SOME SUGGESTED METHODS FOR HYDROLOGIC INSTRUMENTATION

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From the standpoint of fundamental physics, there are only three direct ways to measure water. You can determine its mass as by weighing; you can measure its volume, or you can count the number of molecules. However, none of these methods lends itself to practical means of direct approach, except for a few isolated examples as the old dumping raingauge, the weighing raingauge or the snowtube and scale.

For most hydrologic measurements, especially for use with automated data acquisition systems, we must therefore look to indirect or inferred methods of measurement. Some of the more common automated means consist of surface detection methods, pressure measuring methods, radiation gauges for snowpack, use of sound waves, and a number of methods for flowmetering in open and closed waterways.

Of these methods one stands out as unique in that it is applicable to the largest number of situations, one that is economically sound and one that is capable of providing what is probably the highest order of accuracy of any when properly applied.

This method consists of the measurement of pressure. Most hydrologic gauging requirements can be reduced in their fundamentals to the measurement of pressure.

The principal purpose of my paper is to illustrate how a single form of operational battery powered pressure transducer can be employed to monitor a rather wide variety of parameters, and how this transducer may be employed economically and with an exceptional order of precision and reliability in either remote or attended stations.

Since I serve as director of a commercial instrument manufacturing concern and you have extended to me the courtesy and honor of addressing your esteemed group, I shall endeavor to be as objective as possible. References to my Company's products that I will make in the course of my paper are intended to be descriptive of methods. It will be apparent that other means of measuring these pressures may be employed.

My paper relates to the use of Exactel Hydrogauges [1] and in a few instances, Exactel Servomanometers[1] for the gauging of water bodies, precipitation, snowpack, rivers, channels, tides and subsurface water tables with employment of the purge bubble principle.

I am sure most of you are familiar with the purge bubble principle and might well ask what can be noteworthy about its use. I would like to point out a number of facets that often tend to go unnoticed and others that tend to illustrate how remarkably accurate, versatile and reliable the method is when properly used. I specify "when properly used" as there have been rather surprising numbers of engineering errors made in system planning that detract from the performance that might otherwise have been attained.

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[1] Hydrogauge, Servomanometer and Analog Temperature Compensation are registered trade names of Exactel Instrument Company.

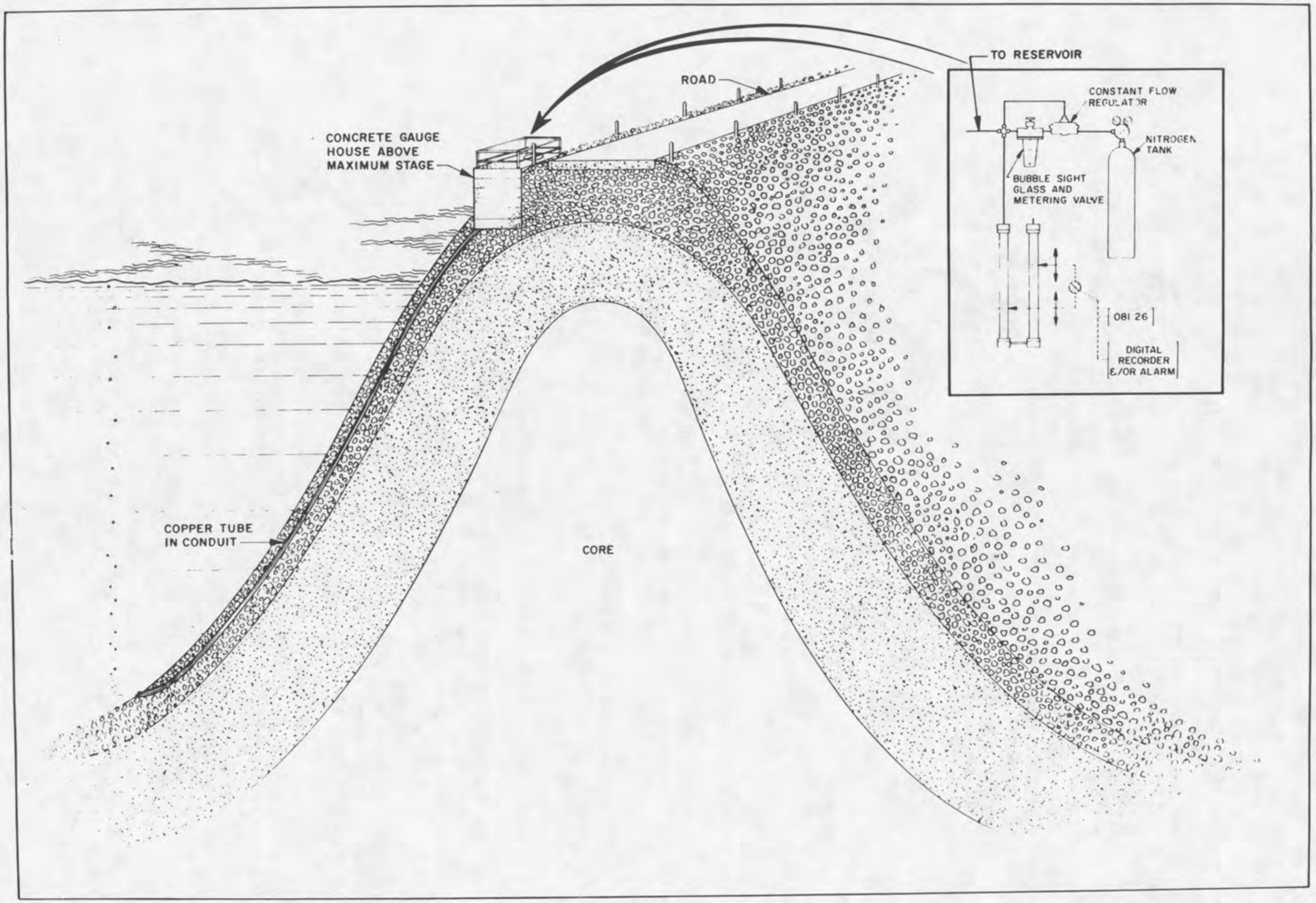

Fig. 1 - Typical Reservoir Gauging
System Employing Purge
Bubble Principle and
Servomanometer

the indication. At the conclusion, I dropped a coin in the oil which caused the Servomanometer indication to increase by approximately 0.001 foot, in precise accord with theory. Two theoretical sources of error exist in the purge bubble principle but they are so small as to be negligible in practical application. The first is the pressure drop caused by the flow of gas in the piezometer line.[1] At a bubble rate of approximately eight bubble/min, this error amounts to only about 0.003 foot of water per 1000 feet of piezometer line. The second source of error is the vertical component of the weight of gas in the piezometer line; or to be more accurate, the variation thereof. I would list the following rules for installation of the piezometer line. Practically all of the difficulties that are experienced with bubble systems are caused by non-adherence to these rules. (1) It is essential that all plumbing be leak-tight. (2) Care must be taken to avoid dips or valleys in the piezometer line where water can accumulate. This is easily accomplished by having a continuous descent of the piezometer line between the pressure instrument and the lower orifice. The slope need not be uniform but it must be free of valleys in which water can collect. (3) The piezometer line should be buried a short distance beneath the ground surface or otherwise protected from direct sun which tends to introduce small perterbations due to expansion and contraction of the gas. (The change of weight of the gas does not cause much error, but cooling results in a transient error by water being sucked back into the line if the bubble rate is low.) (4) The lower tip of the piezometer line should be well secured and located at a point selected to avoid the orifice tip being buried in the silt. Let me mention, however, that the purge bubble principle has ability in large measure to purge itself of silt except under severe silting conditions such as encountered in flooding streams. (5) I would recommend that the last few inches of piezometer line be run in a vertically downward direction and terminated with approximately 3/16" ID tubing cut diagonally at an approximately 15° included angle. This practice eliminates "blurping" and bubbles of small, uniform diameter. (6) The piezometer line must have adequate safeguards against erosion, ice and other hazards.

Locate the instrument above the maximum water stage level, except that it may be located on the downstream side of a dam below the maximum stage, provided the piezometer line runs up and over the dam at a point above the maximum stage level.[2]

Exactel, in the manufacture of its products for the subject type of service, employs a reference temperature for water of 9°C, at which water has a specific gravity of 0.99981.

For most applications, I would recommend that the piezometer line be of 1/4-in diameter copper tubing. Larger sizes only tend to increase the volume of the line and reduct the response rate when levels are ascending. It should be run in protective conduit in locations where physical hazards exist. Plastic tubing is quite serviceable in many instances but it is vulnerable to attack by rodents. Aluminum and stainless steel tubes are sometimes difficult to pull through conduit without damage. Considering the low cost involved, it is usually advisable to pull in a spare tube for use in event leakage or damage should occur in the first. A second tube can sometimes prove useful, also, to provide a comparison reading for troubleshooting purposes in the event difficulty is encountered.

Let me relate a second experience that indicates the precision and utility of the purge bubble principle. During the past sixteen months, my Company has worked with a river and ocean barge company on a cooperative experiment to

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1. An alternate practice to eliminate pressure drop due to flow, is to run a "dual" piezometer line; consisting of two lines, one for gas flow and the second T'd to the first near the submerged orifice tip to supply the pressure

2. Although the text relates principally to the bubble technique, an alternate useful method is to employ a water filled piezometer line and locate the pres-

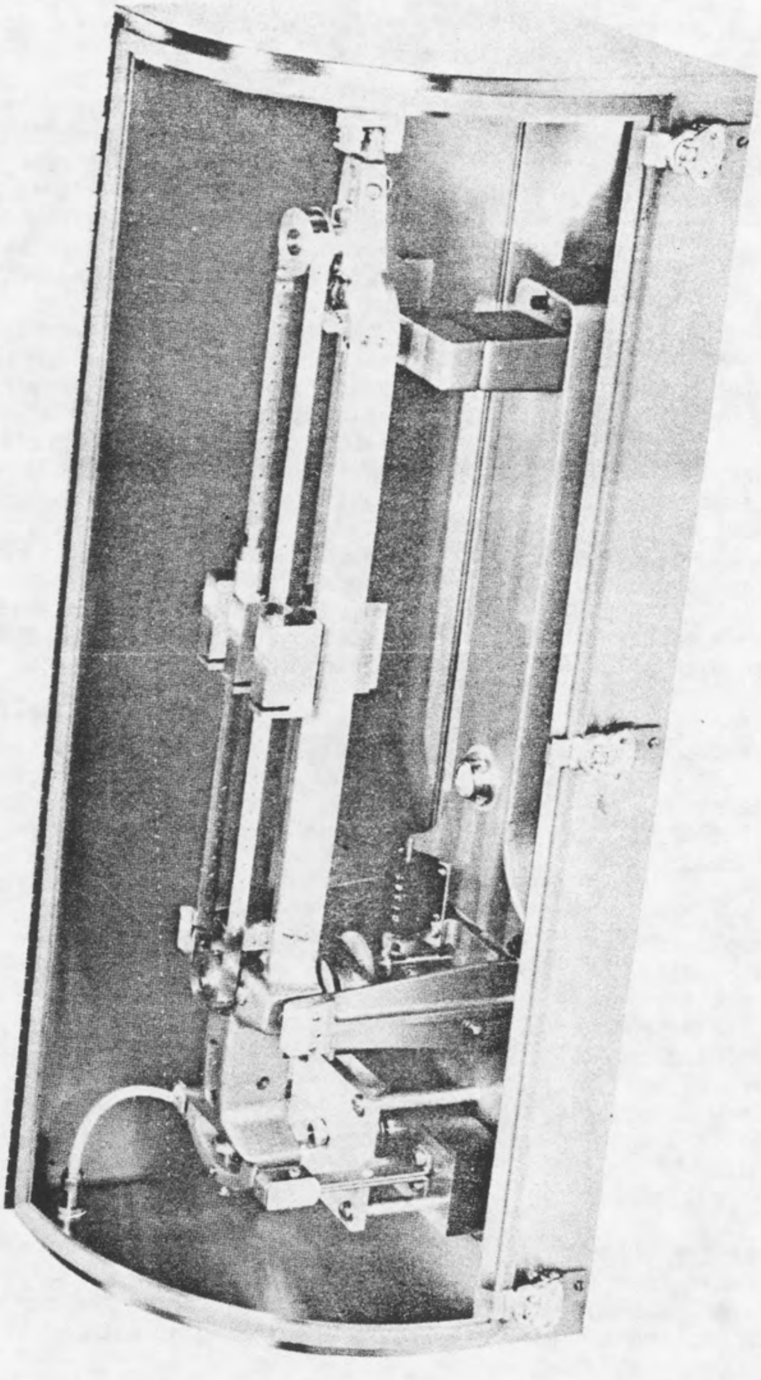

Fig. 2 - Exactel Hydrogauge

In the employment of the principle, a tube, generally of the order of 1/4 to 3/8 inch diameter and commonly called a piezometer line, is run to the bottom or other suitable reference point in the lake or body of water to be monitored. The upper end of the line is connected to a source of compressed gas, usually bottled nitrogen, which is allowed to pass into the line at a slow rate, being restricted by a throttling or metering valve. The gas passes to the lower end of the tube and bubbles up through the measured water. With this arrangement, the pressure of the gas in the line is equal to the hydrostatic pressure of the water above the point at which the piezometer or bubbler line terminates. The pressure is then manifolded or T'd to a suitable pressure - responsive instrument calibrated in appropriate scale units; usually feet, inches, or meters of water. In practice, the bubble rate is adjusted to a slow rate so as to conserve the gas supply. Typically, a standard 250 cu-ft cylinder of nitrogen will last one to three years. For quasi-static service, I suggest the bubble rate be set at about three to eight bubbles per minute. Higher rates may be required for streams, rivers and other bodies subject to rapid rise. As illustrated, a pressure regulator is used to reduce the nitrogen tank pressure to a value slightly higher than the maximum pressure required to overcome the static head pressure of the water being gauged. The pressure should be less than that, however, which might cause instrument damage in the event of improper operation of valves or system malfunction. An oil-filled sight glass is usually provided in the line to visually indicate the bubble rate. In the illustrated assembly the metering valve is combined in the sight-glass assembly. A constant flow regulator may be employed across the metering valve to keep the flow relatively uniform and eliminates variations that would be caused by wide fluctuations in the head pressure of the gauged water body. For example: without the flow-regulator, if the <u>absolute</u> pressure valve of the back pressure in the piezometer line were reduced by 50%, the bubble rate would double. This would not introduce significant error, but would waste gas. Incidentally, however, we advise against the use of flow regulators in ranges of less than about eighty feet, as they are somewhat vulnerable to rupture of an internal diaphragm or to being put out of commission by oil from the sight glass getting back in the regulator, either of which can occur with an improper sequence of operations when changing N_2 cylinders. Below 80' of range the change of bubble rate that occurs with omission of the regulator is usually not significant.

A subtle but major advantage of the technique is that it is essentially one of weighing, rather than gauging of surface level, inasmuch as it senses and responds to hydrostatic pressure at the reference point where the piezometer line terminates. The reading remains unchanged, for example, with wide variations of surface level that may come about with temperature change or variation in the quantity of absorbed gases or suspended silt.

Provided a few basic rules are observed, and if an appropriate pressure measuring instrument is employed, the technique is capable of truly remarkable precision. Under favorable conditions a variation in depth of 0.001 ft. may be sensed. To illustrate, I once filled a cylinder of about 3-in diameter and 3-ft depth with SAE 100 weight oil at room temperature. The cylinder was placed in a bucket of ice water and allowed to chill. A piezometer line was installed and connected to a Servomanometer and readings observed while the bubble rate was varied from a bubble about every 20 seconds to an exaggerated rate of practically steady flow with no discernible change in reading on the Servomanometer. A gas burner beneath the ice water bath was ignited and the oil brought to the boiling temperature of water with no change of reading.

The viscosity of the oil changed greatly during this period, approaching a viscosity comparable to that of SAE 30 at room temperature. The liquid surface raised about 7/16 inch, but with no change of indication on the Servomanometer. The bubble rate was again varied over the preceding range with no variation in

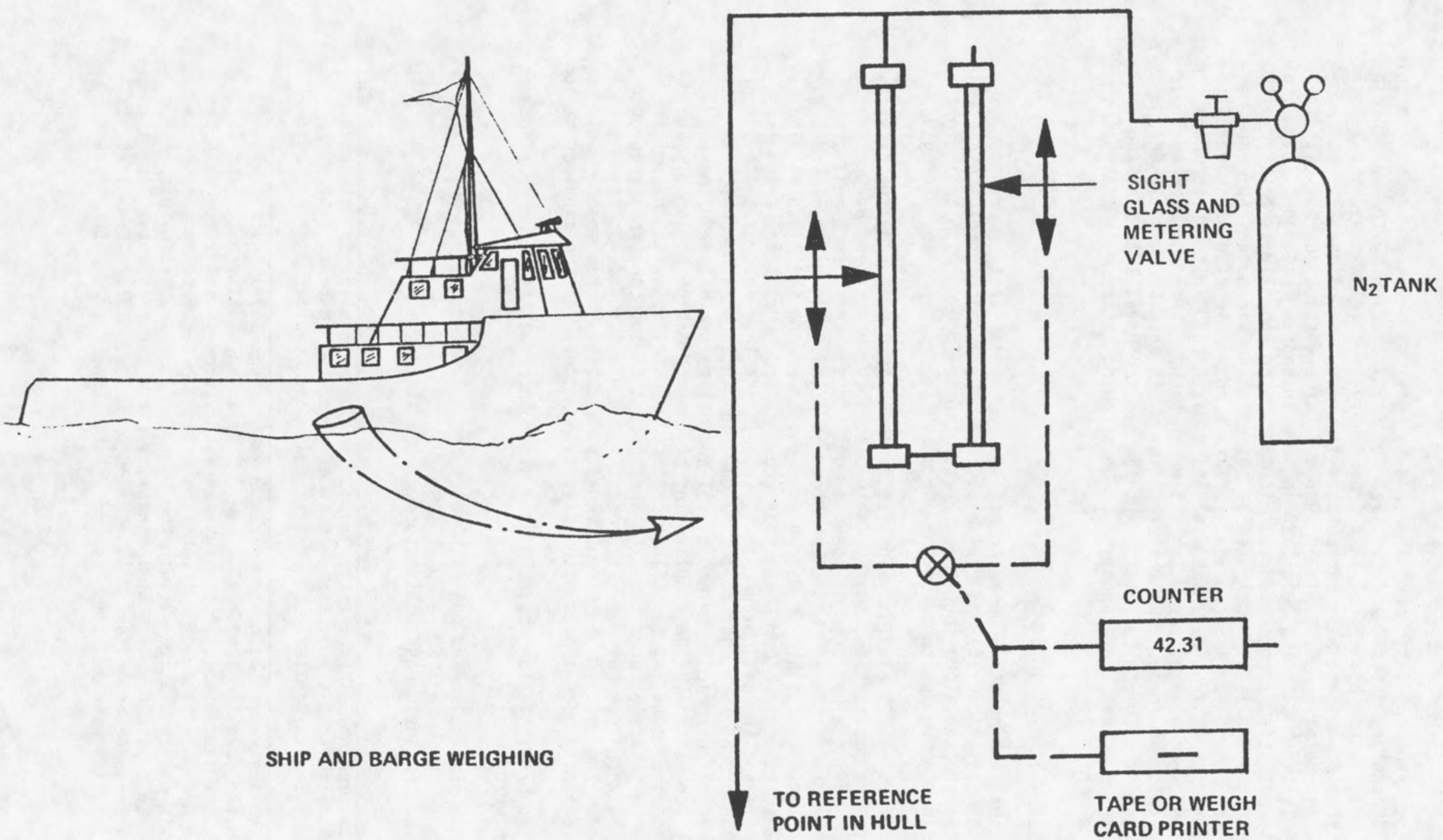

Fig. 3 - Barge Weighing with Purge Bubble Principle and Servomanometer

determine the feasibility of these techniques for the "weighing" of barges. By theory, the principles are ideally suited. The system was installed in the manner illustrated in Fig. 3.

Although the technique and instrument appeared to work quite well, we were not able to get the 0.1% accuracy desired and required for certification by the California Department of Weights and Measures. This proved very frustrating, as by all logic and theory we should substantially exceed this figure. We consistently got excellent accuracy, exceeding the 0.1% figure when the barge was loaded, but with it empty, we experienced a shifting zero that in some instances exceeded 0.1%. After quite extensive analysis, I concluded that it must be an anomally associated with the barge. I attributed it to such possible causes as an air pocket (of varying size) beneath the hull which is essentially flat, a change in size or shape of the hull or to warm water as from a sewage line being discharged in the area where the barge was berthed when some of the weighings were taken. These theories were discounted by the customer for quite a while. A few weeks ago, however, I had a pleasant call from the Company President who advised the naval architect who designed the vessel conceded there appeared to be a bowing in the hull plates that was causing the difficulty.

PRECIPITATION GAUGING

For precipitation gauging using these principles, I suggest that a very economical, yet exceptionally accurate and reliable, form of standpipe precipitation gauge may be constructed along the lines illustrated in Fig. 4, with the weight of water contained being monitored by the purge bubble principle and Hydrogauge.

The cylinder, of 10" - 12" aluminum pipe, is fitted with a polypropylene plastic rod for temperature compensation, subsequently described, and a cone at the top per convention, having a net area of opening equal to the cross sectional area of the standpipe minus that of the compensator rod. This area ratio provides a direct reading system. A plate is welded over the lower end for closure. The height is made suitable to accommodate year round catch. (Or other period as selected.) Where soil conditions permit, I suggest the lower end of the cylinder be buried in the ground as a post to secure the pipe in an upright position. It contains an initial charge of ethylene glycol and oil to prevent freezing and evaporation per convention. The annular ring at the top may be optionally equipped with a heating element and electrical contact which closes with the weight of snow buildup with its occurrence. The arrangement is such that heating would be provided only when snow buildup was present and would turn off as soon as the snow was melted. The heating power requirements, with this arrangement, would be within the capacity of a single automotive type battery for a seasons operation.

In uncompensated precipitation gauges of the standpipe type there are four sources of temperature error:

1. Expansion and contraction of the collected water.

2. Expansion and contraction of the standpipe.

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valve to the instrument. In the writer's opinion, this practice is only rarely justified and has several disadvantages including reduced response rate with ascending stage, increased liklihood of leaks and added cost.

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sure responsive instrument below the minimum water stage level, such as at a power house on the downstream side of a dam. This is an equally valid and accurate method. If a Servomanometer is employed, the water forms an interface with the mercury on the pressure side. The top of the reference leg V is vented to the atmosphere. (Via a dust filter) as with the bubble principle. With this method there should be a continuous descent in the line, from the piezometer line downward to the Servomanometer, to avoid entripment of air bubbles. (Dissolved air comes out of solution with reduction of hydrostatic pressure, as with descending

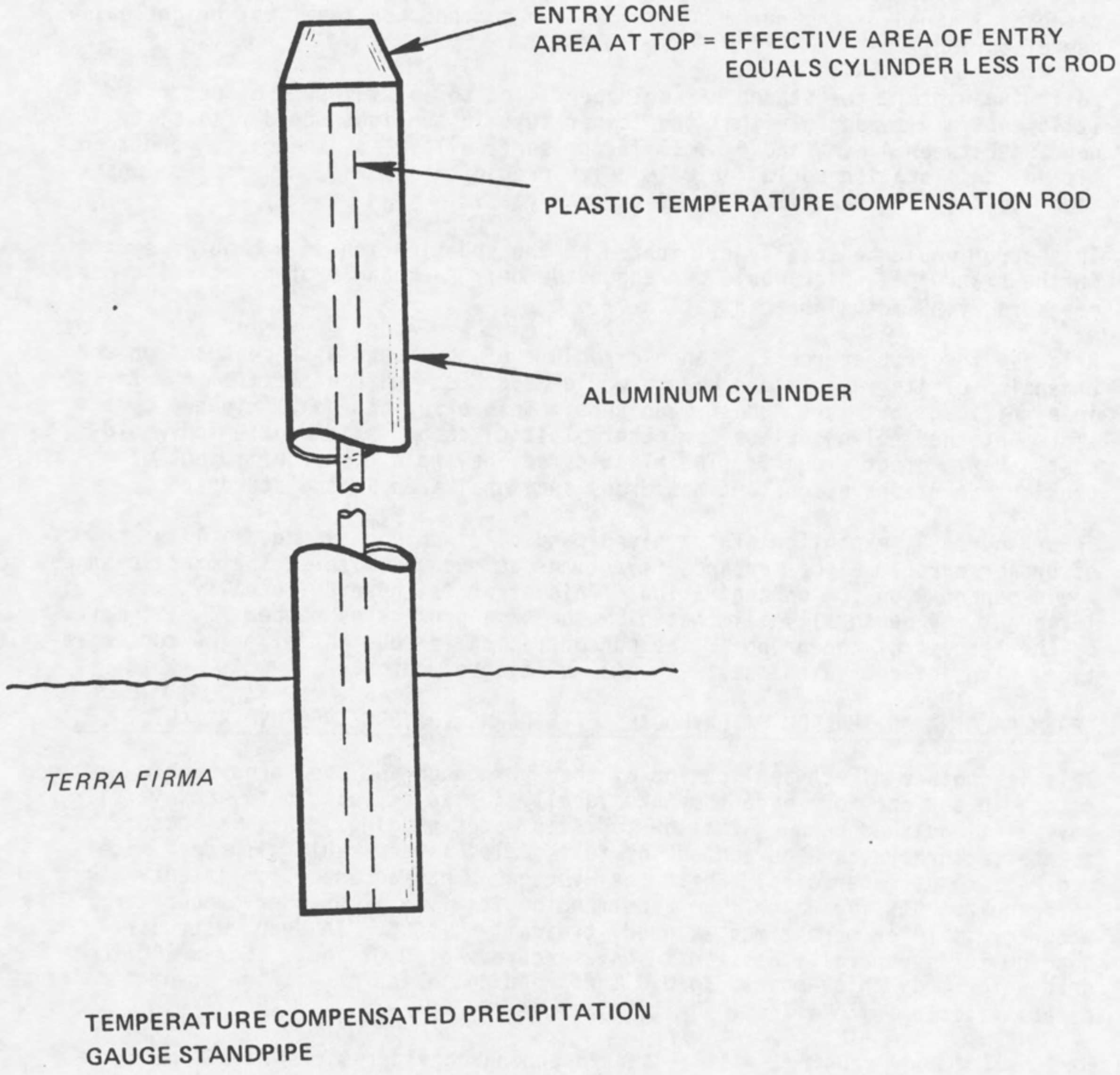

Fig. 4 - Temperature Compensated Precipitation Gauge Standpipe

3. Expansion and contraction of the ethylene glycol and oil.

4. Instrument temperature error in the measurement means.

In the proposed construction and measurement technique, the first three are eliminated and the fourth is negligible.

The change of surface level of water, due to its own expansion and contraction represents a large diurnal fluctuation. For a standpipe having a 120" catch, subjected to a 60° temperature change, the level would change 120 X 110 (10)$^{-6}$ x 60 = 0.857 in. Visualize, if you will, a remote mountain area transmitting station sending precipitation data from such a standpipe equipped with a surface detector instead of the purge bubbler as I recommend, on the first bright balmy day of spring.

Following winter, the standpipe would be filled to a level such as described. It is entirely reasonable that the temperature in sunlight would rise sixty degrees between 4 a.m. and 4 p.m. If the surface level of the gauge were transmitted, this station would indicate heavy precipitation was occurring on what might be the most beautiful day of the new year.

This error would be totally eliminated by the substitution of a bubbler system in the standpipe, which would be responsive only to changes of hydrostatic head pressure, i.e. actual precipitation.

Relative to error source 2, change of volume of the tank, with contraction and expansion of its walls, this change would have been subtractive from the first, in significant but more modest magnitude. This error can be eliminated by the aforementioned polypropylene (or other plastic) compensation rod which would cost a very modest amount. (The plastic rod, having a high coefficient of expansion, maintains a constant net cross sectional area in the standpipe.)

Error source 3, expansion of the glycol and oil, would have added a large amount of urther error. Glycol expands five times as much as water. The exact change would depend upon the concentration. This error is, however, usually quite large but may be totally eliminated by the same process as number 1. (It may be the largest of the group if the concentration is substantial. The concentration, also, of course changes with accumulation of catch.)

DEPTH GAUGING OF SHALLOW WATER BODIES. (STREAMS, RIVERS, RESERVOIRS, ETC. 80')

This is another direct application of the Hydrogauge and the purge bubble principle and one for which they are ideally suited. Please note, however, I have distinguished between shallow and deep water gauging. This is because greater accuracy, as a percentage of full scale, is desirable with deep water bodies such as reservoirs. While the Hydrogauge has accuracy consistent with the requirements for which I am recommending it, i.e. 1/10%, Servomanometer accuracy is 10 or more times as good, typically 1/100%. In deep reservoir gauging it is generally desired to have accuracy of 0.01 foot. For a 100 foot deep water body this amounts to 0.01% of reading, which is within Servomanometer capabilities. (With a lower limit tolerance of 0.01'H_2O.)

For shallow body gauging, most of the foregoing considerations relating to the

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surface level) A bubble in the line having a vertical component of height of 0.1' will cause a 0.1' error.

A signigicant advantage of the purge bubble principle is that it permits use of an instrument of lesser rante, considering the slope that should be provided for a water filled piezometer line.

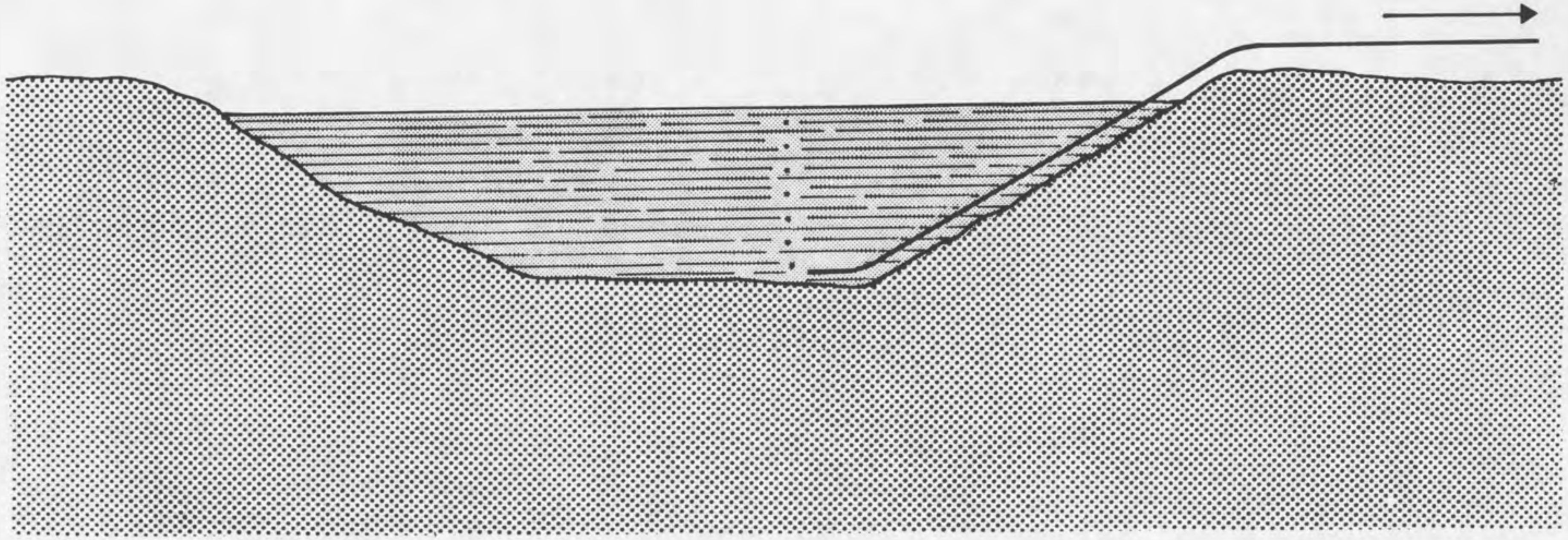

Fig. 5 - Schematic of Stream Gauging Piezometer Line Arrangement

purge bubble principle and Hydrogauge apply. The following supplemental considerations are worth noting and may be briefly stated. (1) The technique permits locating the gauging equipment on high ground, out of harms way in the event of severe flooding. It is during these periods that the data are of greatest value and it is an important point that it is usually simpler and much more economical to provide two flood resistant piezometer lines than it is to provide a flood resistant stilling well. (2) The bubbler orifice is best installed on a column or riser to get it off the channel bottom to minimize silting problems and (3) locate the orifice preferably on the lee side of a bend or other location having reasonably calm water. (4) Usually somewhat higher bubble rates are employed, typically 24 - 30 bubbles/minute, as compared to gauging of quasi-static phenomenon, to obtain more rapid instrument response in the event of a rapid rise in river stage level.

I feel there is considerable constructive purpose in siting differences and parallels between the Federal Government developed manometer-servo, which has seen wide application in the past decade, principally for river gauging, and the Exactel Hydrogauge. The manometer-servo was a well conceived instrument that has reasonably well filled a need. However, there is at least one large basic inaccuracy in the manometer-servo that is not well understood by many organizations that use it. It has a very large basic inaccuracy in the manometer-servo that is not well understood by many organizations that use it. It has a very large uncompensated temperature error of $94.53(10)^{-6}$ft. per ft. per °F. This error at a 40' measurement and 60°F away from its reference temperature is nearly 0.25 foot or three inches. The $94.53(10)^{-6}$ figure is the net difference between the coefficients of expansion of mercury minus steel as used for the lead screw. The Hydrogauge temperature error under the same conditions would be only 0.014 foot.

The manometer-servo and the Hydrogauge are functionally interchangeable. The Hydrogauge has been introduced to compete with the manometer-servo in the belief it is technically superior and can provide a cost saving as compared to the manometer-servo. Some other advantages the Hydrogauge provides can be briefly stated as follows:

1. One basic Hydrogauge can serve several range requirements by simple change of bellows location and use of change gears on the output shaft. (Now being made possible by a design modification.) Standard ranges: 12-1/2', 25', 50' and 100'H_2O.
2. The Hydrogauge eliminates need for (or permits use of a simpler form of) wave damping technique.
3. The Hydrogauge is less expensive (all factors considered) and available as an off the shelf item.
4. The higher response rate and flexibility of the Hydrogauge can, in some instances, be employed to provide flood or rate of change warning.
5. The Hydrogauge is much more reliable.
6. The Hydrogauge is smaller, lighter and more rugged.
7. The Hydrogauge has calibration proving provisions for use in field.

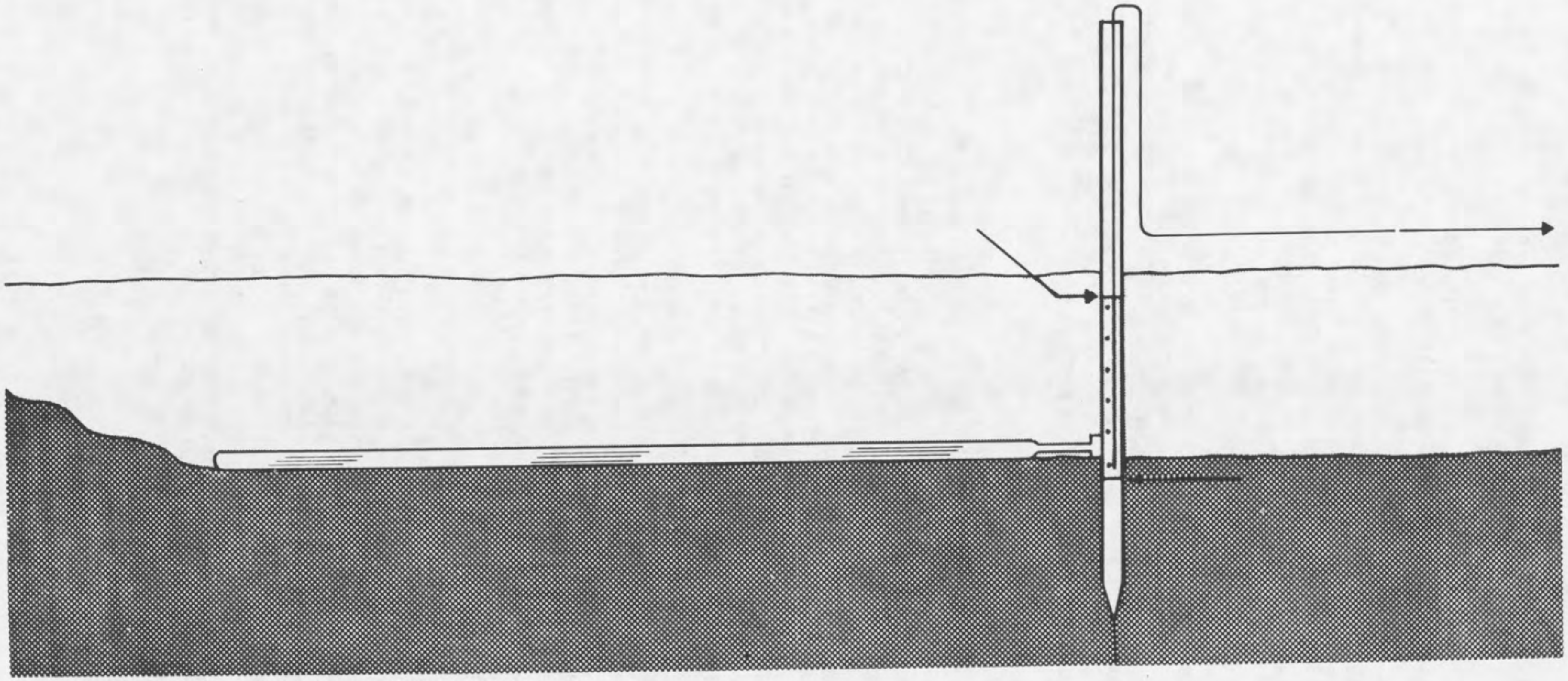

Fig. 6 - Schematic Arrangement of
snow pillow, "manometer"
tube and piezometer line.

8. The Hydrogauge battery power requirements are much less.

9. The Hydrogauge (in future) will have a built in voltmeter to indicate when batteries are discharged.

10. The Hydrogauge is more easily understood and much more easily serviced without special skills.

11. Mercury cannot be blown out of Hydrogauge (or Servomanometers) as with manometer-servos. (As when servo in manometer-servo is disabled or cannot keep up with rapid increase of water level change. This occurs especially in areas subject to flash floods. It cannot occur with Servomanometers because manometer tubes encompass full instrument range, as contrasted with movable cistern).

12. Usuable with any conventional means of data recording/transmission. Small readout devices mount inside dust cover. Large devices; A-35 recorders, ADRs, Telemarks, etc. mount outside and are driven by output shaft and ladder chain.

13. Hydrogauge may be AC line powered by exchanging a small control circuit module.

SNOWPACK GAUGING

Now let me describe how I feel these principles can optimally be employed for snowpack gauging. In recent years, the snow pillow has proven its merits. The snow pillow, a double-slack diaphragm, is filled with a non-freezing liquid. With accumulation of snow pack, the pressure or burden of snow on the pillow causes a small portion of the liquid from the pillow to move to a vertical manometer tube. A fundamental advantage of the snow pillow is that it is responsive to the weight of snow burden, hence water content. In the construction I recommend, the liquid rises to a level at whcih the static head pressure of the vertical column is equal to the static pressure induced by the snow burden. The static pressure head established in the tube may then be monitored with the purge bubble principle.

Now please note, I stated that the static head pressure in the tube is representative of the snow burden. I did not say the height of the liquid would be representative nor did I say that the pressure within the pillow would be representative. There are subtle but important differences involved that constitute the difference between satisfactory and unsatisfactory operation. The manometer tube serves a dual purpose in providing a thermal expansion chamber and a point for measurement of hydrostatic head with the bubbler principle.

For proper operation, the snow pillow should be designed to maintain as nearly constant volume as possible. Unfortunately most of the low freezing temperature liquids that are suitable for filling; ethylene glycol, water/alcohol solutions, oils, etc., have very high coefficients of thermal expansion, causing a void to develop between the snow pillow and snow burden with lowering temperatures. This results in some but indeterminate amounts of snowpack settling. Conversely with temperature rise and expansion of the filling liquid, the pillow expands causing physical lifting of the snow burden with attendant shear force transmittal as the peripheral edge of the snow burden moves relative to the surrounding snow. These phenomena can introduce sizeable errors, the magnitudes of which are unpredictable as they depend upon the physical properties of the snow. Although it is argued that snow provides good insulation, such insulation is only partially effective at best.

Let me illustrate. A good many snow pillows placed in service in recent years have employed a large diameter standpipe to accommodate a float type of surface detector. There are some fundamental flaws in this approach.

1. To accommodate a float the standpipes are usually made eight to twelve inches in diameter and consequently are of such large volume that, with transferral of liquid from the snow pillow to the pipe to establish pressure equilibrium, there is substantial reduction of volumne of the snow-pillow, resulting in settling of the snow-pack and attendant "bridging". By using the purge bubble principle to monitor the level in the manometer tube, this tube need only be of fractional inch diameter, resulting in negligible volume change.

2. Surface detection means are subject to substantial temperature error due to change of volume and specific gravity of the filling liquid with temperature. This particular error may be totally avoided through use of the purge bubble principle as the bubbler system senses pressure at the reference point where the piezometer orifice is located, hence is insensitive to temperature expansion of liquid in the tube. <u>This consideration is so meaningful, in fact, that it eliminates the need to even know the specific gravity of the filling liquid</u>.

I have computed that the optimum ratio of cross sectional areas of snow pillows to the manometer tubes approximates the coefficient of expansion of the filling liquid. This results in as nearly a constant volume snow pillow as appears possible. The coefficient of expansion of ethylene glycol, for example, is nominally $640(10)^{-6}$. Using a piece of common 1" NPS pipe as the manometer tube with sectional area of 0.934", from which we subtract the sectional area of a 1/4" piezometer line which passes down through the pipe, leaving a net area of 0.885 in^2, results in a pillow diameter of nominally 42". I would suggest the pillows be made of polyvinyl chloride, polyurethane or polyethylene sheet plastic. Rolled up such a snow pillow is sufficiently small to be carried in one hand. The pillows in service that use float type surface detectors in large diameter standpipes, are in some instance, quite large themselves so that they have diameter ratios approximating the coefficient of expansion as I have suggested. By my theories, these could be expected to provide good service.

However, due to their large size, weighing several hundred pounds as compared to less than five pounds, they become cumbersome, expensive and difficult to install in remote areas. My analysis indicates the recommended construction will provide as good data as a large pillow and the entire system with Hydrogauge, 55 $ft^3 N_2$ cylinder, batteries, filling oil, etc., but excluding radiotelemetry equipment, would weigh less than 200 lbs. With a minor modification now in progress the Hydrogauge will be sufficiently rugged and light, approximately 30 lbs., to permit backpacking over rough terrain in fully assembled form. Also, the pillow must be as thoroughly evacuated of air cavities as possible. In the field this can be quite difficult with large pillows, but rather easy with small sizes through mechanical manipulation.

Another practice being employed for snow pillow data acquisition is the placement of a pressure transducer inside a filled and sealed snow pillow. This practice, too, has similar shortcomings as described above, but the temperature errors are of even greater magnitude. If ethylene glycol is used as a fill, the pillow will expand and contract at the rate of 640 parts per million per °C, causing very appreciable rising and settling of the snow burden. Or worse, if the pillow should be filled full, so that it were stretched at any time with the volumetric change, it would register a large increase in snow-level during spring thaw when the suns rays first reached the pillow. However, these shortcomings can be overcome with the addition of the small bore manometer tube to serve as a thermal expansion chamber even though it is not used directly for measurement. If the implanted pressure transducer is of good quality it would then be responsive to hydrostatic head, rather than pressure, and should provide reliable data.

There is no purpose in making the pillows thick. The suggested 42" diameter should be filled to about 1" to 1-1/2" thickness and the body should remain slack.

GAUGING OF DEEP WATER BODIES (80')

Such gauging relates principally to water reservoirs for which we recommend Servomanometers for their high accuracy, and the use either of the purge bubble principle or a direct water-mercury interface. The choice depends principally on the location of the Servomanometer.

In light of the foregoing similar subject matter, the pertinent considerations may be briefly listed as follows:

Advantages and Comments:

1. Methods have proved exceedingly reliable and well suited.
2. Technique senses/measures hydrostatic pressure at piezometer orifice, hence measures true water content, unaffected by thermal contraction and expansion.
3. Provides a practical maximum of accuracy, nominally 0.01% of reading or better.
4. Instruments are temperature compensated.
5. If gauging station is downstream from dam, as in a powerhouse, water filled piezometer line may be run downward through dam to carry water to form water/mercury interface in Servomanometer. Care must be exercised to have a continuously descending line to the instrument, to avoid bubbles being trapped.
6. In instances where ambient temperature variation is not great, the new Exactel Precision U-Tube Series Servomanometers (Ref: Bulletin U-550) are more economical than prior Precision Cistern Series, but are slightly less accurate.
7. Maintenance requirements are negligible.
8. Operable from storage batteries with addition of power pack. (Two types are used; standby, for use during power failures and "momentary" to energize system at timed intervals.)

OCEAN TIDE AND TSUNAMI GAUGING

Method: Servomanometer or Hydrogauge in combination with purge bubble principle.

Ref: Figs. 34 and 35, Bulletin GEN-65.

Comments and Advantages:

1. Methods are generally similar to those described for river and stream gauging.
2. Instruments readily equipped with alarms based upon tide elevation and/or rate of change.