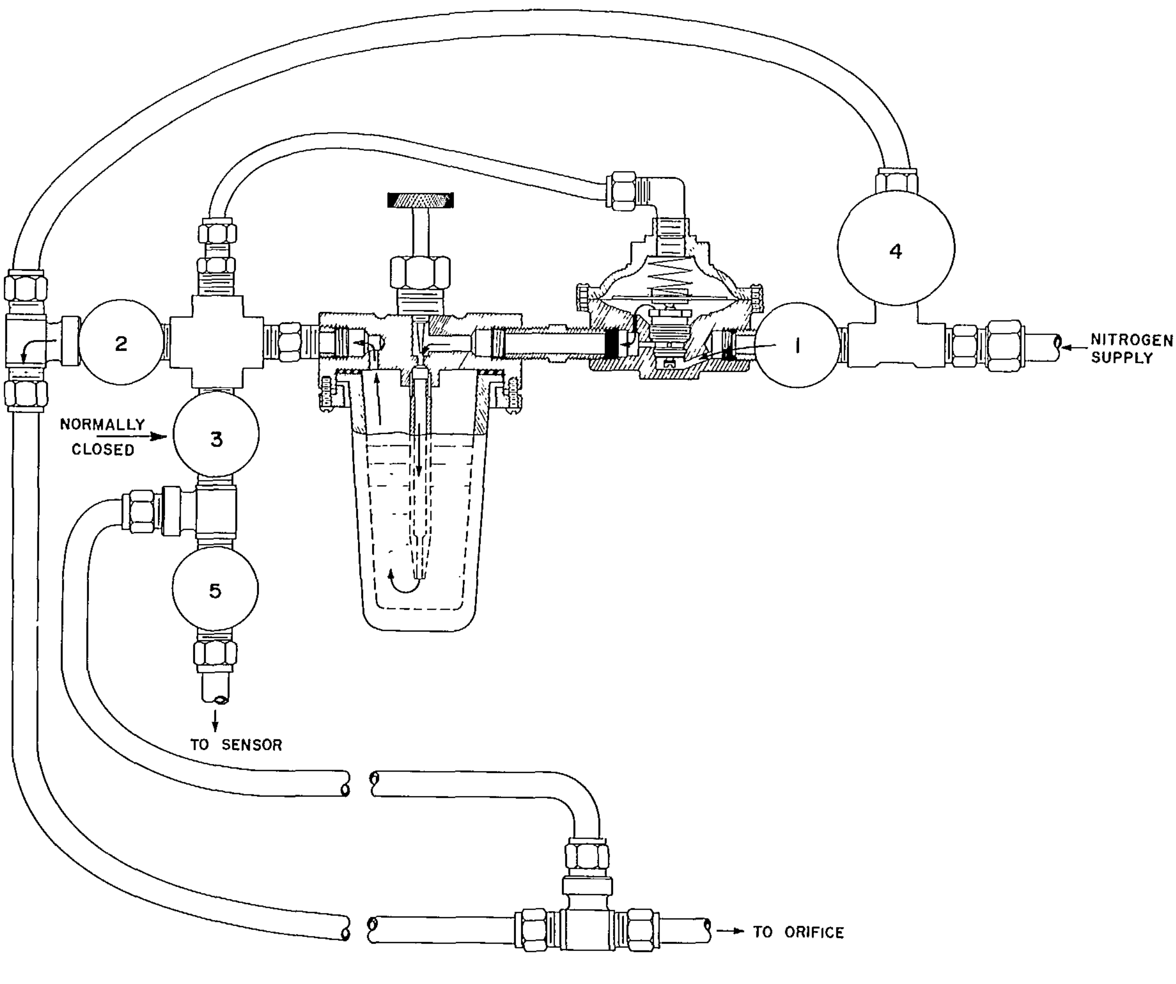


Figure 16. Gas purge system (dual line).

Such lags can be detected easily only when the stage is changing.

Installation — If a gas purge system is to be installed at a new location, a calculation should be made to determine whether a single length of bubble tubing would provide sufficient accuracy. Variations in the bubble rate caused by a malfunction in the Conoflow regulator or by heating of exposed tubing by sunlight result in variations in the friction of the gas as it flows through the tubing. These variations in friction cause errors in water level that may be significant for long lengths of tubing. The error may be overcome through the use of dual tubing. One line is used to feed gas to the orifice, and the other line, joined near the orifice with a T-connector, is used as a static return line to the instrument. Figure 16 shows a typical dual-line system.

Figure 17 may be used to provide a conservative check on the requirement for dual tubing. In Figure 17, it is assumed that the maximum permissible error is 0.002 m and that the variation in bubble rate may be 100%. To

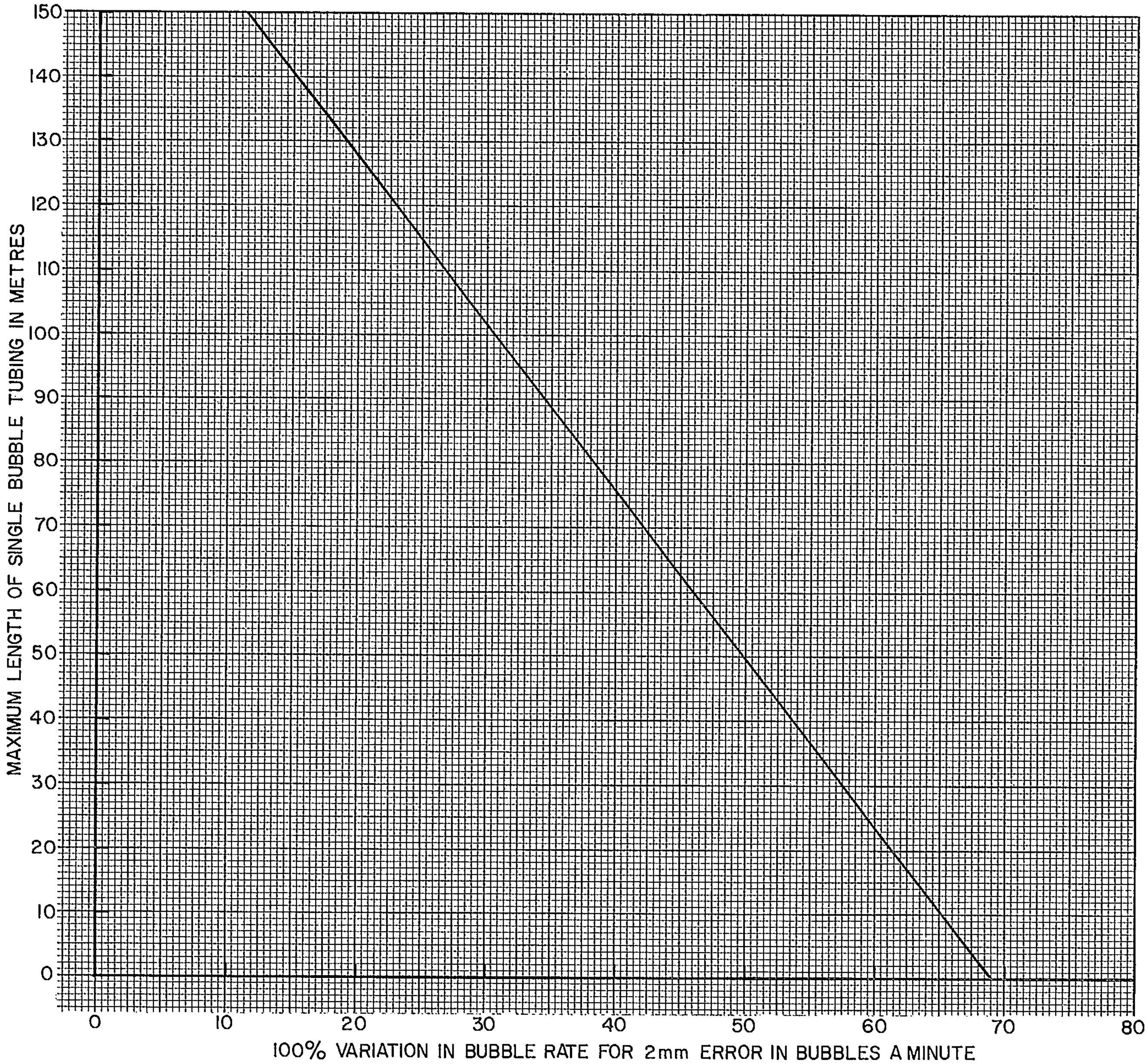


Figure 17. Graph for calculating maximum length of single gas purge line.

compute the maximum length of single tubing, enter Figure 17 with the value that represents the 100% variation in bubble rate and read the maximum length of tubing. For example, if 40 bubbles a minute is taken as the 100% variation in bubble rate, then the maximum length of single tubing can be 75 m.

The requirement for dual tubing may be checked at an existing installation by doubling the bubble rate and observing the water stage recorder pen to see if any movement occurs.

The steps followed in the installation of bubble tubing are:

1) Push the bubble tubing through the protective conduit (if used) and connect the conduit segments. This is no problem for conduit lengths of 30 m if the conduit is fairly straight; longer lengths require use of a fish wire to pull the tubing through the conduit.
2) Connect the tubing at the orifice end, ensuring that the tubing does not become twisted. This can be accomplished in the case of the standard orifice by leaving the bulkhead connector at the cap loose until all other connections are tightened. A typical orifice assembly is shown in Figure 18.

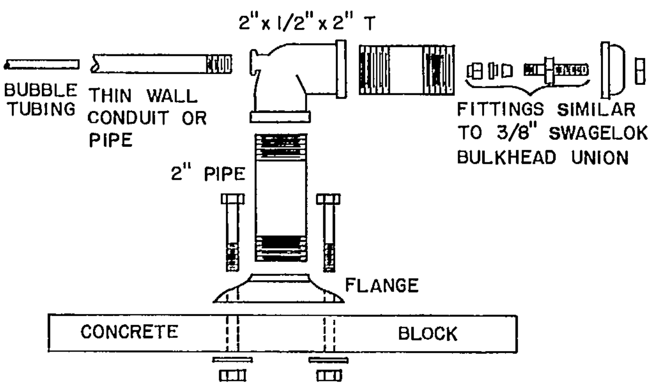


Figure 18. Conventional orifice assembly.

3) If dual tubing is used make connections at the T-connector. This connection must not leak and therefore should be made with Swagelok fittings.

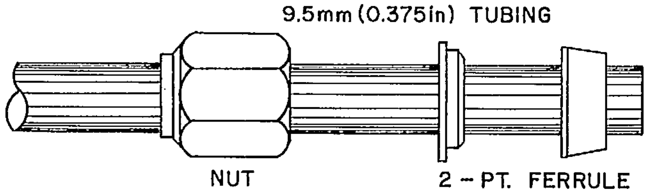


Figure 19. Assembly of Swagelok fittings.

Assemble the fittings as shown in Figure 19, wrap a short length of Teflon plumbers' tape clockwise (CW) around the male portion of the fitting, tighten the nut to the point where the tubing will not turn by hand in the fitting, then tighten 1.25 turns with a wrench.

4) Attach the cylinder regulator to the nitrogen cylinder by first "cracking" the cylinder valve to blow out any dust from the valve opening, then wrapping the male portion of the connector with Teflon tape in the direction that a nut would be turned on [counter-clockwise (CCW) in this case] and tightening the regulator connection nut. **Before removing its protective cap, secure the nitrogen cylinder to the wall of the shelter with a chain so that it cannot be toppled over.** Never attempt to move a cylinder without first removing attached regulators and replacing the protective cap.
5) Attach the Conoflow regulator to the wall or shelf of the gauge house near the nitrogen cylinder and connect it to the tank using a short length of polyethylene tubing and Swagelok fittings. (The Conoflow regulator may also be attached directly to the cylinder regulator as a means of eliminating sources of leaks.) Remove the brass plug in the top of the sight-feed and pour in silicone oil until the reservoir is one-half to two-thirds full. Replace the plug after wrapping the thread with Teflon tape.
6) Connect the line(s) from the orifice to the Conoflow regulator using Swagelok fittings. Leave enough slack in the line(s) to avoid placing the connection in tension where the tubing contracts with decreased temperatures.
7) Before starting the flow of gas in the system adjust all valves as follows:

Valve	Position	Rotation
Feed pressure adjustment	closed	fully CCW
Feed rate adjustment needle valve	closed	fully CW
Instrument shut-off valve	closed	fully CW
Orifice line shut-off valve	open	fully CCW

All valves in a gas purge system, except for the needle valve, seat only when fully open or fully closed. If the feed pressure valve is open when the cylinder valve is opened, the cylinder regulator valve seat may be damaged.

8) Start the gas flow by opening the cylinder valve fully counterclockwise. Adjust the feed pressure adjustment valve until the correct feed pressure is attained.

Minimum values for various instrument ranges are listed in the following table:

Range	Feed pressure
0-3.0 m (10 ft)	51 kPa (7.3 psi)
0-6.1 m (20 ft)	81 kPa (11.7 psi)
0-10.7 m (35 ft)	126 kPa (18.2 psi)
0-12.2 m (40 ft)	141 kPa (20.3 psi)
0-15.2 m (50 ft)	171 kPa (21.7 psi)

Adjust the needle valve on the Conoflow regulator counterclockwise until the appropriate bubble rate in bubbles per minute is reached. The required rate may be computed using the graph in Figure 20. Estimate the maximum rate of rise that would occur at the gauging station in metres per hour, then enter the graph and extract the value for bubbles a minute per metre of tubing. Multiply this value by the length of single tubing to obtain the bubble rate. For example, if the maximum rate of rise is expected to be 2 m/hr and the length of tubing is 100 m, then the required bubble rate is 88 bubbles per minute. The bubble rate obtained in this manner should be reduced by a factor of $\frac{10}{H+10}$, where H is the head on the orifice in

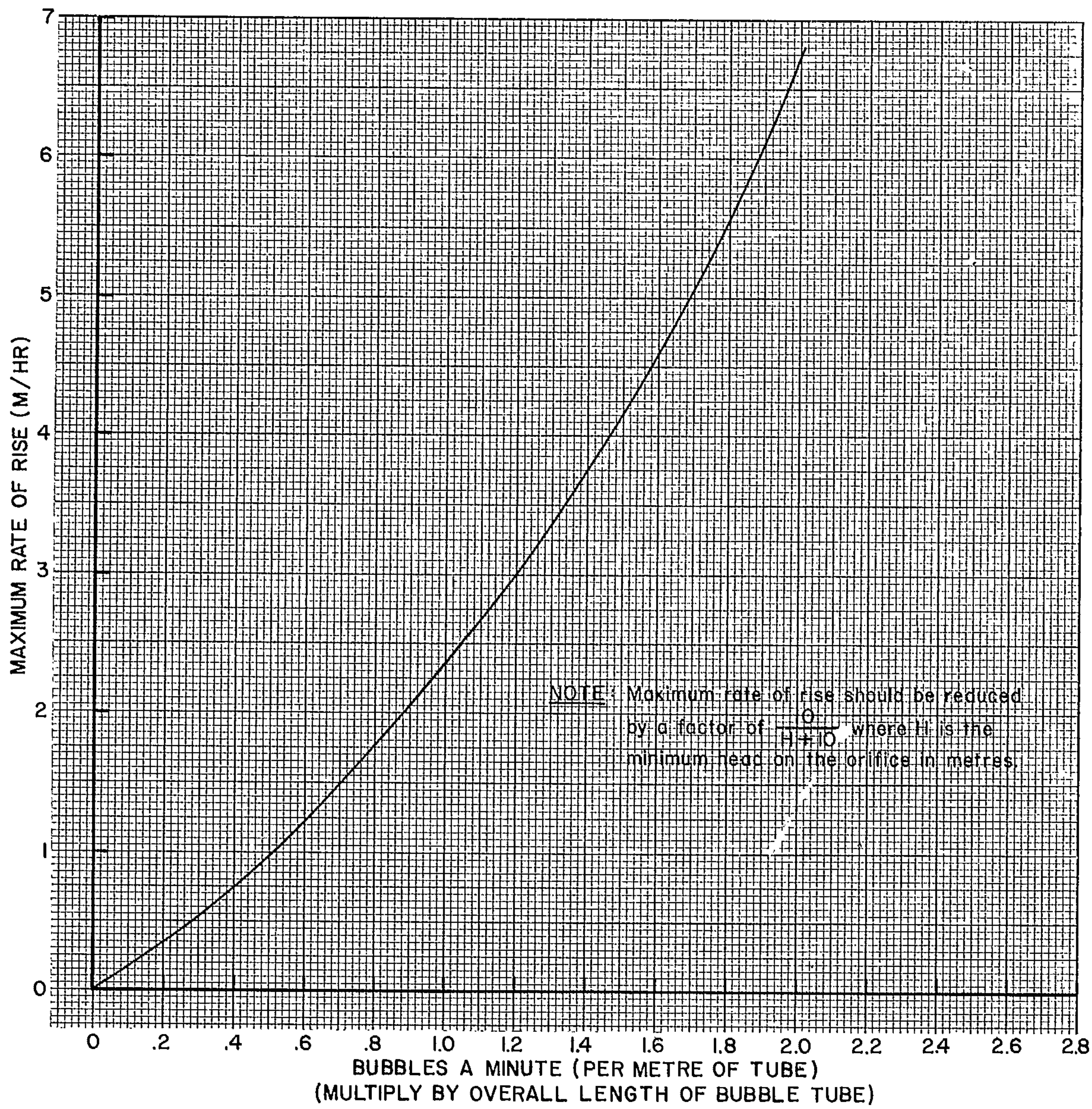


Figure 20. Graph for calculating bubble feed rate.

GAS PURGE SYSTEM SITE LOG

STATION ______________________________ ORIFICE ELEVATION __________ m

DATE	LOCAL STAN. TIME	GAUGE READINGS (M)			AIR TEMP. (°C)	CYLINDER RDGS. IN		GAS IN CYLINDER (m^3)	GAS CONSUMPTION (m^3)	BUBBLE RATE (/MIN)	CALC. CONSUMPTION (m^3)	ADJ. CALC. CONSUMPTION (m^3)	REMARKS
		COUNTER	PEN	REFERENCE		FEED	CYLINDER						

Figure 21. Sample log sheet for gas purge system.

metres. It should be noted that bubble rates lower than ten bubbles per minute are seldom effective.

9) Place the orifice in very shallow water and observe the gas bubbles leaving the orifice. The bubble rate at the orifice should be about half that in the sight-feed. Move the orifice to a position out in the river that is on a line perpendicular to the current at the point where the staff gauge is installed or direct water levels obtained. If a wire weight gauge is to be used as on outside gauge, the orifice should be as close to the gauge as possible, or at least on a line perpendicular to the current from the gauge location to shore.
10) The bubble tubing must be buried so that there is a continuous negative slope to the orifice, i.e., downhill all the way. This is essential for operation of a well point orifice and, in the case of a standard orifice, will result in improved records.
11) Check the fittings with a leak detector, such as "Real Cool Snoop" or "Leak-Tec," to ensure that no leaks occurred after the system was pressurized.

Maintenance — Gas purge systems require very little maintenance other than replacement of the nitrogen cylinder. One problem that may occur is leaking of fittings due to temperature changes. The fittings should be checked for leaks on each visit to the gauging station. Some possible sources of leaks can be removed by soft-soldering all pipe connections. Good results are obtained if 50/50 solder with Duzall flux (made by the Chemtron Division of Allstate Alloys and Fluxes) is used. Quick Connects have been successfully used as a means of eliminating valves in the purge system.

Intermittent gas leaks may be detected by maintaining a site log of the gas purge system performance such as that illustrated in Figure 21. The log is kept in the gauge house and completed using the charts shown in Figures 22 and 23. The information needed for a site log entry follows:

1) date and time of the visit,
2) gauge readings including sensor counter (if used), recorder pen, and reading of the reference gauge,
3) air temperature in recorder shelter,
4) feed pressure and cylinder pressure from cylinder regulator,
5) volume of gas in cylinder from Figure 22, using cylinder pressure and temperature,
6) actual gas consumption by subtracting gas volume on previous visits from the new value computed,
7) bubble flow rate obtained by observing rate at sight feed. (This value should remain constant—large variations are a sign of problems with the Conoflow regulator.)
8) calculated gas consumption obtained from Figure 23, using the mean bubble rate between visits and the days elapsed from last visit. The calculated gas consumption should be similar to the actual gas consumption. If the actual gas consumption is significantly higher, this is an indication of leaks in the system. As the quantity of gas used increases with head, the value obtained from Figure 23 should be multiplied by $\frac{H+10}{10}$ to obtain a more precise value of the consumption.

Recorders actuated by sensors having a gas purge system sometimes exhibit false surges, or "painting," traced by the pen. If the painting is very uniform it may be caused by water or oil that has collected at a low spot in the gas purge line or, perhaps, by high velocities past the orifice. Sometimes the problem may be eliminated by increasing the bubble rate slightly. Failing this, the line should be purged by disconnecting the bubble tube from the Conoflow regulator, connecting it to the cylinder regulator, and purging at a feed pressure of up to 400 kPa (60 psi). The pressure should be increased to this value very gently, as a too rapid change in pressure may damage the regulator diaphragm. To remove oil from the tubing, a solvent such as white gas must be purged through the lines. This is done using a chamber made of standard pipe fittings (Fig. 24). The chamber is filled with white gas, then closed, connected to the nitrogen cylinder regulator, and the line purged as before. [Ensure that the solvent (in type and quantity) is not a significant pollutant for the size of stream involved.] At some troublesome locations, permanent flushing facilities may be installed as illustrated in Figure 13. It is also possible that the orifice may have to be raised and reinstalled, ensuring that low spots are eliminated.

Usually the velocity past an orifice must be in excess of 1.5 m/s before painting is produced. This can be checked by a current meter reading of the velocity at the river bottom near the orifice. When painting occurs, it may be eliminated by installing a well point orifice or by screwing a 90° elbow onto the conventional orifice fitting so that the opening points downstream.

When a problem in the Conoflow regulator is evident, it is usually advisable to replace the regulator. (Syphon the oil out of the faulty regulator.) The problem usually is caused by oil that has been forced into the diaphragm chamber or by graphite packing that has dropped into the bottom of the needle valve. Both the diaphragm chamber and the needle valve can be dismantled and cleaned in the field, if necessary, to put the system back in operation.

The six steps to be followed in replacing a nitrogen cylinder are on page 26.

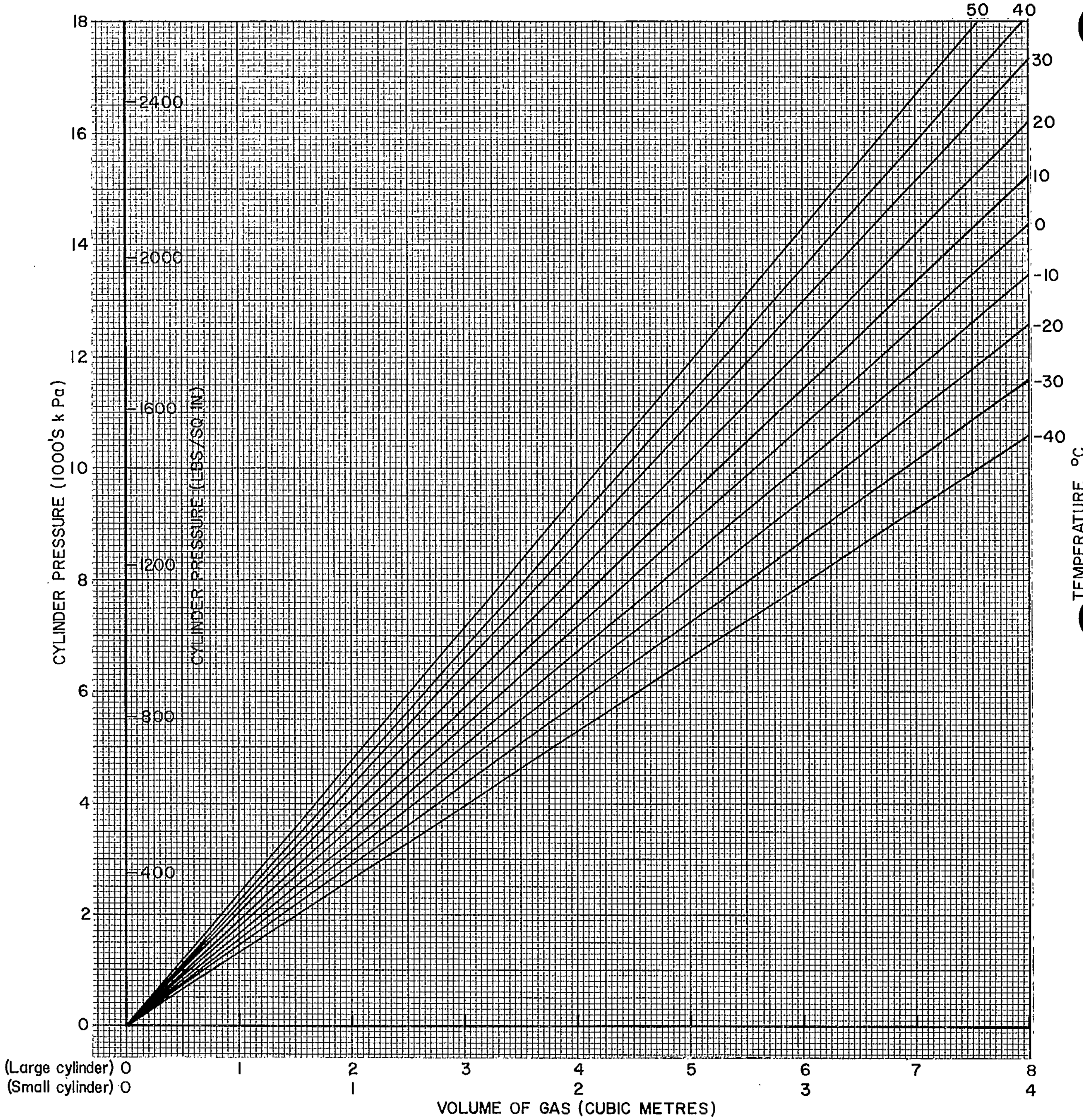


Figure 22. Graph for calculating approximate volume of gas remaining in cylinder.

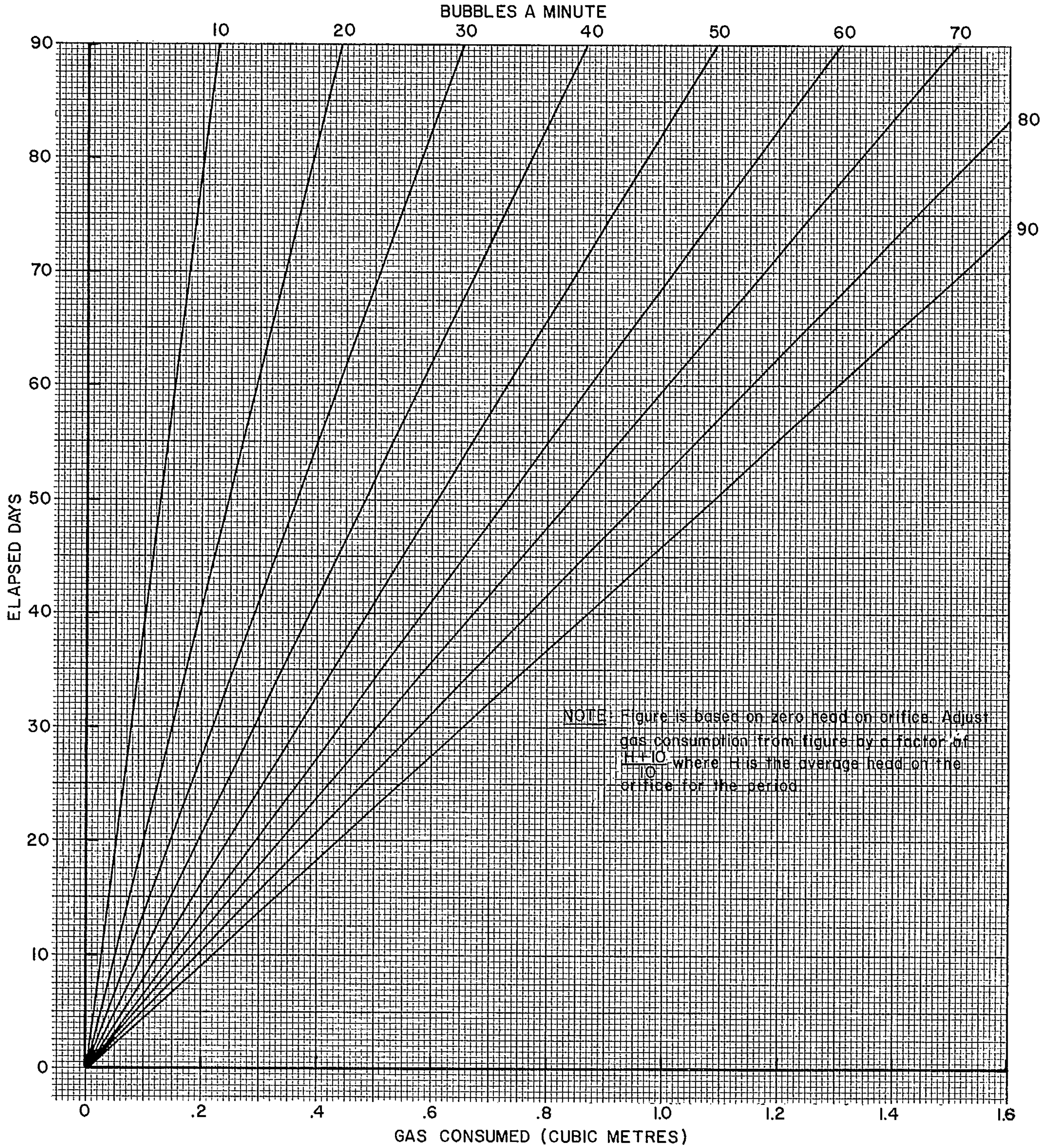


Figure 23. Graph for calculating approximate volume of gas consumed.

1) close the feed pressure adjustment screw (fully CCW),
2) close the valve to the sensor (fully CW),
3) close the bubble tube valve (fully CW),
4) close the cylinder valve (fully CW),
5) remove the pressure regulator and install a new cylinder as discussed under new installations on page 20, and
6) open the valves in the reverse order that they were shut off and check for leaks.

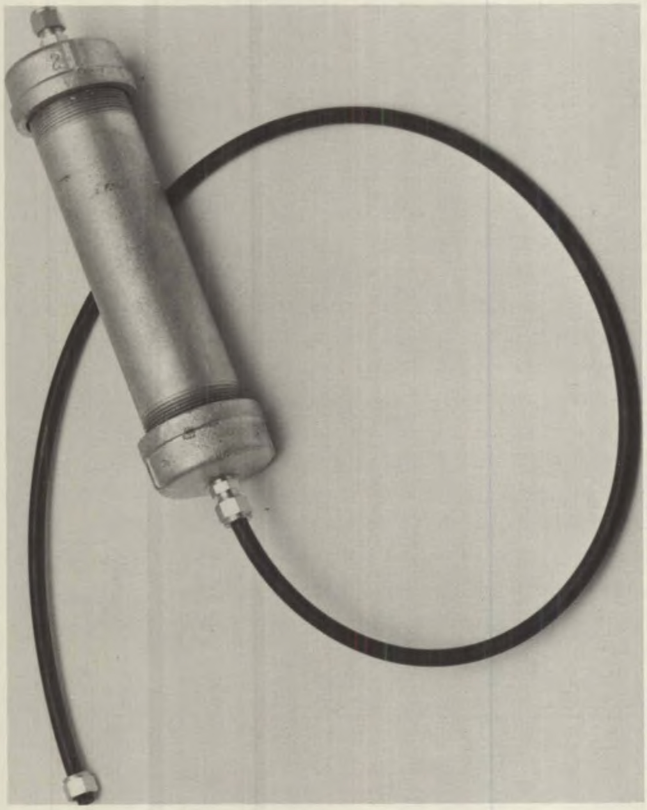


Figure 24. Flushing chamber.

Water Stage Servomanometer

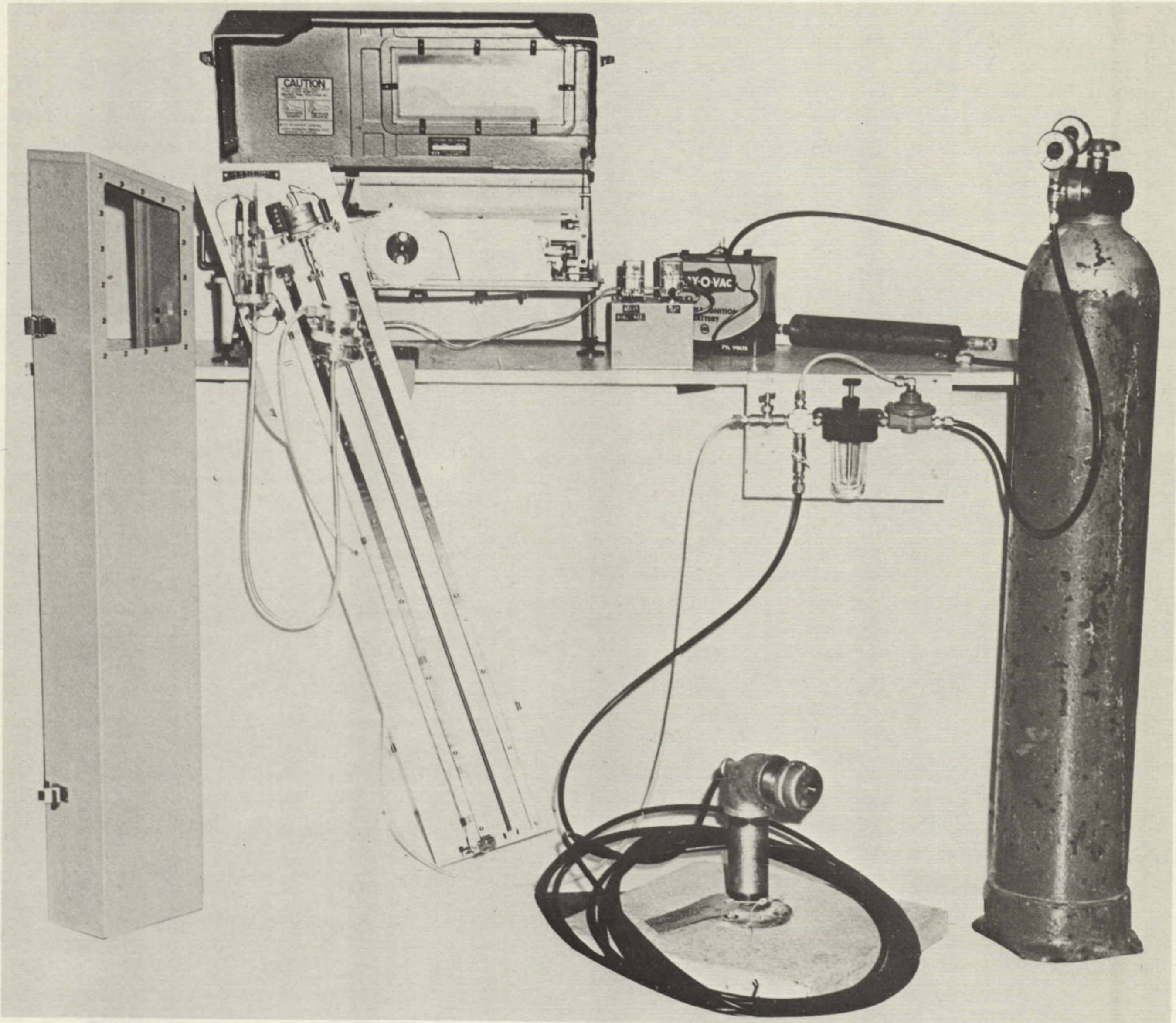
The water stage servomanometer converts the pressure in a gas purge system to a shaft rotation by means of a servo-controlled differential mercury manometer. The servomanometer is illustrated in Figure 25 and in a schematic diagram in Figure 26. The pressure in the gas purge system is exerted on mercury in a pressure reservoir where it displaces an equivalent head of mercury. This causes a change in level of mercury in a float-switch reservoir that is open to atmospheric pressure. The reservoir contains a stainless steel float, having an armature on jewelled pivots that may touch one of two contacts. This activates a reversible electric motor which raises or lowers the pressure reservoir until the difference in mercury levels corresponds to the new water level.

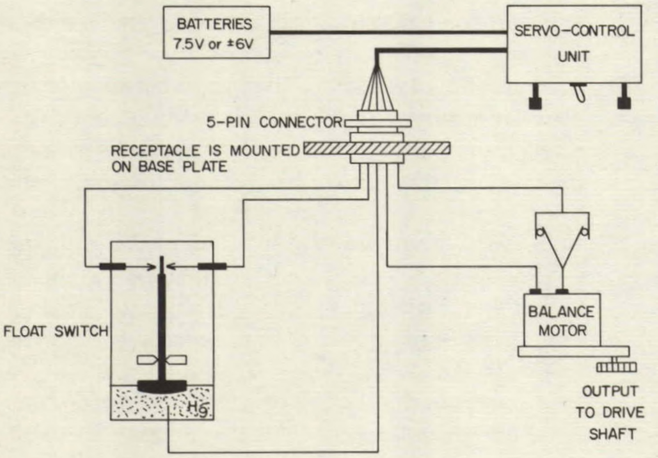
As the pressure reservoir is positioned, an output shaft that can be coupled to a water stage recorder is rotated. At the same time, the shaft of a counter is rotated to provide a direct reading of stage. The output shaft of the servomanometer makes one revolution for each 450-mm (1.5-ft) change in stage. Coupling to the Type A recorder produces a record having a scale ratio of 1:5 (1:6 in yard-pound units). Use of a double-size sprocket on the Type A recorder produces a record having a scale ratio of 1:10 (1:12 in yard-pound units). The output shaft of the servomanometer can also be equipped with multiple sprockets for driving more than one recorder or telemetering device.

The servomanometer is inclined to the vertical at about 18°. This enables the user to eliminate any errors that are linearly proportional to stage by adjusting the angle. A change in water level in the river causes a vertical change of mercury level in the manometer. As the angle of the shaft to the vertical is increased, the number of turns of the shaft required to move the compensating reservoir a given vertical distance is also increased. Since the shaft also moves the recorder pen, the greater the angle, the greater the motion of the pen. Errors as large as 5% can be eliminated by adjusting the angle. The angle must be reduced to about 12° when the servomanometer is used for recording stage in seawater.

The instrument is equipped with limit switches that disable the drive mechanism when the pressure reservoir reaches its upper or lower extent of travel. The switches disable the system in one direction only so that the instrument automatically resumes operation when normal pressure is restored.

The float-switch assembly is designed so that it is extremely sensitive to water level changes. Due to this design, the pressure exerted on the switch contacts is too light for them to conduct enough current to operate the servomanometer drive motor. Therefore a servocontrol unit is used to provide the necessary current amplification. The servocontrol has a delay circuit that is used to dampen short duration pressure fluctuations such as those caused by wave action. This delay circuit can be bypassed and manual controls used to drive the servomanometer to make inspection marks on a recorder chart or to perform system checks. Several different servocontrol units have been manufactured.





↑ **Figure 25. Water stage servomanometer.**

← **Figure 26. Servomanometer.**

Most of the servomanometers in use in Canada are of the original United States Geological Survey (USGS) design. In 1972, however, a new USGS design became available and was adopted for Water Survey of Canada use. This instrument is designated the Stacom servomanometer and has several improvements entailing:

1) a modified pressure reservoir transport system that includes an easy-to-use pressure chamber transport system,
2) a servomanometer angle adjustment based on temperature,
3) a sealed float-switch reservoir complete with mercury overflow reservoir (contact spacing can be adjusted externally),
4) a built-in capability for attachment of several accessory devices, and
5) a mercury transfer tube, 50 mm (3/16 in.) in diameter, which is standard. This helps to reduce the tendency of the instrument to "hunt."

Installation — Experience has shown that these instruments should be bench-checked prior to installation. The servomanometer is installed in a standard walk-in gauge house having a shelf height of at least 0.8 m for a 10.5-m range unit and a height of 1.1 m for a 15-m range unit.

Remove the instrument from its packing crate and bolt it securely to the shelf, swinging the bottom of the servomanometer until the bubble in the level vial is centred. In the case of a Stacom unit, suspend a plumb bob on the pin on the top left corner of the back plate, fold out the temperature scale at the bottom, then swing the bottom of the unit until the plumb line corresponds to the ambient temperature in the shelter. If the servomanometer is positioned so that the Type A recorder is on the extreme left of the shelf (leaving sufficient room to install the winding crank) and the servomanometer a little left of centre, enough space will remain free for future installation of telemetering or other equipment. Connect the recorder to the servomanometer using the sprockets and chain provided.

Install the gas purge system in accordance with the instructions on page 19.

To prevent damage to the bearings in the float-switch assembly, the servomanometer is always shipped with the armature and float removed. To install the float, proceed as follows:

1) Remove any silicon oil from hands and avoid touching the armature or contacts, as silicon forms a non-conducting chemical bond on platinum.
2) Pull off the electric connectors to the stack and remove the cap.
3) Remove the screws in the float-switch stack and remove the stack.
4) Remove the protective tubing from the armature, then place the armature in the stack so that the wire contact is between the two contacts at the top of the stack.
5) Hold the float so that the armature pivot shaft is between the jewels, then screw in the jewels until the armature is centred on the stack, and tighten them until only very slight lateral movement of the armature is possible. A dab of nail polish could be placed on the adjusting screws to prevent them from working loose. Note that these jewelled bearings are the single most fragile item in the servomanometer and should be treated carefully at all times to prevent damage to their surfaces. When the instrument is subject to temperature extremes, it may be necessary to adjust the jewelled bearings to achieve best performance.
6) Replace the stack loosely and adjust the contact screw in the float so that it touches the small pool of mercury that would be held in the reservoir by the stainless steel bottom fitting, but does not touch the bottom of the reservoir itself.
7) Adjust the two contacts at the top of the stack so that they are parallel with a gap of about 1 mm between them. Note that the line of travel of the armature is not perpendicular to the contacts. This allows a sliding contact and thus reduces corrosion build-up on the contacts.

Add mercury to the system in the following way:

1) Ensure that the pressure reservoir is at its highest point of travel — normally instruments are shipped from the factory this way. The Stacom servomanometers have a manual adjustment knob that can be used to move the pressure reservoir if the motor drive is disengaged by loosening a screw. The pressure reservoir on other servomanometers can be adjusted manually by removing the screws holding the pressure reservoir in place, taking the reservoir off, rotating the brass block along the threaded shaft until the required position is reached, and then replacing the reservoir.
2) Hold the mercury-transfer tube about 0.3 m below the float-switch reservoir and lift the tube so that it is higher than the reservoir.
3) Pour about three quarters of the mercury supplied, i.e., 0.35 kg, into the reservoir.
4) Lower the mercury-transfer tube slowly and allow mercury to flow through it into the pressure reservoir.

Tap the tube gently to dislodge any air bubbles, as they cause inaccuracies in the stage record.

5) Replace the float-switch stack and tighten it down.
6) Adjust the float-switch reservoir and the pressure reservoir so that they are both level.

Place the servocontrol unit at a convenient location on the shelf and connect the battery leads being careful to observe polarity. Connect the five-pin connector to the receptacle at the back of the servomanometer. Switch the servocontrol to minimum delay and note that almost immediately the servomanometer will "hunt" until the mercury surfaces in both reservoirs are at the same level. At this time the mercury in the pressure reservoir should be about 5 mm deep. Add or remove mercury until this condition is achieved. (Mercury can be withdrawn by removing the pressure reservoir and pouring the mercury out of the pressure tube fitting.) The volume of mercury in the system is a factor in the overall accuracy.

Ensure that the sensor shut-off valve on the Conoflow regulator is closed, then pass one end of the length of the Tygon tubing supplied through the servomanometer backplate, and connect it to the pressure reservoir using the stainless steel insert and Swagelok fitting provided. The other end of the tubing should be connected to the Conoflow regulator using an insert and Swagelok fitting. (The stainless steel inserts prevent the soft tubing from collapsing under pressure or from blowing out of the fitting.)

Note the reading on the counter, then "crack" the sensor shut-off valve, thus pressurizing the pressure chamber. The pressure reservoir should start to move downward to compensate for the increased pressure in the system. Once the pressure reservoir has stopped moving downward, fully open the sensor shut-off valve and allow the system to stabilize. The difference between the counter reading at this time and the counter reading recorded previously should equal the head of water over the orifice.

As the reservoir is moving down, observe that system polarity is correct by checking that the bottom limit switch, if depressed manually, will stop the motor and that pressing the top limit switch has no effect. Leads can be reversed at various locations to correct polarity as indicated in the following table.

Check that the time delay circuit is operative by using the manual control to drive the servomanometer in one direction, then switch to maximum delay. After a period of about one minute, the motor should start and drive the system back to the correct setting. It is wise to check the delay circuit in the other direction as well.

Leads	Effect
Reversed at drive motor	Changes direction of motor rotation
Reversed at float switch	Changes direction of motor rotation; transposes controlling action of limit switches
Reversed at drive motor and float switch	Transposes controlling action of limit switches

Set the counter to the outside reference gauge reading and set the recorder to the counter. At the time of subsequent visits to the station, any discrepancy between the pen and the counter is treated as "pen correction" and any discrepancy between the counter and the outside reference gauge is considered a "gauge correction."

The servomanometer does not operate at temperatures lower than -39°C, that is, the freezing point of mercury. Where these temperatures are likely to occur, the instrument should be enclosed in an insulated compartment constructed of plywood and expanded polystyrene beadboard. This compartment can be heated using catalytic propane heaters, such as the Catadyne BX 3x4 having a capacity of 300 kJ (Fig. 27). This heater will operate for an entire winter season on one 40-kg tank of propane. **Before removing its protective cap, secure the propane cylinder to the wall of the shelter so that it cannot be overturned. Propane is a liquified gas; to avoid malfunction of the pressure relief valve, always transport full cylinders in an upright position.**

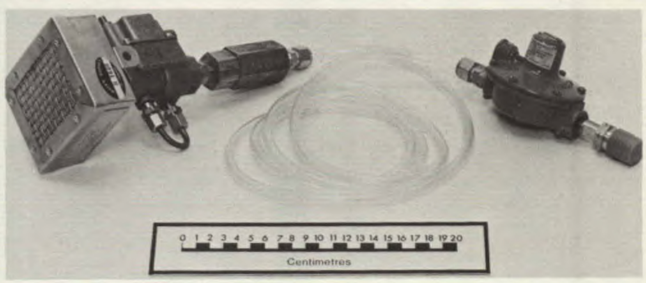


Figure 27. Catadyne BX 3 x 4 heater.

Maintenance — After several comparisons have been made between the outside water level and the servomanometer counter readings, it may be noted that the difference is proportional to stage. If this is the case, plot the difference against stage, draw the best straight line through the plotted points and compute the average difference per metre of stage. (Temperature also has an effect on the difference between the counter reading and the outside gauge reading; because the densities of nitrogen and mercury change with temperature, the temperature in the shelter at the time of observation should be noted beside each plotted point.) Figure 28 depicts a typical plot.

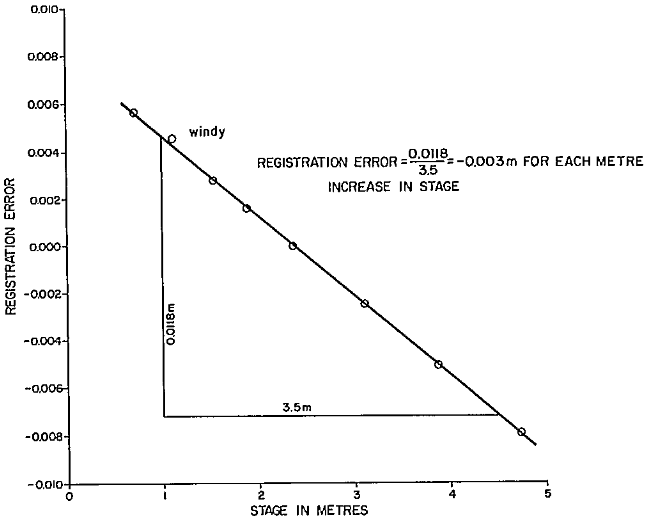


Figure 28. Servomanometer correction.

Adjust the angle of the servomanometer to compensate:

1) Loosen the float-switch level adjustment hex-head bolt and move the pointer on the float-switch support to correct for the average difference (i.e., if the counter reads too low by 6 mm per metre of stage, set the pointer to + 6). Retighten the hex-head bolt. In the case of the Stacom servomanometer, the error can be computed as a "temperature" correction in setting ambient temperature on the fold-out scale.
2) Loosen the three-eighths inch cap screw and the large nut and washer at the back of the servomanometer.
3) Adjust the angle of the instrument until the bubble in the level vial is centred once more. Retighten the cap screw and large nut and washer.
4) Loosen the hex-head bolt, re-level the pressure reservoir and tighten the bolt.
5) Reset the counter to agree with the outside gauge and reset the recorder pen.

The servomanometer requires very little routine maintenance once it has successfully been placed in operation. On each visit, any dust accumulations should be removed and, usually once yearly, the batteries should be replaced. It is best to do this in the fall so that maximum power will be available for winter operation.

Occasionally it may be necessary to tighten or loosen the jewelled bearings, remove corrosion from the contacts, replace the brushes in the electric motor or service the servocontrol unit. These operational problems may be identified by examining the record produced on the recorder chart as the changes in stage may be erratic and step-like in appearance. The jewelled bearings can be tightened or loosened in the same manner as at the time of initial installations. Corrosion on the contacts can be removed by scraping them gently with a sharp knife blade or by lightly sanding them with a fine abrasive material, such as the striking surface from a package of paper matches.

The brushes in the small electric motor are replaced by removing the cap from the top of the motor and inserting new brushes. The brushes in the Barber-Coleman motor used in some Stacom units cannot be replaced. The motor may also suffer gear train damage; in this case, the motor must be replaced. Gear train damage can be detected by an uneven sound when the motor is disengaged and operated without load.

Failure in the servocontrol unit may be caused by a delay circuit failure or the failure of the unit to drive the servomanometer in one direction. Sometimes the problem can be solved in the field by opening the unit and checking for corrosion on any contacts; more often it is necessary to replace the unit and have repairs made at a depot. Part 2 of Table I describes operating problems that could occur and lists possible causes and corrective action.

Pressure Water Level Recorder

The pressure water level recorder (Fig. 29) converts the pressure in a gas purge system to a pen movement through use of a pressure bellows and mechanical linkages. The pressure assembly is designed as an attachment to the Stevens Type A recorder and is normally supplied attached to a recorder as a complete unit. As the pen movement is curvilinear in nature, a special "curved-line" recorder chart must be used. Standard gauge ratios supplied are approximately 1:12 and 1:24. The ratio of 1:24 is also supplied on a unit having one reversal so that larger ranges in stage can be handled. The ratio of 1:12 does not have a reversal. The pressure assembly is equipped with a micrometer screw for adjusting the pen setting.

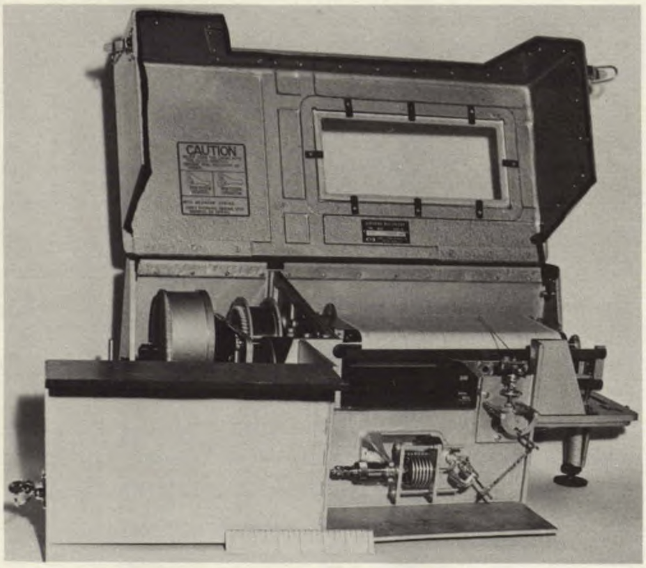


Figure 29. Pressure water level recorder.

Installation — The pressure water level recorder should be installed in a standard walk-in shelter. Installations in more confined spaces, however, can be improvised.

Take the Type A recorder with pressure assembly attached from its shipping container and remove all packing. Install a roll of curved line chart paper. Install the gas purge system as discussed on page 19, but keep the sensor shut-off valve closed.

Unpack the pen and fill the ink reservoir with non-freeze ink. (The standard Stevens ink will clog the pen.) Never fill the ink reservoir with the pen in place, as any ink spilled will foul the pen linkages. The flow of ink through the pen can be initiated by holding a finger over the fill hole and flicking the pen several times.

Place the pen in its saddle and adjust the pen counterweight so that the pen will bounce several times when the tip is released from a point 20 mm or 30 mm above the chart. Check the reversal of the pen at the right margin (on those units having a reversal) by turning the micrometer adjustment. If the pen does not reverse at the margin, adjust the reversal point using the adjusting screw immediately below the pen mount.

Using the micrometer adjustment, move the pen back to the left margin. Push the free end of the Tygon tubing through the hole in the bottom of the Type A recorder and connect it to the Conoflow regulator using a stainless steel insert and Swagelok fitting. Open the sensor shut-off valve and observe the reading indicated by the pen. This reading should be equal to the depth of the orifice below the water surface.

Use the micrometer screw to adjust the pen to the outside gauge reading. Check the fittings at both ends of the Tygon tubing with a leak detector, and complete the gas purge system log sheet before leaving the site.

Maintenance — The pressure water level recorder requires very little maintenance other than routine maintenance of the gas purge system and the recorder.

When inspecting the instrument, use the micrometer to make an inspection line on the chart, and then make the appropriate notations on the chart as discussed on page 15. Should it be necessary to remove the pen from its saddle, place it on the recorder shelf with the tip hanging over the edge to prevent tip damage. The pen should be cleaned annually using the pen cleaner wires supplied with the recorder. If ink dries out in the pen, it can be removed by soaking the pen in a pen cleaning solvent.

A log of differences between the water level and the pen reading should be maintained as for the servomanometer. Since the pressure water level recorder does not have a counter reference, the amount of paper correction in any discrepancy must be estimated by observing if any "coning" on the paper take-up roll has occurred. The error can be measured using a scale, or estimated. The paper correction is then subtracted algebraically from the total discrepancy. For example, if the outside water level is 3.956, the pen reading is 3.954, and if the apparent paper correction is 0.004, then a value of 3.956 - (3.954 + 0.004) = -0.002 should be plotted against elevation 3.956 on the correction curve. The temperature in the gauge house should also be noted so that temperature effects, if any, can be determined. Part 2 of Table I describes operating problems which could occur and lists possible causes and corrective action.

Other Recording Gauges

There are many other water level sensors and recorders available, although none is widely used in Canada. Some of these systems are discussed in the following section.

Servo-Beam-Balance

The servo-beam-balance principle is illustrated in Figure 30. Pressure in a gas purge system is applied to a bellows, and this pressure is balanced by the movement of a weight along the beam. The movement is servo-controlled and the drive system geared to provide an output shaft rotation and a counter reading. The servo-beam-balance system uses a null balance system that tends to eliminate errors caused by imperfections in the pressure bellows.

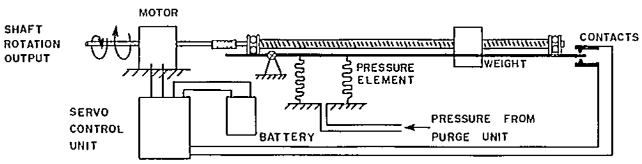


Figure 30. Servo-beam-balance principle.

Accuracy of the system is dependent mainly on the quality of manufacture. The knife edge on which the beam balances must be constructed precisely, the electrical contacts designed for maximum sensitivity and backlash in the gear train minimized. Some instruments do not have an electrical delay circuit; this deficiency can cause unnecessary painting on the recorder chart.

Servo-beam-balance systems are manufactured by Ott of West Germany, Sherlock Pty. of Australia, and Exactel Instruments of the United States.

Pressure Transducers with Analog Voltage Output

There are many differential pressure transducers available which produce an analog voltage that can be related to stage. The sensing element may use pressure sensitive semiconductors, strain gauges, diaphragms, etc. In all cases the accuracy of these transducers is a percentage of the full-scale output. This means that when water level fluctuations are small, satisfactory results may be obtained. Generally the accuracy of a pressure transducer and its associated recorder is not better than 0.5% full scale.

Other Transducers with Electrical Output

Transducers that relate water level to the resistance, capacitance, impedance or other property of an element which extends through the entire range in stage have also been developed. The output from these transducers may be either an analog voltage or a frequency-modulated signal. The main use of such instruments has been in recording wave height as the transducer responds virtually instantaneously to changes in water level. The instruments are expensive and do not operate under ice conditions.

Surface Followers

These systems consist of a plumb bob suspended from a power reel. The wire to the bob is wrapped around the float pulley of a recorder, and as the bob "hunts" for the water surface, a record of stage is produced. Circuitry for signal conditioning is usually incorporated in the system to prevent painting.

Surface followers are frequently used for groundwater applications where long stilling wells (small in diameter) are necessary. One such device is manufactured by Johnson-Keck of the United States.

Other Analog Recorders

There are many instruments designed to record water levels in analog form. These recorders all have certain elements, such as a clock-controlled chart drive system, a shaft input for water stage, and usually a pen reversal mechanism. Major differences are in length of unattended operation, types of clocks and low temperature performance. Manufacturers other than Leupold & Stevens are Ott[4] of West Germany, Neyrpic of France, and Rittmeyer of Switzerland.

Digital Recorders

Digital recorders (Fig. 31) convert angular shaft positions into coded digital data and periodically record the data as a pattern of punched holes in a paper tape. Typically water level data are punched at 15-minute intervals, thus giving a total of 96 readings a day. The punch cycle can be adjusted to punch a water level at intervals ranging from every five minutes to hourly.

A digital recorder (frequently called an ADR, Analog-to-Digital-Recorder) usually has three main components, namely, an encoding assembly, a punch assembly and a programmer. The encoding assembly consists of an input shaft geared to encoding drums or discs. The ADR will encode values ranging from 0000 to 9999; the appropriate gearing must be provided to meet the user's requirements for precision of recording, for example, 1-mm resolution. Data are usually encoded in binary coded decimal (BCD) format, that is, each channel on the tape is assigned a value of 8, 4, 2 or 1, depending on its position. These numbers can be combined to produce decimal digits. Figure 32 is an example of a BCD tape from a 16-channel recorder. Most encoding systems provide a method of visual indication of the reading that would be punched if the punch mechanism was actuated.

[4]Used at some tide gauging stations. For further information, refer to the *Hydrographic Tidal Manual*, 1970, prepared by Tides, Currents, and Water Levels, Ottawa.

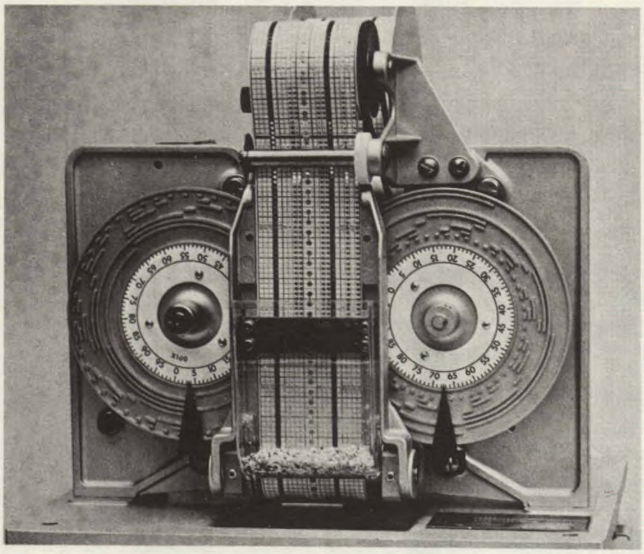


Figure 31. Digital recorder (Courtesy of United States Geological Survey).

The ADR punch assembly consists of a tape advance, a punching head, and a motor and cam assembly. On command from the programmer, a punch cycle commences, and a series of pins in the punching head is pressed against the encoding mechanism. Translator alignment holes and tape drive holes are punched at the same time. Some instruments advance the paper tape after a punch cycle so that the most recently punched readings can be examined. During the punch cycle the encoding mechanism is locked up. Therefore, a method of protecting the encoding mechanism if the water level changes during the punch cycle should be provided.

The programmer consists of an externally mounted electromechanical or electronic timer. The electromechanical timers use a cam and switch arrangement to initiate a punch cycle, whereas electronic timers have a crystal clock that generates the necessary contact closures to start a punch cycle.

The advantage of digital recording is that the tapes can be processed without extensive documentation or handling. The disadvantage is that when sensors malfunction (e.g., an intermittent leak in a gas purge system), it is usually necessary to prepare an analog record from the digital tape to interpret the record properly. In streamflow computations, an analog record is usually produced by computer to make backwater interpretations. It is often found advantageous at digital recorder installations to operate an analog recorder as well.

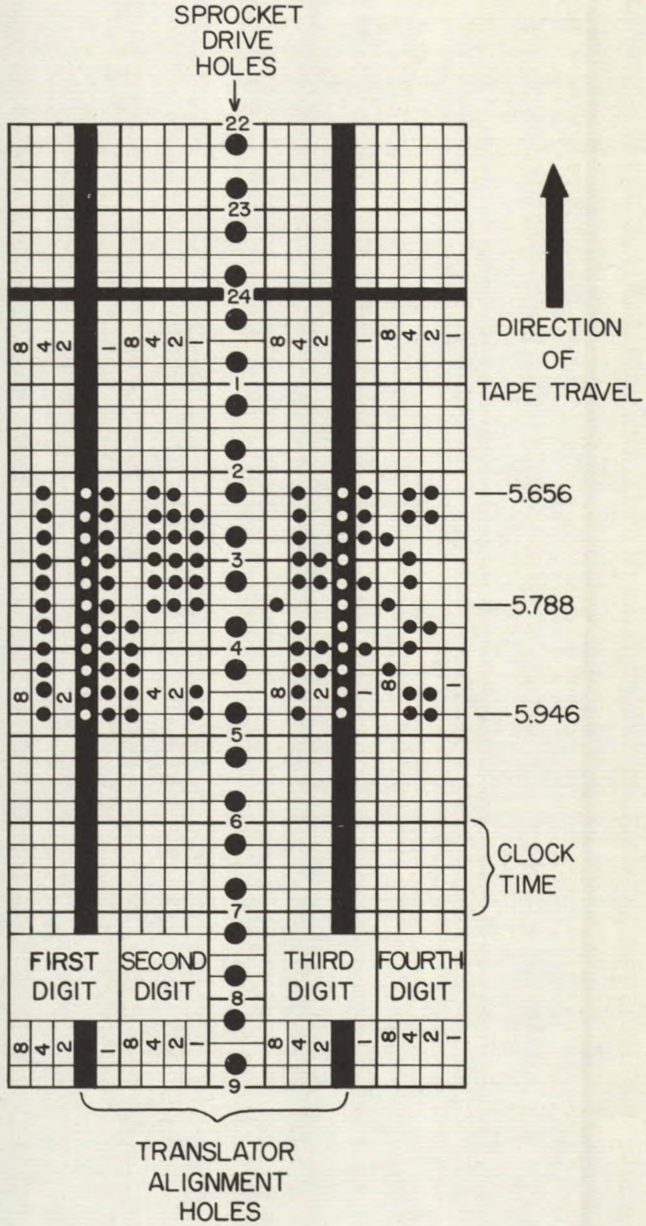


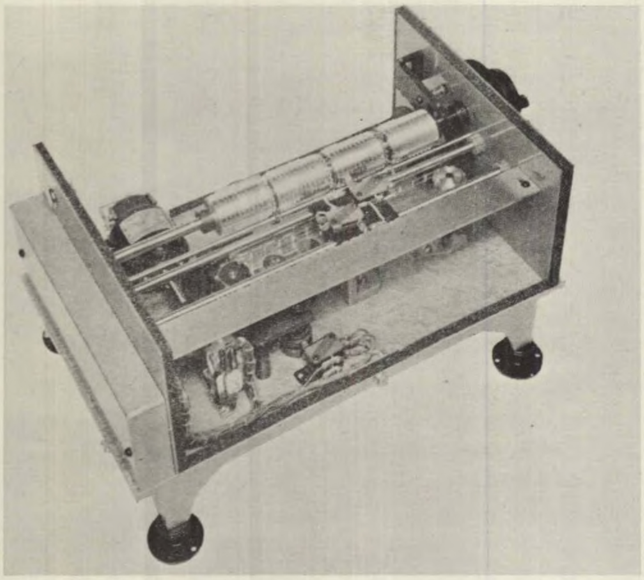
Figure 32. Sample output from digital recorder.

TELEMETERING DEVICES

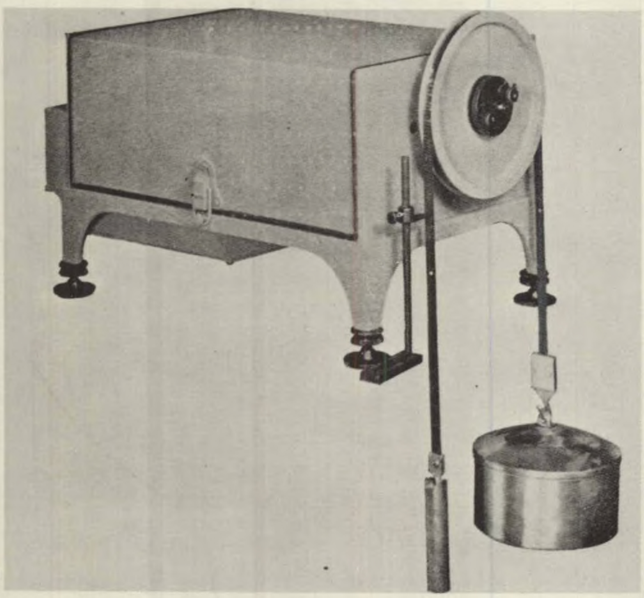
At some gauging stations there is a requirement for immediate water level data for flood or flow forecasting or for operational purposes. To meet this requirement, water level data must be encoded into digital format and transmitted to the users by means of telephone, radio or satellite systems. Two types of encoding systems, Stevens Telemark or Memomark, are frequently used.

Telemark

The Telemark (Fig. 33) consists essentially of two interdependent elements: 1) a positioning element and 2) a signalling element.



a



b

Figure 33. a) Stevens Telemark with coding bar and switch for signalling radio station identification call letters and numerals in International Morse Code and b) float-operated Telemark (Courtesy of Leupold & Stevens Inc.).

The positioning element is a pulley that is rotated by a float operating in a stilling well or by a sprocket and chain drive from a water stage servomanometer. The pulley is connected by a gear train to a group of encoding drums — one drum for each digit. The drums are interconnected by counter gearing so that the second drum rotates one tenth of a turn for each revolution of the first; the third drum, one tenth of a turn for each revolution of the second, etc. Four drums are standard and a fifth can be supplied as an option. Each drum has ten sectors with ridges, one ridge for the first sector, two for the third, etc. The number of ridges denote the digits 1 to 9. A wider ridge denotes the 0 reading. Numerals are also stamped on the circumference of the drum so that the encoded reading can be indicated visually. Usually water levels are encoded to 10 mm or 0.01 ft, although other increments are available.

The signalling element is a switch mounted on a carriage that sweeps across the ridges of the drums for a preselected number of times. The carriage is motor-driven and operates automatically. The motor starts when the Telemark is interrogated by telephone or by radio. The carriage sweeps the drums, then returns to the start position and normally sweeps a second time to give a check reading. After the second sweep the carriage automatically returns to the carriage rest position ready for another call. As the carriage switch moves across the face of the drum, it causes pulses, corresponding to the ridges on the drums, to be transmitted. A person listening to an incoming message hears a series of groups of beeps that can be counted to obtain the gauge reading; a longer beep represents a zero. Typical message sequences are in the table on page 35. To receive significant data the user must know the location of the decimal point and the systems of units in use.

The Telemark is coupled to a standard Series 500 telephone set by use of a Code-a-Phone telephone adapter. This adapter is available from Leupold & Stevens and has been approved for use anywhere in Canada by the Trans-Canada Telephone system. For additional information on Telemark installation and maintenance, refer to the *Telemark Manual.*

Memomark II

The Memomark II (Fig. 34) is the Stevens Model 7000 digital recorder with the paper tape punch mechanism removed. The Memomark II consists of two elements: 1) an encoding assembly and 2) a mechanically latched memory.

Water levels are encoded by a drum assembly consisting of four or five interdependently rotating drums

1st Group	2nd Group	3rd Group	4th Group	Interpretation
About 5 seconds after call	Several seconds later	Several seconds later	Several seconds later	
. . .	. . . .	. .	______	3720
______	.	. .	. . . .	0124

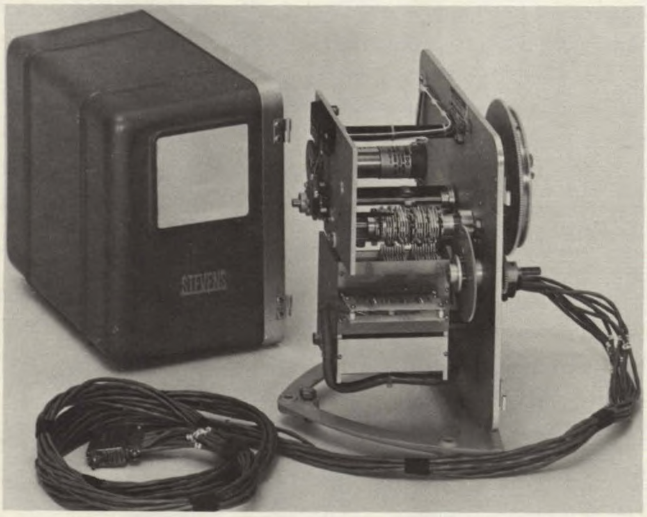


Figure 34. Memomark II.

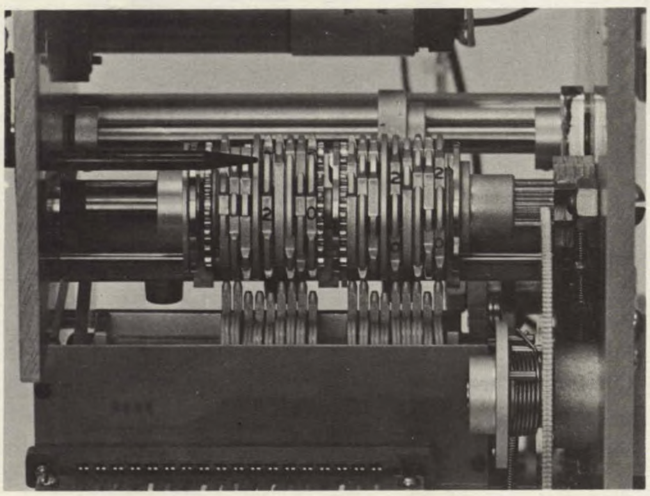


Figure 35. Memomark encoding assembly.

that are geared to the input shaft. One revolution of the input shaft is equivalent to 375 mm or 1.00 ft of stage; readings are usually encoded to 1 mm or 0.01 ft.

Each encoding drum is made from discs; the circumference of each disc is notched in a code. Each disc carries a binary code value of 8, 4, 2 or 1 so that binary coded decimal digits from 0 to 9 may be obtained. The even numbers are stamped on the drum so that a visual readout of the reading can be taken. Figure 35 shows the Memomark II encoding assembly.

During the update cycle the encoding drums are locked up. Any change in shaft position during the update is stored in a torsional spring on the input shaft. When the drums are released, the spring drives them to the correct position. Owing to this feature, it is unnecessary to inhibit the operation of a servomanometer during the update cycle.

The memory in the Memomark II consists of a set of sliding fingers with hermetically sealed reed switches attached. A multi-toothed ''comb'' type spring detents in one of two notches on each switch mount finger such that the switch is always held in one of two positions. The set of switch mount fingers is held in a frame which is moved by a pivoting arm assembly actuated by a cam driven by the update motor.

During update all fingers are first driven downward (Fig. 36). As the fingers contact the clearing bar their motion is stopped. The pivot assembly and frame continue to move until the comb spring detents in the lower notch of all fingers, thus clearing out the old reading. The motor continues to run and the pivot assembly now lifts the frame and all the switches. If the encoding drum is turned such that a lobe is facing the finger, that finger's upward progress is stopped when it contacts the drum. The pivot assembly and frame continue to move and the detent spring is pulled into the upper notch or ''1 bit'' condition.

Conversely, if the encoding drum is turned such that a notch is presented to the switch finger, the finger does not contact the drum and the detent spring stays in the lower notch or "0 bit" condition.

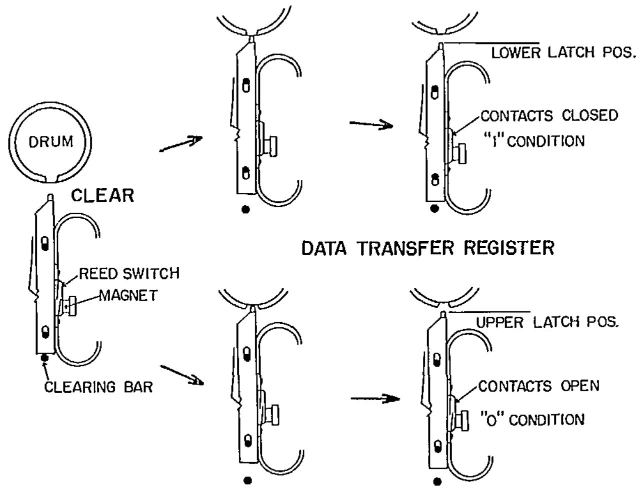


Figure 36. Memomark encoding cycle.

The update motor continues to run, moving the fingers downward away from the drums, far enough that the drums are free to turn, but not so far that the fingers touch the clearing bar. This completes the update cycle.

The switch mount frame carries a strip magnet. The magnetic field closes and holds closed any switch slid into the "1 bit" position. Switches in the "0 bit" position remain open. The combination of a mechanical detent spring and a permanent magnetic field gives a memory which will not be lost due to voltage fluctuations or induced signal noise, and one which requires no standby current.

In addition to the data switches, the Memomark has two ready-to-read switches that are positioned so that they open earlier and close later than the data switches. This ensures that the data switches are in position before the ready-to-read switches close; therefore any device reading the memory can be signalled when the memory is ready to read.

The memory can be read by a satellite Data Collection Platform and the reading retransmitted to the user or the Memomark II can be equipped with the Stevens Scanomark telemetering module and the reading transmitted as an audible message on a telephone or radio system just as the Telemark signal is transmitted.

Installation

The Memomark II is generally installed in a walk-in gauge house because of space requirements of the ancillary equipment, such as a servomanometer and recorder.

Take the unit from its shipping container and remove all packing. Place the Memomark on the instrument shelf so that the input shaft can be easily connected to a float or servomanometer as the case may be. Note that the shaft must turn counterclockwise on a rising stage for a metric unit and clockwise for a yard-pound unit Memomark. If a servomanometer input is used, the servomanometer case must be inset into the recorder shelf or an extension to the shelf constructed for the Memomark II when yard-pound units are used.

Drill holes for float lines, if required, and bolt the Memomark to the shelf, levelling it with the levelling screw. Rotate the input shaft until the present water level is indicated on the encoding drums. Do not turn the shaft too quickly as this may damage the trip-tooth gearing — five trips a second should be the maximum speed. Attach the float pulley and float line as for any other Stevens instrument and set the exact water level on the encoding drums.

If the Memomark is driven by a servomanometer, place a standard 18-tooth sprocket on the servomanometer and a 15-tooth sprocket on the Memomark. When yard-pound units are used, a 30-tooth sprocket is needed on the servomanometer and a 20-tooth sprocket, on the Memomark II. Connect the two instruments with a length of chain and set the water level to the counter reading of the servomanometer.

Connect the timer to the Memomark II if a separate external timer is used and connect the battery to the timer, observing polarity (either 7.5-V or 12-V supply may be used). Press the test button on the Memomark II to see if the unit updates. Rotate the cam on the timer manually to ensure that the unit updates. Set the cam so that the approximate time of future updates will be known and let the instrument update on its own before leaving the site.

Connect one end of the cable harness to the output connector on the back of the Memomark II and connect the other end to the transmitting device.

Maintenance

If the Memomark II is operated in a clean environment, the only maintenance required is an annual lubrication and battery changes. Using SAE 30 motor oil, or an equivalent, lubricate (one or two drops) the porous bronze shaft bearings, the index arm and micro-switch rollers and the bushing between the torsional springs hub and the

Table II. Trouble-Shooting of Contact Closure-Actuated Memomarks

Symptom	Possible cause	Corrective check
Unit will not update from external command or from test button SW1	No power or wrong polarity of dc is applied	Check connections; check voltage polarity with a voltmeter
	Update motor or connections defective	Depends on circuit (see manufacturer's diagram); manual actuation of SW2 should run the motor
	Relay K2 or SW2 contacts are bad	Disconnect power and check with ohmmeter
Updates from SW1 but not from external command	Command signal inadequate	Check clock signal with voltohmmeter or oscilloscope
	Relay K2	Coil open or contacts defective; pull relay and check with ohmmeter
	SW2 out of adjustment or defective	Check that switch actuates (clicks) both as roller goes into and out of cam notch; disconnect power and check contacts with an ohmmeter
Update motor runs more than one cycle or continuously	Dynamic braking not working or K2 relay stuck in actuated condition	Disconnect power and check resistor R2 and relay K2 with an ohmmeter
Encoding drums count in wrong direction	Float installed on wrong side of float pulley	Reverse float and float line
Encoding drums locked up or lag owing to binding	Index mechanism locking drums	Check for proper update as per above; index cam or motor maintain cam has rotated relative to the other; tighten setscrews after readjustment
	Mechanical binding of drums or input shaft	Correct interference; clean or replace bearings

input shaft. Do not lubricate the gears and ball bearings on the input shaft, since this increases the input torque. The electric motor gearing should be re-lubricated annually with Dow Corning Molykote M-8800.

The standby power drain of the Memomark II is zero. Therefore the battery life is directly proportional to the update interval used and is also dependent on the operating temperature. Low batteries become apparent as the instrument updates more slowly. The battery voltage can be checked with a voltmeter during an update cycle.

If the Memomark malfunctions, trouble-shooting can be carried out using the check list in Table II, the circuit diagram for the instrument and a voltohmmeter. If the source of the problem is isolated to the timer, this should be replaced in the field and repairs made in a shop.

Other Telemetering Devices

There are other digital telemetry systems that can operate on a clocked basis or on demand. Essentially they all consist of a water level encoding mechanism and a memory, either electromechanical or electronic. As an example, the Fischer and Porter digital recorder can be fitted with a binary-decimal transmitter for data telemetry.

Another digital system is the impulse type in which pulses transmitted along telephone wires actuate solenoids that adjust the reading displayed at a receiving site. These systems operate at distances of up to 100 km without repeater stations. The main disadvantage of such systems is that loss of power or telephone interruptions cause the receiver to get out of synchronization with the transmitter.

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APPENDIX A

FLOAT-ACTUATED WATER STAGE RECORDERS

All float-actuated devices operate on the same principle that the vertical movement of a float resting on the water surface can be used to actuate a mechanical device as the water surface rises and falls. Figure A-1 depicts a typical situation in which a float and counterweight are connected by a flexible line that passes over a pulley.[5] The terms used and their customary units are as follows:

F	=	the force required to move the recorder mechanism (N)
P	=	tension in the float line at the point of attachment to the float (N)
M_f	=	mass of the float (kg)
A	=	area of the float (m^2)
D	=	diameter of the float (m)
M_c	=	mass of the counterweight (kg)
L	=	total length of the float line (m)
l	=	length of float line on the counterweight side of the float pulley (m)
Δl	=	change in length on the counterweight side (m)
M_u	=	mass of the float line per unit length (kg/m)
ρ	=	density of the water on which the float rests (kg/m^3)
x	=	depth of immersion of the float (m)
h	=	stage in the stilling well (m)
g	=	acceleration of gravity (standard acceleration is 9.806 65 m/s^2)

When the stage in the stilling well does not change, the force of gravity on the float is balanced by the buoyant force on the float plus the tension in the float line at the point of attachment, that is,

$$M_f g = \rho g A x + P \tag{1}$$

[5] Some float-actuated systems use a tensioned spring mechanism to take up the float line rather than a counterweight. Also some systems use potentiometers rather than mechanical components to translate float movement to pen (or output shaft) movement. Nevertheless, the basic discussion in this Appendix still applies (although some specific topics do not).

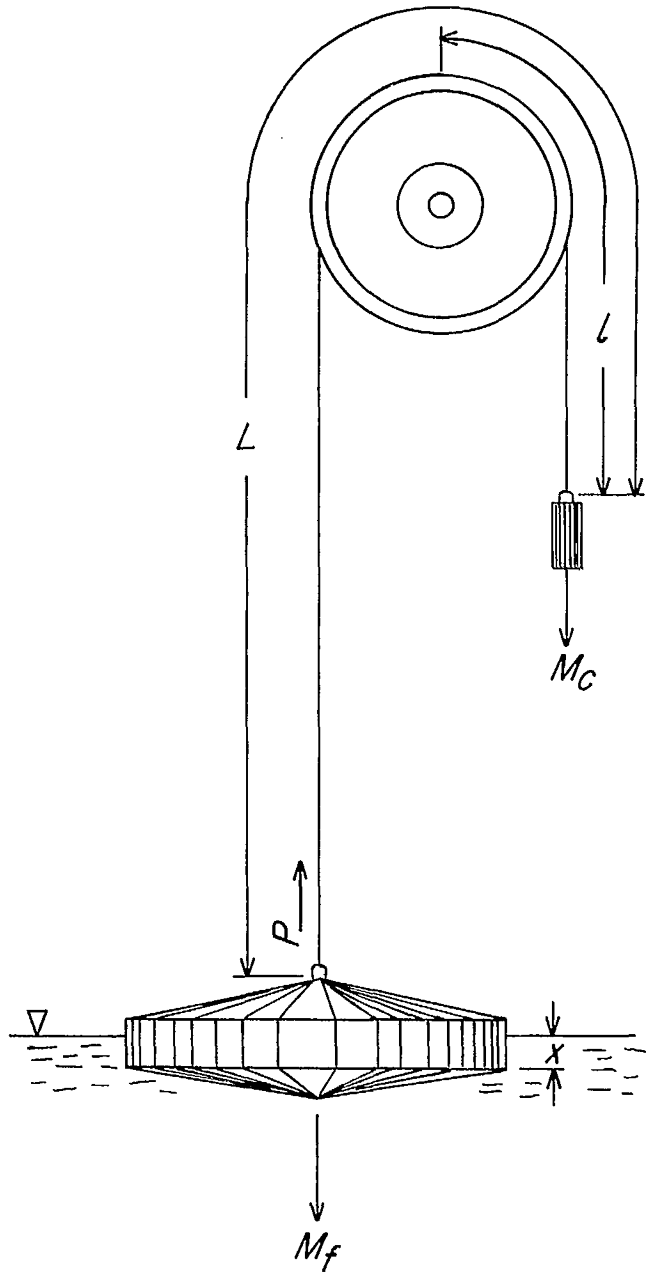

Figure A-1. Typical float system.

If the stage changes the depth of immersion of the float changes, as will the tension in the float line. This can be shown by

$$\rho g A x_1 + P_1 = \rho g A x_2 + P_2 \qquad (2)$$

substituting for A and solving for P_2-P_1

$$P_2 - P_1 = \rho g \frac{\pi D^2}{4} (x_1 - x_2) \qquad (3)$$

or

$$\Delta P = \frac{1}{4} \rho g \pi D^2 (\Delta h) \qquad (4)$$

The factors affecting the performance of a float-operated system are discussed in the following sections.

FLOAT LAG

It can be seen from equation (4) that the force available to actuate a recorder is directly proportional to the square of the float diameter. Taking Δh as 0.002 m, Δp is 0.616 N for a float 200 mm in diameter, and 0.963 N for a float 250 mm in diameter. For a worst case situation in which a 200-mm float is used to actuate a Stevens Type A recorder having a 1:5 scale ratio, the moment of force provided by the float is 36.8 mN·m. This is significantly greater than the 14.1 mN·m needed to overcome the force F, which is the friction in the pen drive mechanism.

Equation (4) can be rewritten to compute the maximum float lag caused by the force, F, that is,

$$\Delta x = \frac{4F}{\rho g \pi D^2} \qquad (5)$$

For the worst case situation with a Type A recorder, Δx (the float lag) is 0.0008 m. Float lag will result in "clipped" peak water levels and a displacement of the trace.

LINE SHIFT

If the value of P is substituted into equation (1), the equation can be generalized to

$$M_f g = \rho g A x + M_c g \pm F - M_u g (L-2l) \qquad (6)$$

where F is positive for a falling stage and negative for a rising stage. With a change in stage this equation becomes

$$M_f g = \rho g A (x + \Delta x) + M_c g \pm F - M_u g L + 2 M_u g (l + \Delta l) \qquad (7)$$

Subtracting (6) from (7) yields

$$\Delta x = -\frac{2M_u}{\rho A} \Delta l \qquad (8)$$

As Δl is exactly equal to the change in stage, Δh, equation (8) may be expressed in metric units as

$$\text{Line shift correction} = -0.002\,55 \frac{M_u}{D^2} \Delta h \qquad (9)$$

Equation (9) can be used to produce tables of line shift corrections. Tables A-1 and A-2 depict these corrections for frequently used Stevens floats and float lines. It may be seen that beaded cable is superior to tape but that in either case, the error tends to be small for most applications.

SUBMERGENCE OF COUNTERWEIGHT

If the counterweight and a portion of the float line become submerged, the tension in the float line is reduced by the buoyant force on the counterweight and line. The depth of immersion of the float is therefore increased. To compute this effect, equation (6) can be rewritten as

$$M_f g = \rho g A x' \pm F + \left(\frac{\rho_c - \rho}{\rho_c}\right) M_c g - \left(\frac{\rho_u - \rho}{\rho_u}\right) M_u g (L-2l) \qquad (10)$$

where x′ is the new depth of immersion, and ρ_c and ρ_u are the densities of materials used in the counterweight and float line, respectively.

Subtracting equation (10) from equation (6) then yields

$$x' - x = \frac{M_c}{\rho A}\left(1 - \frac{\rho_c - \rho}{\rho_c}\right) - \frac{M_u (L-2l)}{\rho A}\left(\frac{\rho_u - \rho}{\rho_u} - 1\right) \qquad (11)$$

The second expression on the right-hand side is zero at the point when the counterweight becomes submerged and is negative at higher stages. When a standard counterweight and float 200 mm in diameter are used, the error is -0.001 m and thus tends to compensate for the line shift error.

Table A-1 Corrections for Line Shift for Float Line Having Mass of 0.62 kg/100 m

Float diameter (mm)	Change in stage from initial setting				
	1 m	2 m	5 m	10 m	20 m
200	0.0004	0.0008	0.0020	0.0040	0.0079
250	0.0003	0.0005	0.0013	0.0025	0.0051

Note: Correction is negative for an increase in stage; positive for a decrease.

Table A-2. Corrections for Line Shift for Float Tape Having Mass of 1.49 kg/100 m

Float diameter (mm)	Change in stage from initial setting				
	1 m	2 m	5 m	10 m	20 m
200	0.0009	0.0019	0.0047	0.0095	0.0190
250	0.0006	0.0012	0.0030	0.0061	0.0122

Note: Correction is negative for an increase in stage; positive for a decrease.

LINE SHIFT WITH COUNTERWEIGHT SUBMERGED

Equation (11) can be used to determine the line shift once the counterweight has become submerged. The change in stage, h_2-h_1, is equal to 2l-L, which may also be written as -(L-2l). The latter expression, when substituted into (11), yields

$$\Delta x = \frac{M_u \Delta h}{\rho A} \left(\frac{\rho_u - \rho}{\rho_u} - 1 \right) \qquad (12)$$

The difference between line shift with the counterweight submerged and without the counterweight submerged is negligible under almost any circumstance.

TEMPERATURE EFFECTS ON STILLING WELLS

A stilling well is subject to changes in length as the temperature changes. Fortunately these changes are small under most circumstances and do not affect recording accuracy except for deep wells and large temperature changes. Also, the change in length of the well tends to be compensated for by the change in length of the float line. Consider a wood stave well, 10 m long, with the water level near the bottom and a temperature change of 30°C. The increase in length of the well will be 10 x 30 x 0.000 007 2 = 0.0022 m, while that of the float cable will be 10 x 30 x 0.000 010 1 = 0.0030 m. The change in pen reading would be the difference or +0.0008 m; therefore a negative correction must be applied. Since most stilling wells are buried in soil, a temperature change as great as 30° is highly unlikely. Also very few stilling wells are as long as 10 m.

SATURATION EFFECTS ON STILLING WELLS

Wooden stilling wells can absorb water, thus lifting the recorder as the wood expands. This would become a factor only in the case of very long wells, and as the change occurs very slowly, saturation does not present any problems.

DYNAMIC EFFECTS ON THE FLOAT

Many stilling wells are subject to oscillations in the level of the water surface. The oscillations generally have a short period (a few seconds) and small amplitude (1 mm to 20 mm). As the float attempts to follow these oscillations, the result on a recorder chart will be "painting" or in the case of a properly designed stilling well, evidence of "pen action."

The closeness with which a float follows the oscillations depends on its mass. When the initial movement of the water surface takes place, the movement of the float will lag that of the water surface. In effect, an "inertial force" is set up to oppose the movement of the float. From Newton's second law of motion, this force is equal to $M_f(dv/dt)$, where dv/dt is the acceleration of the float. As movement of the water surface continues, the depth of immersion of the float and hence the buoyant force acting of the float changes. Eventually the buoyant force will overcome the inertial force and accelerate the float past the equilibrium point. The amplitude of the float oscillations could therefore be greater than that of the water level.

There are forces that tend to damp this movement of the float. These are set up by surface tension and viscous shearing stress effects on the vertical surface of the float. The surface tension force is directly proportional to the diameter of the float. The force set up by shear stress is a function of the diameter and the depth of immersion of the float. In addition, the force required to move the recorder mechanism will tend to make the recorder movement less than that of the float. (This has been described in the previous section on "Float Lag.")

At gauging stations where unwanted pen oscillations cannot be eliminated by other means, a specially designed damping float may be used. Most manufacturers of water stage recorders will supply these floats.

EFFECTS OF WELL INTAKES

Up to this point, only those factors have been discussed that affect the accuracy with which the record produced by a float-actuated recorder corresponds to the true water level in a stilling well. As the object of operating a water stage recorder is to record water levels in a lake, stream or other body of water, some discussion of the factors that may cause the water level in a stilling well to be different from that in a stream is warranted.

Aside from such obvious items as intake damage, silt effects, and ice effects, there are two other main considerations: the size of intakes and the water velocity past the end of the intakes. If intake pipes are too small, changes in stage in the stilling well will lag those in the stream. Intakes that are too large, however, may result in surging in the well, particularly when water velocities past the orifice are high. An empirical equation for computation of stilling well lag is

$$\Delta h = \frac{0.01}{g}\,\frac{L}{D}\left(\frac{A_w}{A_p}\right)^2\left(\frac{dh}{dt}\right)^2 \qquad (13)$$

where

Δh = lag (m)
g = acceleration of gravity (m/s^2)
L = length of intake (m)
D = intake diameter (m)
A_w = cross-sectional area of stilling well (m^2)
A_p = cross-sectional area of intake pipe (m^2)

and

$\frac{dh}{dt}$ = rate of change of stage (m/s).

For example, if a standard stilling well, 1.2 m in diameter, has two 50-mm intake pipes, 5 m in length, and could be subject to a rate of change of stage of 1.0 m/hr, the lag would be 0.000 59 m. This lag is not significant but note that when only one intake is in the water, however, the lag becomes 0.0028 m. Under such conditions it would be advisable to use a larger bottom intake pipe.

As the water velocity past the end of an intake pipe becomes high the well will be subject to drawdown. This drawdown is proportional to the square of the velocity and therefore will also be proportional to the stage and discharge at the gauging station. Because of this, the error incurred in the recording stage will be covered in the stage-discharge relationship. Yet if the stage record has some other purpose besides computation of streamflow data, for example, groundwater recharge calculations, it is advisable to take measures to prevent drawdown. This can be done by fitting the end of an intake pipe with a static tube. The tube consists of a short length of pipe of the same diameter as the intake, capped on one end and fitted with an elbow on the other so that it can be screwed onto the intake pointing horizontally downstream. A series of holes approximately equal in area to the cross-sectional area of the intake is drilled in the tube to allow water to enter and leave the well.

Problems with respect to intakes to stilling wells can be readily identified if readings of an inside and outside gauge, set to the same datum, are obtained on each visit to a gauging station.

CONCLUSIONS

Although the foregoing discussion is limited, several of the factors that could affect the accuracy of a float-actuated water stage recorder are discussed. If a water stage recorder is well maintained and adjusted in accordance with manufacturer's instructions, it should be possible to achieve good results provided that the factors that affect recording accuracy are kept in mind. The discussion also points out the necessity for obtaining both inside and outside gauge readings when inspecting a float-actuated recorder.

APPENDIX B

PRESSURE-ACTUATED WATER STAGE RECORDERS

All pressure-actuated water stage recorders operate on the principle that the water level is directly proportional to the pressure at a fixed point below the water surface. Instead of installing a pressure sensor in a stream, a gas purge system is frequently used to transmit the pressure from beneath the surface to a point on shore. (Closed pneumatic systems have also been used, but such systems can be subject to problems due to leaks.) Figure B-1 shows a typical gas purge system connected to a differential mercury manometer and to a pressure sensor (the type of sensor is irrelevant to this discussion). The terms used are:

p_r = recorded pressure
p_a = atmospheric pressure at the instrument
Δp_a = difference in atmospheric pressure between the instrument and the water surface
p_p = pressure at pressure side of the instrument
h_p = height of pressure side of manometer above the orifice
h_w = height of water column above the orifice
h_o = elevation at the orifice
h_r = recorded height of water column above the orifice
p_o = pressure at the orifice
p_f = loss in pressure owing to gas friction in the purge system
Δp_g = difference in pressure owing to the weight of gas column, H
H = difference in elevation between instrument and orifice
ρ_w = density of water in the water column
ρ_g = density of gas in purge system
ρ_m = density of mercury in the manometer
g = acceleration of gravity
T = thermodynamic temperature, 0°C = 273.15 K.

The density, ρ_g, can be affected by changes in water level, h_w, and by changes in temperature. For the sake of this analysis, it is assumed that the gas temperature throughout the purge system is the same at any given time.

With reference to Figure B-1, the following equations may be written:

$$p_r = p_p - p_a \quad (1)$$

$$p_o = \rho_w g h_w + p_a + \Delta p_a \quad (2)$$

$$p_p = p_o + p_f - \Delta p_g \quad (3)$$

Combining equations (3), (4) and (5) yields

$$p_r = \rho_w g h_w + \Delta p_a + p_f - \Delta p_g \quad (4)$$

and for the mercury manometer

$$p_r = \rho_m g\,(H - h_p) - \rho_g g\,(H - h_p) \quad (5)$$

since $\rho_m >>> \rho_g$, equation (6) becomes

$$p_r = \rho_m g\,(H - h_p) \quad (6)$$

In this Appendix, some of the factors that affect the performance of pressure-actuated systems, particularly those that use gas purge systems, are discussed. Some calibration considerations are also reviewed.

EFFECT OF THE WEIGHT OF NITROGEN

Under most operating conditions, the weight of the nitrogen in the gas purge system does not significantly affect the accuracy of recording. This factor becomes significant as the difference in elevation of the instrument and the orifice increases, thus causing the instrument to under-register. An expression for this effect is

$$h_r = h_w \frac{\rho_w - \rho_g}{1000} \quad (7)$$

The values for ρ_w are:

999.87 kg/m³ at 0°
1000.00 kg/m³ at 4°
999.73 kg/m³ at 10°
998.23 kg/m³ at 20°
995.68 kg/m³ at 30°

and the value of ρ_g may be computed from

$$\rho_g = 1.25 \frac{273.15}{T} \frac{H + p_a}{10.332} \tag{8}$$

Since purge systems are not very sensitive to atmospheric pressure changes, the following standard values of p_a can be used:

Altitude (m)	p_a	
	m_{H_2O}	kPa
0	10.332	101.325
500	9.736	95.474
1000	9.166	89.887
1500	8.623	84.560
2000	8.108	79.510

For example, if an instrument is 25 m above the orifice, the registration error for an installation at sea level and gas temperature of 10°C would be -0.044 for a depth of water of 10 m. This error is essentially linear and can be adjusted to zero for many types of pressure-actuated sensors including the servomanometer.

TEMPERATURE EFFECTS

There are several ways in which temperature changes can affect the results produced by pressure-actuated stage devices. The first of these is the effect of density changes of water with temperature. (Density is also affected by changing sediment concentration but this effect tends to be negligible under most circumstances.) This effect is small even for large temperature changes (less than 0.5% for 30°C change), and as water temperature generally does not change quickly, the effect is virtually eliminated when the instrument is inspected and the correct stage noted. (Where density changes frequently, e.g., in tidal estuaries, operation of two

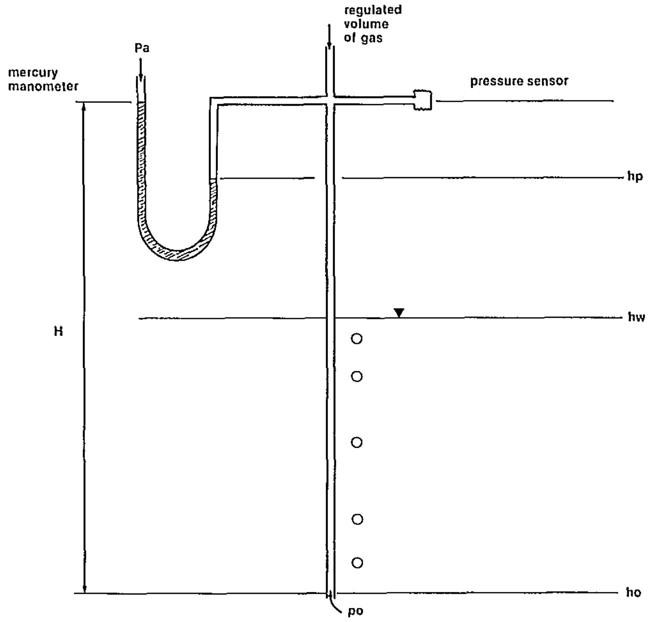

Figure B-1. Gas purge system with stage sensors.

instruments whose orifices are a known distance apart will provide data for a density correction.)

Another temperature effect is that caused by temperature changes of the gas in the gas purge system. An instrument will tend to under-register more as gas temperature increases. This effect cannot be evaluated rigorously, as the gas temperature will change as the gas moves through the bubble tubing to the orifice. In the shelter, the gas is stored at a temperature that may range from -50°C to 50°C. On leaving the shelter, the bubble tubing is usually buried so gas temperature fluctuations will be less severe; probably the range from -10°C to 20°C would cover most cases.

When the tubing enters the water, the gas temperature will be influenced by the water temperature; here again the range tends to be small, 0°C to 20°C. As soil and water temperatures change slowly, the effects of these changes tend to be eliminated as the instrument is inspected. Since shelter temperature changes quickly, even diurnally, noting shelter temperature at the time of visits to a site will assist in interpreting the effects.

The servomanometer is subject to a temperature effect caused by density changes in the mercury used in the system. This effect will cause the instrument reading to be incorrect by $0.000\,018\ h_w \Delta T$. The servomanometer will over-register for an increase in temperature and under-register for a decrease. Generally this error is eliminated by observing the correct water level at the time of visits to the site. Where a very accurate record of water level is required, the Stacom servomanometer can be fitted with a thermistor-actuated servo temperature compensator that automatically adjusts the angle of the manometer as the temperature changes, thereby eliminating the temperature error.

Other pressure-actuated instruments may also be subject to inaccuracies caused by temperature changes of mechanical or electronic components. Indication of slight diurnal fluctuations in water level at a gauging station where this should not occur naturally may be the result of temperature effect on the instrument. In some cases the only way to be absolutely certain of the temperature effect would be to operate two different types of instruments from one gas purge system.

ATMOSPHERIC PRESSURE EFFECTS

The gas purge system is subject to two effects caused by changes in atmospheric pressure. One effect arises when the atmospheric pressure at the recorder is different from that above the orifice in the stream. This effect will be negligible under virtually all circumstances. The other effect is caused by changes in atmospheric pressure throughout the period of operation of the instrument. These changes are less than ±1% in any given year, and as discussed earlier, the purge system is not sensitive to this change. For example, consider a purge system installed at Banff, Alberta, where the atmospheric pressure may range from 848.7 kPa to 862.3 kPa. From equations (8) and (7), the density of gas at 0°C will vary no more than 1%, and the effect on the stage reading would be less than 0.001%.

GAS FRICTION EFFECTS

The friction of the gas flowing in the purge system is a function of the bubble rate, the gas density and the inside diameter of the purge tubing. The significance of gas friction can be determined experimentally in the field by adjusting the bubble rate and observing the effect, if any, on the stage reading. (Increasing the bubble rate will tend to increase the stage reading if gas friction is significant.) If the reading is affected, use of dual bubble tubing will eliminate the problem. Use of a single tubing having a larger inside diameter will also reduce the problem.

DYNAMIC EFFECTS

The effect of changes in water level (i.e., changes in pressure) on the gas purge system and related pressure sensor should also be considered. First, the response of the system is related to the depth of water over the orifice. As the depth increases, the effects of wave action tend to be damped more and more. Furthermore, some instruments such as the servomanometer and some servo-beam-balance units have an electronic delay circuit that tends to eliminate the effects of wave action.

When the pressure at the orifice does drop, the gas purge system responds almost instantly by releasing a burst of bubbles at the orifice. The water level recorded by the instrument will then drop to the correct level as soon as any delay time has expired. With increasing pressure, the situation is slightly different. In this case, water is drawn into the purge tubing and is expelled gradually as the gas pressure builds up in the system. The response of the instrument to a rise in stage may therefore be slower than its response to a fall in stage. Increasing the bubble rate will shorten response time. (Note that if there is a point in the bubble tubing that is lower than the orifice, a continuous cycle of water being drawn into the tubing and then expelled will be set up. The result will be uniform painting on a recorder chart.)

Another factor which affects the results produced by servo-driven units is the maximum rate of response of the servo motor. For example, the servomanometer motor will move the mechanism quickly enough to follow a change in stage of about 0.02 m/s. This is fast enough to record tidal fluctuations, but may be insufficient to record peaks caused by flash floods or ice jams accurately. For some very flashy streams, it may be necessary to use a higher than normal power supply with a special servocontrol to ensure that the servo motor can keep up with the change in stage.

Just as water velocity past the end of an intake pipe affects float-actuated instruments, so does velocity past the orifice affect pressure-actuated units. The problem is usually not as great for orifices, since they tend to be installed near the bottom where velocities are low. An orifice "static tube" can be improvised by attaching an elbow to the orifice and pointing it downstream. Alternatively, a well point orifice could be used.

CALIBRATION

A float riding in a stilling well provides a direct indication of water level, subject to the conditions noted in Appendix A. Recording of pressure, however, gives an indirect determination of water level. Therefore it is necessary to calibrate the instrument to obtain good stage data. The calibration factors most commonly cited are "span" and "linearity."

Span refers to how well the zero and full-scale readings of an instrument correspond to true readings. In some cases, it is necessary to first "zero" the instrument or set a zero offset before adjusting the span. For the servomanometer, the adjustment of the angle of the manometer is, in effect, a span adjustment. Some electronic instrumentation is subject to "zero drift" with time, thus affecting the span.

Linearity is a measure of how close intermediate scale readings correspond to true readings once the span adjustment has been made. Linearity tends to be a measure of quality of manufacture. The terms repeatability, hysteresis or dead band are frequently used in describing linearity. Note that an instrument's readings may be very repeatable but still be incorrect by a significant margin. Hysteresis or dead band provides a measure of whether or not the same reading is obtained on both a rising and falling stage.

Many manufacturers of pressure transducers quote an overall accuracy figure in terms of percent full scale. These percent accuracies can seem deceptively good at first glance. An accuracy of ±0.1% for a 10-m range instrument, however, is only ±0.01 m.

CONCLUSIONS

Several factors that could affect the performance of pressure-actuated water stage recorders have been discussed. Provided good records are kept of recorder readings, water levels and temperatures, it is apparent that it is possible to obtain accurate results from the pressure-actuated instruments presently in use.