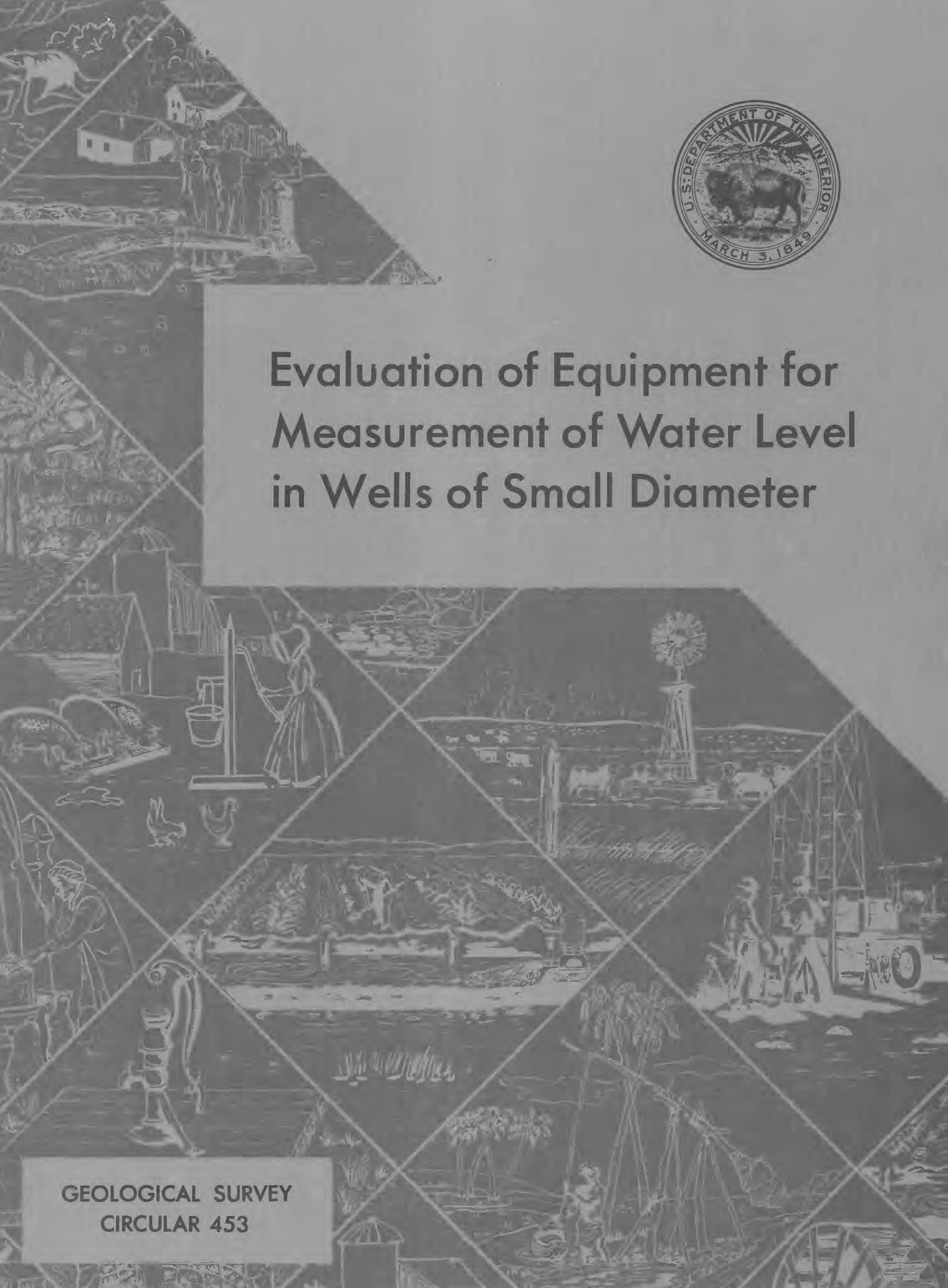
Evaluation of Equipment for Measurement of Water Level in Wells of Small Diameter



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Evaluation of Equipment for Measurement of Water Level in Wells of Small Diameter

By Eugene Shuter and A. I. Johnson

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CONTENTS

ILLUSTRATIONS

Evaluation of Equipment for Measurement of Water level in Wells of Small Diameter

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ABSTRACT

For many years hydrologists have needed a device for recording the changes of water level in wells less than 4 inches in diameter. The hydrologic laboratory, U.S. Geological Survey, Denver, Colo., was assigned the responsibility of evaluating several models of such devices that have been developed in recent years. The assignment included laboratory and field evaluation of three major units—the Drescher float-gage, Columbus cradle-gage, and the Koopman ferret-gage attachments—all developed by personnel of the Geological Survey. Several other devices were evaluated by examination or by study of pertinent literature and plans.

The evaluation indicated that none of the units meets all field requirements. The Koopman ferret-gage attachment was found to be the most versatile, reliable, and accurate of those evaluated. The Drescher float-gage attachment is recommended for use on wells having a shallow depth to water. The evaluation indicated also that electronic pressure transducers might be potentially useful for water-level measurement.

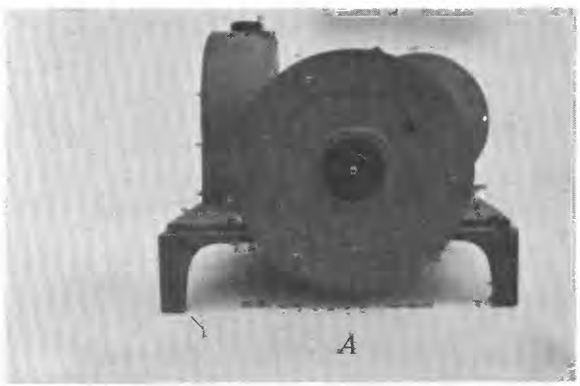
INTRODUCTION

PURPOSE AND SCOPE

In 1937, O. E. Meinzer, chief of the Ground Water Branch of the U.S. Geological Survey, stated, "The automatic water-stage recorders are among the most valuable instruments of precision used in the study of ground water." In all types of water-resources investigations throughout the world the water-stage recorder (also called water-level recorder or recording gage) has become an important instrument for obtaining continous records of water-level fluctuations in wells.

Nearly all water-level recorders now used are of the mechanical, float-actuated type. (See fig. 1.) The recording energy is produced by the movement of a float as it rises or falls with changes in water level. The float is fastened to a flexible cable that extends upward, over a pulley, and downward to a counterweight at the other end. The pulley is connected to a recording drum that revolves as the cable moves, and a trace of the water-level fluctuations is made by a clock-actuated pen that moves across the chart.

A certain minimum force is required to move the mechanism of the recorder. This actuating force must be supplied from the float and must be sufficient to overcome mechanical losses due to the bending of the cable over the pulley, gear play, friction in the bearings and gears, and friction of the pen on the paper. Stevens [no date, p. 20] suggests that the float lag (lag of the record behind the true water level) is directly proportional to the force required to move the mechanism and is inversely proportional to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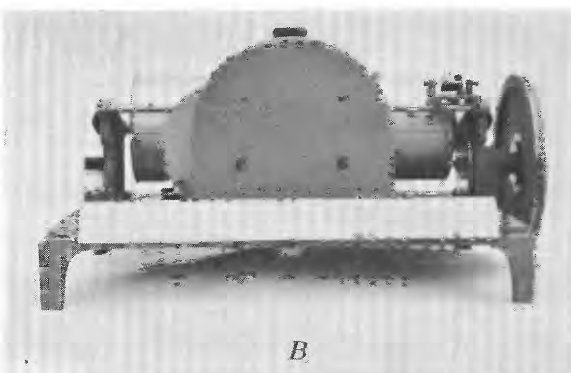
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Figure 1.—A standard-type water-level recorder. *A*, Side view; *B*, Front view.

the square of the float diameter. The force available for sufficient response energy to operate a recording gage is equal to the weight of water corresponding to the fraction of the volume of the float emerged or submerged as a result of change in water level. Small-diameter floats have a lesser amount of usable force; consequently, this force must be magnified by a mechanical attachment to obtain adequate recording ability.

A float of sufficient size to produce an acceptable record can only be used in a well having a minimum diameter of 4 inches. Because of the expense of constructing wells 4 inches or more in diameter and because of the need for obtaining records of water levels by means of a float lowered into the narrow annular space around the pump column in a pumped well, a device to record these water levels accurately has been greatly needed.

During the past few years several gage attachments or mechanisms for use in recording water-level changes in small-diameter wells have been proposed and constructed. The purpose of this project was to test and evaluate some of these units.

Three units—the Drescher float-gage attachment, the Columbus cradle-gage attachment, and the Koopman ferret-gage attachment—were evaluated. Several other devices were evaluated by examination and by study of pertinent plans, literature, correspondence, and, in some cases, the equipment itself. The evaluation in the laboratory and field was limited to equipment for which at least one pilot model had been constructed previously and which showed the most promise at the time the project was begun. The lack of duplicate pilot models of the three units evaluated in this report prevented simultaneous evaluation at different field locations.

HISTORY

Many substitutes for the standard recorder float have been used in attempts to record water levels in small-diameter wells. During the past 10 years, these substitutes have become more elaborate and many have taken the form of electrically actuated, motor-powered devices designed to overcome the float lag caused by small-diameter floats.

In 1947, W.G. Keck, consulting geophysicist, East Lansing, Mich., designed the "Keck immersion element"—one of the first known workable models of an electrically activated float.

In 1954, J. H. Criner, engineer of the Ground Water Branch, Memphis, Tenn., developed the "Criner gage attachment."

In 1955, W. J. Drescher, branch area chief, Ground Water Branch, U.S. Geological Survey, Madison, Wis., developed the "Drescher float-gage attachment."

In 1956, F. C. Koopman, engineer of the hydrologic laboratory, U.S. Geological Survey, Denver, Colo., developed the "Koopman ferret-gage attachment."

In 1959, the equipment-development laboratory, U.S. Geological Survey, Columbus, Ohio, developed the "Columbus cradle-gage attachment."

ORGANIZATION

Recognizing the great need for the evaluation of equipment to measure water levels in small-diameter wells, the junior author formally proposed the evaluation project in the spring of 1958 and started the preliminary investigation. The senior author was designated project leader in July 1959, and the project was continued by him under the general supervision of the junior author, who is chief of the hydrologic laboratory. The project was carried out at the laboratory in Denver, Colo. Some studies were made also at offices of the Ground Water Branch in several States.

ACKNOWLEDGMENTS

Field-evaluation data were provided by Messrs. W. J. Drescher and C. L. R. Holt of the Madison, Wis., office of the Ground Water Branch and by V. C. Fishel and S. W. Fader of the Lawrence, Kans., office. Many others of the Branch made helpful suggestions regarding the operation of this equipment.

METHODS OF INVESTIGATION

TECHNIQUES

LABORATORY PHASE

Three units—the Drescher float-gage attachment, the Columbus cradle-gage attachment, and the Koopman ferret-gage attachment—were tested under variable temperature and humidity conditions in a temporary outdoor laboratory and under controlled temperature and humidity conditions in the main laboratory. In both locations, the three units were tested simultaneously in a tank (fig. 2) in which the water level could be made to fluctuate in any desired cycle. The gage attachments were actuated by small-diameter floats suspended within 2-inch inside diameter plastic-tube "wells" in the test tank. All units were tested on Stevens type-F recorders (fig. 1), but the attachments were designed to function with any type of float gage using a pulley on a horizontal shaft to drive the recording mechanism. A Stevens type-F water-level recorder equipped with a $3\frac{1}{2}$-inch-diameter float provided a standard for comparison with the three tested gage attachments.

Several different switches, relays, motor drives, and other parts of the gage attachments were investigated to obtain components giving maximum efficiency and economy.

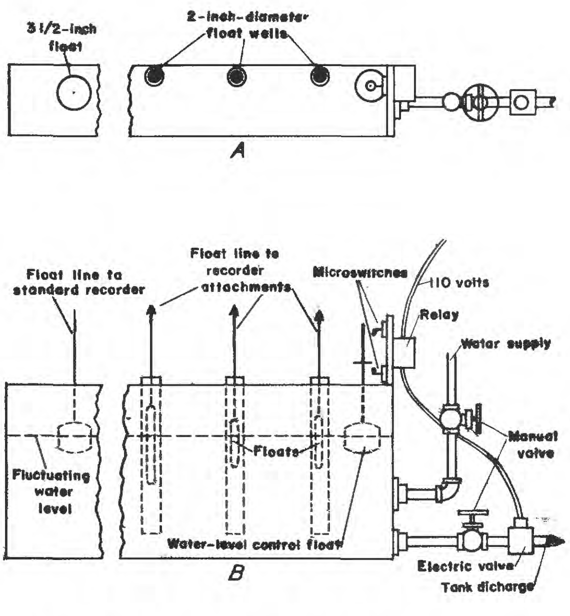


Figure 2.—Laboratory tank for testing gage attachments.

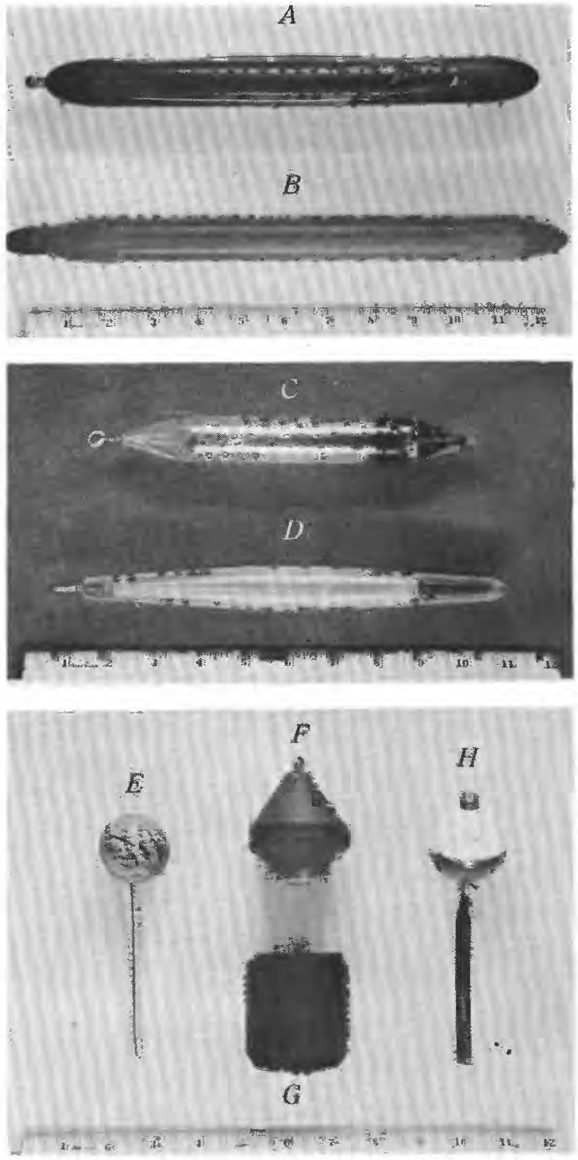


Figure 3.—Floats used in testing gage attachments. Floats *A–D* and *F–H* are plastic; float *E* is cork with lead ballast.

Eight floats of different design were tested in order to obtain the best possible float and gage combinations. (See fig. 3.) Only those floats found to be the most satisfactory are discussed in the remainder of the report.

FIELD PHASE

All three gage attachments were tested in the field; however, this testing was less comprehensive than that in the laboratory.

The Columbus cradle-gage attachment was tested extensively in Wisconsin. The attachment was equipped with a float, 1 inch in diameter and 11 inches long (float *B*, fig. 3), which in turn was installed in $1\frac{1}{4}$-inch steel pipe (1.38-inch inside diameter) suspended within a 6-inch-diameter well. A $3\frac{1}{2}$-inch-diameter float attached to a standard water-level recorder was installed in the space between the $1\frac{1}{4}$-inch pipe and the wall of the 6-inch-diameter well. Thus, the water-level changes were recorded simultaneously on both recorders. The average depth to water was 72 feet. The maximum change in water level was approximately 1 foot.

The Drescher float-gage attachment was tested in several observation wells in Wisconsin, Colorado, and Kansas. In Wisconsin the gage attachment, equipped with a float 1 inch in diameter and 12 inches long (float *A*, fig. 3), was installed on shallow wells constructed of $1\frac{1}{4}$-inch steel pipe. In Kansas the gage attachment was installed in $1\frac{1}{4}$-inch-pipe wells having a depth to water of approximately 150 feet. In Colorado the gage attachment, equipped with a $1\frac{1}{4}$-inch-diameter float (float *H*, fig. 3), was installed in a 2-inch plastic pipe. The 2-inch pipe was suspended in an 8-inch-diameter well. Daily water-level measurements were made by steel tape for control. The average depth to water was 263 feet.

The Koopman ferret-gage attachment was tested in the hydrologic laboratory's observation well at Denver, Colo. It was equipped with a 1-inch detector probe and was installed in a 3-inch plastic pipe. Daily water-level measurements were made by tape for control. The average distance from the recorder to the water surface was 10 feet.

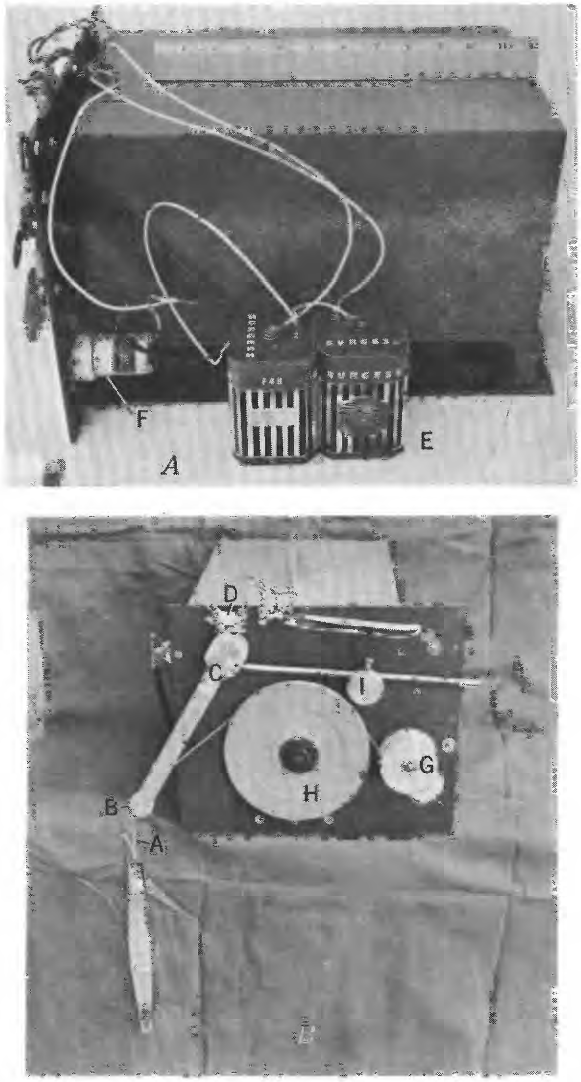


Figure 4.—Drescher float-gage attachment. *A*, Side view; *B*, Front view.

DESCRIPTION AND OPERATION OF EQUIPMENT

DRESCHER FLOAT-GAGE ATTACHMENT

The Drescher float-gage attachment is added to the standard recorder to record water levels in small-diameter wells (fig. 4). The device is unique in its design and in the assembly of the parts but not in the parts themselves. The unit uses a small-diameter float connected to a float line, which runs from the float over a pulley on the end of a balance arm, and thence around the recorder pulley to a motor-driven reel powered by two 6-volt lantern batteries in series. A float movement causes the balance arm and attached mercury switch to tilt, and the resulting electrical contact starts the motor, causing the float-line reel to retrieve or release cable until the balance arm returns to the equilibrium position. This movement of cable on or off the reel turns the drum of the recorder. An L-shaped stand which holds the balance arm, motor, and reel assembly, is a convenient means of adding this attachment to recorders already installed on wells. As of 1960, the cost of construction was approximately $60.

The operation of the Drescher float-gage attachment can be best understood by following the action of the gage as the water level rises and lowers. (See fig. 4.)

As the water level rises the float is buoyed upward, thereby releasing tension on the float line (*A*) and exerting less pressure downward on the idler pulley (*B*). The lever-arm assembly (*C*) with attached mercury switch (*D*) moves clockwise, as shown in figure 4 *B*. One of the contacts of the switch closes the circuit between the battery (*E*) and motor (*F*), and the motor turns the reel (*G*) clockwise, retrieving the float line. The recorder pulley (*H*) rotates and the water-level rise is recorded. When the float line has been retrieved an amount equivalent to the rise in water level, the motor tends to pull the float out of the water; the resulting increase in line tension causes the lever-arm assembly to move counterclockwise. The contact is broken on one side of the mercury switch, and the mechanism remains at rest until the water level changes again. The balance weight (*I*) permits adjustment for the weight of the float and float line.

As the water level lowers the float is lowered, increased tension is applied to the float line, and the lever-arm assembly moves counterclockwise. The switch closes the electrical circuit and the motor-powered reel releases the float line until the water is supporting the weight of the float and the line tension is reduced. The lever-arm assembly then moves clockwise, causing the switch to open the electrical circuit, and the mechanism remains at rest until the water level changes again.

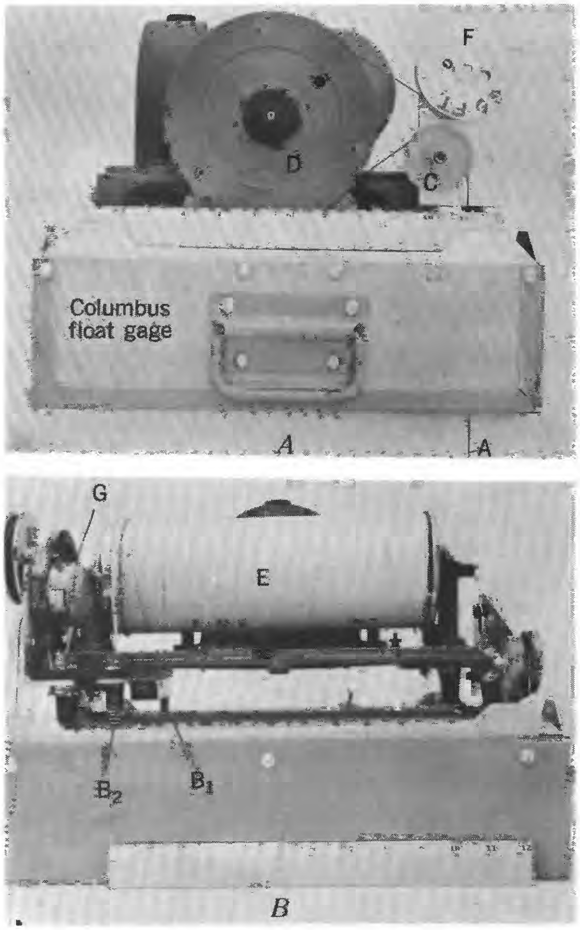


Figure 5.—Columbus cradle-gage attachment. *A*, End view. *B* Side view.

COLUMBUS CRADLE-GAGE ATTACHMENT

The Columbus cradle-gage attachment is a revision of the standard water-level recorder that makes possible the recording of water-level changes in small-diameter wells. (See fig. 5.) It consists of a framework designed so that the recorder chassis itself tilts with a change in float position. The recorder, with attached control mechanism, is balanced on knife edges that are attached to a plastic base. Electrical contacts of palladium, which are equipped with spring-type overload protection and mounted on each side of the recorder frame close an electrical circuit as the recorder chassis tilts because of movement of the float and thus operate a motor-driven reel. The two-battery circuit has a switch for changing the direction of the recorder motion. An adjustable balance weight is attached to the recorder frame. The equipment is designed so that a water-level change as great as 3 feet per minute will be recorded. A metal box encloses the recorder and all the control mechanism. The plastic recorder base described above is approximately 5 inches above the bottom of the box, and the space below is utilized for battery storage. As of 1960, the cost of construction was approximately $200.

The operation of the Columbus cradle-gage attachment can be best understood by following the action of the gage as the water level rises and lowers. (See fig. 5.)

As the water level rises the float rises; the reduced tension on the float line (*A*) permits the recorder assembly to tilt counterclockwise, as shown in figure 5 *A*, thereby causing one set of electrical contacts (B_1, fig. 5 *B*) to touch, complete the circuit, and actuate the motor-driven reel. The float line is retrieved over a pulley (*C*) and around the recorder pulley (*D*) that drives the recorder drum (*E*). The line is retrieved onto the reel (*F*) attached to the motor (G), so located that a change in proportion of float line in the well or on the reel does not disturb the balance of the instrument.

As the float line is reeled in, the float is raised, and the increased weight on the line causes the recorder assembly to tilt clockwise. The previously closed electrical circuit is opened and the mechanism comes to rest.

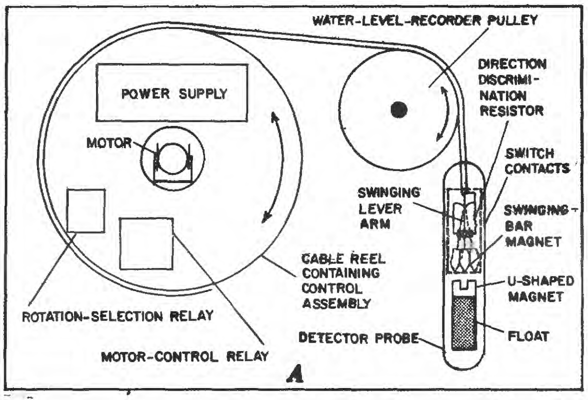
As the water level lowers the float lowers; the increased tension on the float line causes the recorder to tilt clockwise until the other electrical contacts (B_2, fig. 5 *B*) touch, thereby completing the circuit. The motor-powered reel then releases float line until the line tension is reduced and the recorder tilts counterclockwise, opening the previously closed electrical circuit. The mechanism then will remain at rest until the water level changes again.

KOOPMAN FERRET-GAGE ATTACHMENT

The Koopman ferret-gage attachment may be used with any standard water-level recorder without modification of the recorder. (See fig. 6.) The gage consists of an 8-inch-diameter hollow aluminum reel and a 1-inch-diameter detector probe.

The compact reel encloses the relays, motor, and power supply (mercury battery) and stores as much as 750 feet of strong and durable 0.08-inch Ellsworth coaxial (armored) control cable. Although different response rates can be obtained by changing the ratio of the gear-drive assembly, the gearing ratio for the present reel was selected to permit response to water-level changes of 2 feet per minute.

The detector probe is a streamlined unit of sufficient weight to maintain tension in the cable in spite of any dragging of the probe or cable against the well casing. The probe contains a single-pole, double-throw, center-off switch with attached swinging bar magnet, enclosed in a waterproof section of the probe. Below is a small float, in a section of the probe that is open to the water, on which is mounted a U-shaped magnet used to actuate the magnet switch above. As of 1960, the cost of construction was approximately $250.



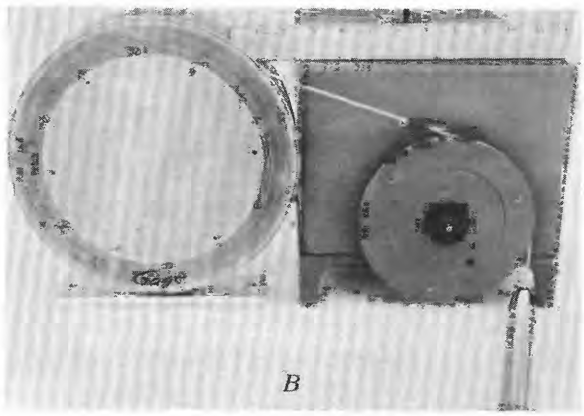


Figure 6.—Koopman ferret-gage attachment. *A*. Schematic. *B*. Front view, with reel cover attached.

The operation of the Koopman ferret-gage attachment can be best understood by following the action as the unit records a water-level change.

As the water level rises the float in the probe is buoyed upward, and the opposition between the attached U-shaped magnet and the magnet on the lever arm of the switch causes the arm to swing in one direction and to close an electrical circuit, which in turn causes the motor to rotate the cable reel counterclockwise, as shown in figure 6 *B*. The direction of rotation is governed by the current that passes through the rotation-selection relay in the cable reel and that in turn is determined by the presence or absence in the circuit of the direction-discrimination resistor in the detector probe. (See fig. 6 *A*.) The detector probe is thus retrieved until it reaches the new water level, at which time the float returns to its original position, and reduction of the opposing magnetic force allows the switch lever arm to return to "off" position. The unit will then remain at rest until there is another change in water level. The probe cable, passing around the recorder pulley, actuates the recorder to record the change in water level.

As the water level lowers the float in the probe moves downward, further reducing the force of the attached U-shaped magnet on the switch magnet, and the spring-loaded switch lever arm closes the other electrical circuit. This causes the motor to rotate the cable reel clockwise and thus lowers the detector probe until the new water level is reached. The float then returns to its original position and causes the switch lever arm to return to the "off" position.

OTHER WATER LEVEL EQUIPMENT

Equipment and attachments, other than the three units just described, have been studied; three types are described in general terms below.

The Keck immersion element probably is the first small-diameter sensing device that has a probe-activated rather than a float-activated float line. This equipment consists of a weighted probe suspended in the well by an electric cable that passes over the recorder pulley and is attached to a reel powered by a 6-volt motor. The probe consists of a pressure-sensitive switch encased in a flexible rubber membrane. As the water level rises or lowers in the well, the resultant change in pressure is transmitted by the membrane to the pressure switch. The switch, through the electric circuit, actuates the reel motor, and the probe is raised or lowered as required until it reaches a neutral pressure position at the new water level. The probe then remains at rest until the water level changes again.

Several models of the Keck immersion element were designed and constructed; the differences between models are mainly in the number of conductors in the electric cable used for the float line. Model KDC-1 has a 3-conductor cable; model KDC-2 has a 2-conductor cable with an added relay circuit; model KDC-3 has a 1-conductor cable, the well casing serving as the other conductor.

The Criner gage attachment consists of a water-level-sensing probe attached to a 3-conductor cable that passes over the recorder pulley to a powered reel. The reel is powered by two 6-volt lantern batteries. Within the probe, a mercury switch is connected by a linkage to a small float that tilts the switch as it responds to a change in water level. As the switch tilts, one side of an electric circuit is closed, and this causes the motor-powered reel to take in or let out cable until the probe reaches equilibrium at the new water level. When this position is reached, the probe remains at rest until the water level changes.

In 1954 the junior author contacted electronics manufacturers to inquire if they manufactured an electronic pressure-sensing device of small diameter. As part of the present project, renewed contacts with manufacturers indicated that at least 20 of them were producing pressure transducers. A pressure transducer is a device designed to convert pressure changes to changes in electrical current or voltage. A pressure transducer installed below the lowest water level expected in the well can be used to determine changes in water level by recording the change in pressure as the head above the transducer changes.

There are two principal methods of converting pressure changes to usable electrical data. The amplitude-modulated system converts the output from the transducer to a proportional d-c voltage or current that can be recorded on such equipment as cathode-ray oscilloscopes, strip-chart recorders, or magnetic oscillographs. The frequency-modulated system converts the output from the transducer into a proportional frequency that can be used on equipment such as magnetic tape recorders or frequency counters. Most transducers require demodulators or amplifiers in the electrical circuit to the recording equipment.

There are several primary types of pressure transducers, all having few moving parts (Berkley, 1958, p. 2-326 to 2-358). Some are of the variable-reluctance diaphragm type, in which the only moving part is a small metal diaphragm that moves only a few thousandths of an inch in an air gap between electromagnetic pole pieces. In the Bourdon tube-type transducer, the displacement of a Bourdon tube is transmitted directly to the moving contact of a precision wire-wound potentiometer, producing an electrical output proportional to the input pressure. With the strain-gage transducer, four strain gages are connected in a Wheatstone bridge circuit, which is balanced at zero pressure—all arms having approximately equal resistance. As pressure is applied, the grids of the strain gages are strained, with a resulting change in their electrical resistance, and the bridge becomes unbalanced. When an external fixed voltage is applied at the input terminals, this unbalance is reflected as a change in voltage at the output terminals that is proportional to the change in pressure.

EVALUATION OF EQUIPMENT

DRESCHER, COLUMBUS, AND KOOPMAN ATTACHMENTS

Many factors need consideration in the evaluation and selection of equipment for recording water-level changes in small-diameter wells. These factors are discussed in detail for the Drescher, Columbus, and Koopman gage attachments.

RECORDING ACCURACY

The ability of a gage attachment to transmit accurately a small water-level change in a well to a recorder chart is of primary concern. The principal factors affecting this accuracy are design of the float, float and float-line friction, sensitivity of the switching mechanism to movement of the float when water levels change, and the condition of the power supply.

The type and design of the small-diameter floats used in this evaluation (fig. 3) had a bearing on the accuracy of the Drescher and the Columbus attachments. The Drescher float-gage attachment gave the best results when equipped with a 1 3/8-inch plastic float of type *H*. Float types *A*, *D*, and *C* were next best, in that order. The Columbus cradle-gage attachment comes equipped with a float of type *B*, but any of the small-diameter floats will work. All the floats, except types *F* and *G*, will fit inside $1\frac{1}{2}$-inch pipe.

Float and float-line friction, or "drag," against the well casing greatly affects the recording accuracy of the Drescher and the Columbus attachments. For float-activated attachments of this type, this problem becomes especially acute in crooked or deep wells. The drag between the float and the well casing can be reduced by the addition of a light oil, such as kerosene, to the water surface. However, the largest error is not caused by float drag, but by float-line drag along the well casing. Although small-diameter monofilament nylon line had less drag than other float-line material, it did not completely overcome the problem. The drag effects are more easily understood when it is realized that one of the small-diameter floats may have a total weight of only 6.5 ounces, and the weight added to or subtracted from the float line by a decline or rise of the water level would be only 0.2 ounce for an 0.1-foot change.

When the Drescher and the Columbus attachments were carefully installed in the laboratory test tank or on a shallow well in the field, and the float line was prevented from dragging along the casing, their recording accuracy was approximately 0.02 foot. (See fig. 7 for an example of a Drescher-gage record.) As installed on the deep observation wells near Denver, Colo., and Madison, Wis., however, the gage attachments showed a pronounced effect from float and float-line drag. (See figs. 8 and 9.)

Figure 9 shows that the record of water-level fluctuations obtained by the Columbus

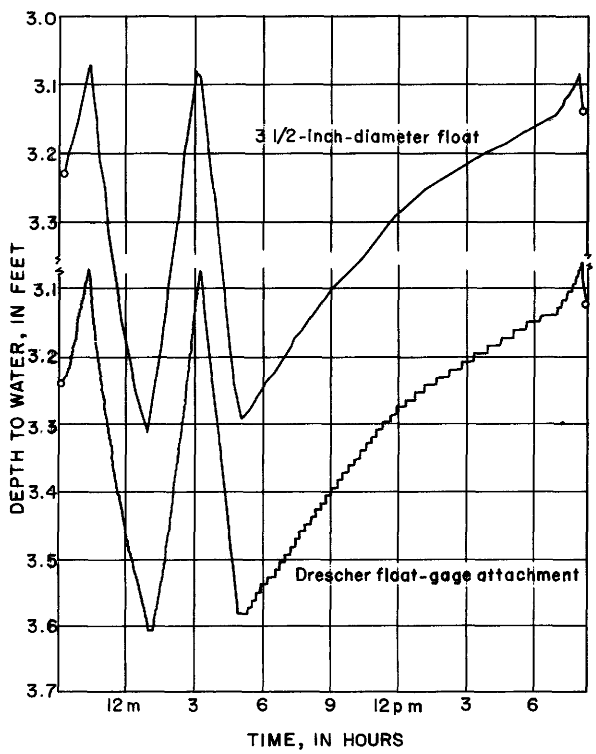


Figure 7.—Comparison of water-level record from recorder with $3\frac{1}{2}$-inch-diameter float with record from similar recorder with Drescher float-gage attachment and $1\frac{1}{4}$-inch-diameter plastic float.

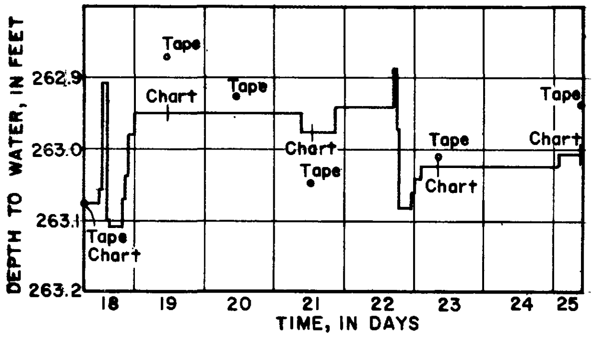


Figure 8.—Drescher float-gage record showing the effect of float and float-line "drag."

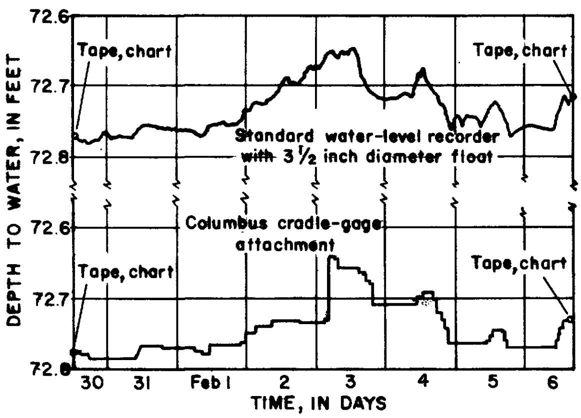


Figure 9.—Columbus cradle-gage record showing the effect of float and float-line "drag."

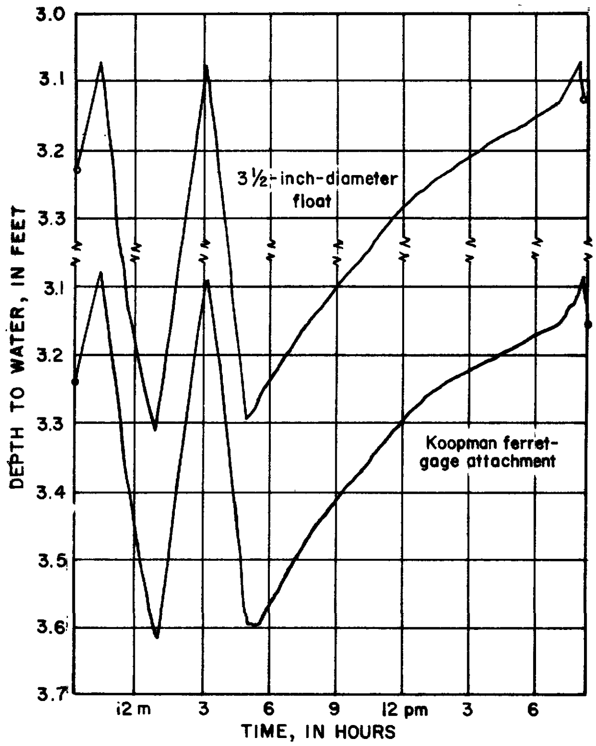


Figure 10.—Comparison of water-level record from recorder with $3\frac{1}{2}$-inch-diameter float with record from similar recorder with Koopman ferret-gage attachment.

cradle-gage attachment corresponds generally with that obtained by the standard water-level recorder. However, fluctuations of less than 0.02 foot are not discernible, and the record for February 3, 1959, is in error as much as 0.09 foot.

The Koopman ferret-gage attachment obtained records of water-level changes on wells of considerable depth with an accuracy of 0.01 foot. As shown in figure 10, the record of water-level changes obtained with this unit corresponds very closely to that obtained with a standard water-level recorder. The tendency to produce "steps" was not nearly as great as that with either the Drescher or the Columbus attachment. Thus, the principal disadvantage of the Drescher and Columbus attachments—float and float-line drag and hang-up—is not a problem with the Koopman ferret-gage attachment because the weight of the detector probe overcomes the drag forces.

The sensitivity of the switching mechanism to the float movement also is very significant. Both the Drescher and the Columbus attachments required about an 0.01-foot change of water level to raise or lower the float a sufficient amount to actuate the switches and drive the recorder. The Koopman attachment will respond to a water-level change of 0.005 foot.

The condition of the battery power supply was critical. The accuracy of the Drescher and Columbus attachments was affected by weak batteries. When weak batteries were purposely used as the power supply for these two attachments, the record shown in figure 11 was obtained. This record shows a poor response to water-level changes even though the response normally would be good for wells having such a shallow depth to water. To avoid this effect, the batteries should be replaced after a maximum of 60 days of normal use.

The Koopman ferret-gage attachment also was affected by a power loss but much less than were the other two attachments, owing to a better float-to-switch response and to a longer peak-power life provided by the mercury-battery pack. The battery pack could operate efficiently for approximately 90 days under normal conditions.

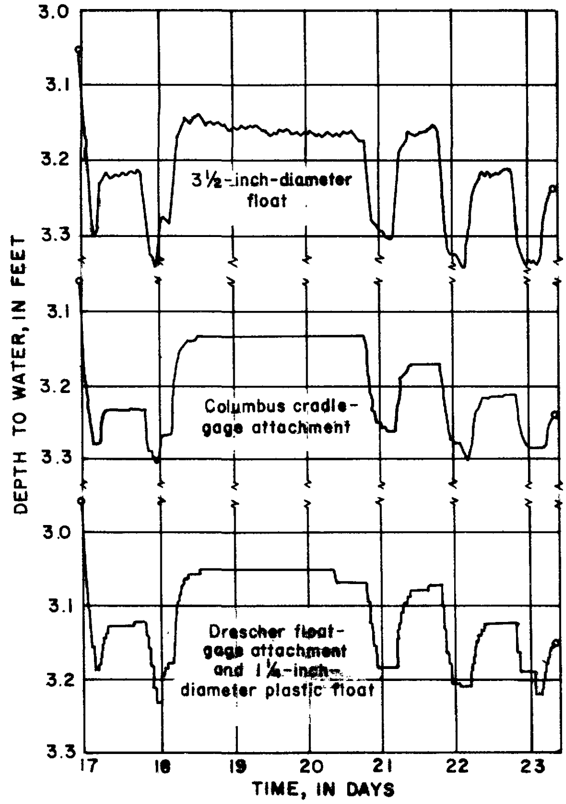


Figure 11.—Effects of weak batteries on water-level records obtained by use of recorder equipped with the Drescher float-gage attachment, the Columbus cradle-gage attachment, and conventional $3\frac{1}{2}$-inch-diameter float.

RATE OF RESPONSE TO WATER-LEVEL MOVEMENT

The rate of response to water-level movement is determined by gear-drive and motor-speed ratios and also by an increase in the amount of power supplied to the motors. The Drescher float-gage, Columbus cradle-gage, and Koopman ferret-gage attachments had a rate of response to water-level movement of 1, 3, and 2 feet per minute, respectively. The response rate could be safely increased to 2, 6, and 4 feet per minute by gear-ratio changes. The response rate of the Drescher and Columbus attachments could be doubled again—4 and 12 feet per minute, respectively—by doubling the power supplied to the motors. This increase, however, should be used only for short periods, such as during aquifer tests, because continuous operation at the higher voltage could injure the motors.

EASE OF REPAIR IN FIELD

Because of the possibility of a malfunction of a gage attachment and a resulting loss of record, the ease of repair in the field is a significant factor. The Drescher and Columbus attachments are of simple construction and could be maintained and repaired by most field personnel with a minimum of instruction. The Koopman ferret-gage attachment, however, is more complex and, except for a battery change, could not be easily serviced or repaired in the field. Although the sealed design of this instrument makes it virtually trouble free, it probably would be necessary to maintain a spare attachment in the field to be used while a faulty unit was being repaired.

STABILITY UNDER INFLUENCE OF WEATHER

If the gage attachments are installed inside a recorder house, the effect of weather (temperature, humidity, and wind) is negligible, except for the Columbus cradle-gage attachment. With this attachment, temperature changes of only 10°F cause loss of sensitivity to water-level movement and even a shorting of the circuit, followed by battery failure. These effects are due to the design of the recorder framework, which is constructed of plastic, steel, aluminum, and brass sheets, all fastened together in such a manner that differences in expansion or contraction cause undue movement of the contact points.

The moisture in humid climates or dust in dry climates may injure the reel motors on the Drescher and Columbus attachments.

In the absence of a protective shelter, wind could cause considerable difficulty in the balance of both the Drescher and the Columbus attachments.

The Koopman ferret-gage attachment is completely enclosed and is not affected by any of these conditions.

EASE OF INSTALLATION

The Drescher and Koopman attachments are small and are simple enough that they can be installed with a minimum of effort and instructions. The time required for installation of either of these attachments would exceed only slightly the time required for the installation of a standard water-level recorder. The Columbus cradle-gage attachment is so designed that its size and weight (approximately 40 lb) make installation somewhat difficult and time consuming.

ADAPTABILITY TO STANDARD WATER-LEVEL RECORDERS

Although the Drescher attachment was designed to be used with the standard water-level recorder, it can be adapted easily to operate any water-level recorder that uses a horizontal-shaft pulley to drive the recorder drum. The Columbus cradle-gage attachment would require a complete new design before it could be used with any recorder other than the Stevens type F or FM. The Koopman ferret-gage attachment was designed to be used with any standard water-level recorder.

OTHER EQUIPMENT

The Keck immersion element was used with some success in several localities where the units could be closely observed and where personnel were proficient in maintenance and repair. Model KDC-1 proved to be the most satisfactory of the three models but had the disadvantage of requiring bulky and expensive 3-conductor cable. The rubber membrane of the immersion element and the insulation on the electric cable deteriorated rapidly, and the resulting leaks quickly shorted the electric circuit. These difficulties prevented universal acceptance of this device, and its development was discontinued. The device costs $50 to $100 to construct.

The Criner attachment offers a possibility for general use in all types of wells, because its motion is powered by a sensing probe. If the probe could be made heavier, effects of "drag" could be overcome; and the attachment would provide greater sensitivity than devices having larger floats. However, this attachment has several other disadvantages—it requires bulky and expensive 3-conductor cable and a specially constructed mercury switch, and the mechanical connections within the sensing probe are subject to corrosion. This attachment probably costs between $50 and $100 to construct.

Electronic pressure transducers are potentially promising for use in automatic recording of water-level movements in small-diameter wells. Answers to questionnaires and personal interviews with many producers of transducers have been encouraging. An accuracy of at least 1 percent and as small as 0.5 percent of full scale can be obtained readily, and it is hoped that further development will provide even greater accuracy. Installation of transducer equipment by unskilled personnel would be virtually impossible, however. Transducers cannot be adapted to existing water-level recorders, and the cost of installation would be high. Excluding development costs, a transducer with digital read-out would cost approximately $1,000, and with recorder, approximately $1,500.

SUMMARY

The characteristics considered to be of the most importance in this evaluation are summarized in the table on the following page.

The Koopman ferret-gage attachment obviously is superior to the other gage attachments evaluated in this study. Its primary advantage is its ability to overcome drag and thus to record water levels accurately in deep or crooked wells. It is also more sensitive and efficient in recording water levels in shallow wells and in wells of small diameter.

Because of its simple construction, simplicity of operation, ease of maintenance, and low cost, the Drescher float-gage attachment is good for use on wells where the water level is less than 50 feet below the land surface.

The pressure transducer offers considerable promise for future use in water-resources work and its evaluation will continue. Its general application is limited by its high cost and complicated electronic circuits, but it does offer an accurate means of recording water-level changes in small-diameter or crooked wells of great depth. In addition, transducers offer the intriguing possibility of recording water-level changes in observation wells at a considerable distance from a central-office recorder.

Evaluation summary for the Drescher float-gage, Columbus cradle-gage, and Koopman ferret-gage attachments

Factors considered	Drescher float-gage attachment	Columbus cradle-gage attachment	Koopman ferret-gage attachment
Recording accuracy for depths to water of less than 50 ft............ feet...	0.02	0.02	0.01
Recording accuracy for depths to water of more than 50 ft........... feet...	-------------	-------------	.01
Rate of response to water-level movement...........feet per minute...	1	3	2
Approximate cost in 1960 ....dollars...	60	200	250
Ease of repair in field.........................	Good	Good	Poor
Stability under influence of weather:			
Temperature	Fair	Poor	Good
Moisture................................	Poor	Fair	Good
Wind	Fair	Poor	Good
Ease of installation	Good	Fair	Good
Adaptability to all standard water-level recorders................................	Good	Poor	Good
Reliability under ideal conditions	Fair	Fair	Good
Simplicity of operation	Good	Fair	Good

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