LEVELS AT STREAMFLOW GAGING STATIONS

U.S. GEOLOGICAL SURVEY

Open-File Report 88-710

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By Edward J. Kennedy

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ILLUSTRATIONS

CONVERSION FACTORS

The inch-pound system of units is used in this manual. For readers who prefer the metric units, the conversion factors for terms in this manual are listed below:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

GLOSSARY OF TERMS

BACKSIGHT (BS)	The reading of the rod held on a point of known elevation.
BENCH MARK (BM)	A permanent marker whose description and elevation above National Geodetic Vertical Datum of 1929 (NGVD of 1929) are included in lists compiled for public use by various agencies.
COLLIMATION	Agreement of a surveying instrument's line of sight with its horizontal axis.
COLLIMATION ERROR FACTOR (c)	The inclination of a level's line of sight, in feet per 100 feet, positive when the line of sight points downward from the instrument.
CURVATURE EFFECT (C) *	The increase in a rod's reading caused by the curvature of the earth.
CURVATURE AND REFRACTION EFFECT (CR) *	The increase in a rod's reading caused by the combination of earth's curvature and atmospheric refraction effects.
DATUM *	A level surface that represents a zero elevation.
DIFFERENTIAL LEVELING	Leveling by use of an engineer's level and leveling rod.
ELEVATION	The vertical distance from a point to the datum.
ENGINEER'S LEVEL	A surveying instrument consisting of a telescopic sight and a sensitive leveling device to make the line of sight horizontal.
ERROR OF CLOSURE	The difference between the elevation of the starting point of a closed circuit of levels, and the elevation of that same point as determined from the last rod reading in the circuit.
FORESIGHT (FS)	The reading of a rod held on a point whose elevation is to be determined.
GAGE DATUM *	The datum whose surface is at the zero elevation of all the gages at a gaging station.
GAGING STATION LEVELS	Levels run (traversed) in the vicinity of a gaging station in order to define and maintain a constant gage datum for the individual gages.
GEODETIC BENCH MARK LEVELS	Relatively long lines of levels between bench marks, run in one of three orders of accuracy with special equipment and meticulous procedures designed to minimize systematic errors and keep closures smaller than 0.017 $\sqrt{M}$ ft for first order,

* See figure 1, page ix, for graphical illustration.

	$0.035 \sqrt{M}$ ft for second order, and $0.050 \sqrt{M}$ ft for third-order levels, where M is the total distance run, out and back, in miles. Note: Fourth-order levels, similar to third-order geodetic levels, are run with ordinary equipment and procedures to reference gaging-station datums to NGVD of 1929.
HEIGHT OF INSTRUMENT (HI)	The elevation of the horizontal line of sight of an engineer's level.
HORIZONTAL *	A direction perpendicular to the force of gravity.
LEVEL *	A line or surface whose segments are all horizontal. Also an engineer's level.
LEVELING	The determination of elevations by surveying, usually with an engineer's level and leveling rod.
LEVELING ROD (ROD)	A slender bar graduated on one face from the bottom, used to measure the height of a line of sight above a point on the ground.
NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD OF 1929) *	A spheroidal datum in the conterminous United States and Canada that approximates mean sea level, but does not necessarily agree with the mean sea level measured at a specific locality. The reference datum used for all national mapping activities.
PARALLAX	The relative movement of the image of the leveling rod with respect to the crosshairs as the observer's eye is moved, caused by improper focusing of the objective lens.
PEG TEST	A procedure used to check that a level's line of sight is truly horizontal.
REFERENCE MARK (RM)	A permanent marker installed in the ground or on a structure in the vicinity of a gaging station, and whose elevation above the gage datum is known.
REFERENCE POINT (RP)	A bolt or screw installed on or in the vicinity of a gage structure in order to set or check the gage by taping from the point to a gage graduation or the water surface.
REFRACTION EFFECT (R) *	A rod reading error caused by the bending of horizontal light rays toward the earth's surface, due to variation in atmospheric density at different elevations.
RETICLE	A surveying instrument's cross hairs and their supporting ring.

* See figure 1, page ix, for graphical illustration.

STADIA	A method for measuring the horizontal distance between an engineer's level and a leveling rod by reading two horizontal cross hairs in the level's telescope. The difference in rod readings at the two hairs, multiplied by a constant, usually 100, is the length of the sight.
TURNING POINT (TP)	A temporary reference mark used in the leveling process.
VERTICAL *	The direction of the force of gravity.

* See figure 1 for graphical illustration.

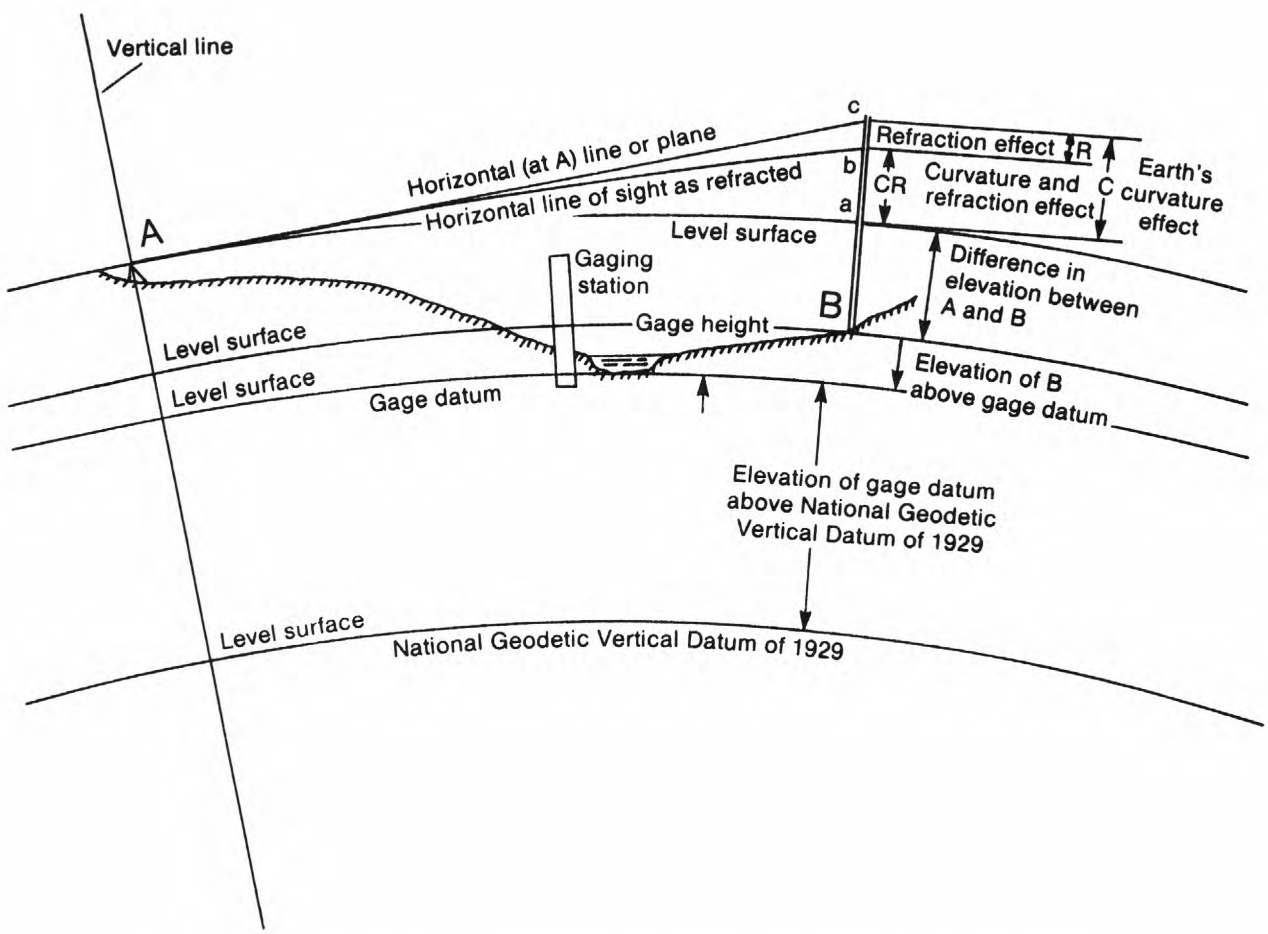

Figure 1.--Leveling terms (curvature greatly exaggerated).

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by E. J. Kennedy

ABSTRACT

This manual establishes the surveying procedures for setting gages at a streamflow gaging station to datum and for checking them periodically for errors caused by vertical movement of the gage-supporting structures. The surveying terms and concepts used are explained; and the details of testing, adjusting, and operating the instruments are outlined. Notekeeping, adjusting level circuits, checking gages, summarizing results, locating the nearest National Geodetic Vertical Datum of 1929 bench mark, and relating the gage datum to the national datum are described.

INTRODUCTION

A newly established gaging station's various gages are set to register the water-surface elevation above a selected level reference surface called the gage datum. The position of this datum is intended to remain unchanged throughout the life of the station. The gage's supporting structures--stilling wells, backings, shelters, bridges and other structures--tend to settle or rise as a result of earth movement or battering by floodwaters and flood-borne ice or debris. Vertical movement of a structure makes the attached gages read too high or too low and, if the errors go undetected, may lead to increased uncertainties in the streamflow records. Leveling, a procedure in which surveying instruments are used to determine the differences in elevation between points, is used to set the gages and to check them from time to time for vertical movement.

Differential leveling, done at intervals, usually between 1 and 4 years, determines the elevations of certain points located on or near the different gages by measuring the vertical distances between those points. When the levels are run, the gages are checked and reset where necessary, usually by taping up or down from reference points to graduations on the gages or to the water surface near them, or by sighting directly on the gage scales. The accuracy of the levels and the time required to run them depends on the weather, the type and condition of the instruments, the procedures used, and especially on the skill of the leveling party. Gages are sometimes checked or reset during routine visits to a station without running levels, by measuring up or down from the reference points, using their elevations as determined from previous levels.

This manual was prepared to provide pertinent information in one document on all aspects of leveling related to gaging-station operation. It is intended for use in formal and informal training programs where hydrographers can learn the approved techniques and develop the degree of skill needed to apply them. Procedures, instruments, and equipment are covered including leveling concepts and terms; equipment selection, maintenance, and operation; checking the various types of gages; recording the field notes; adjusting the

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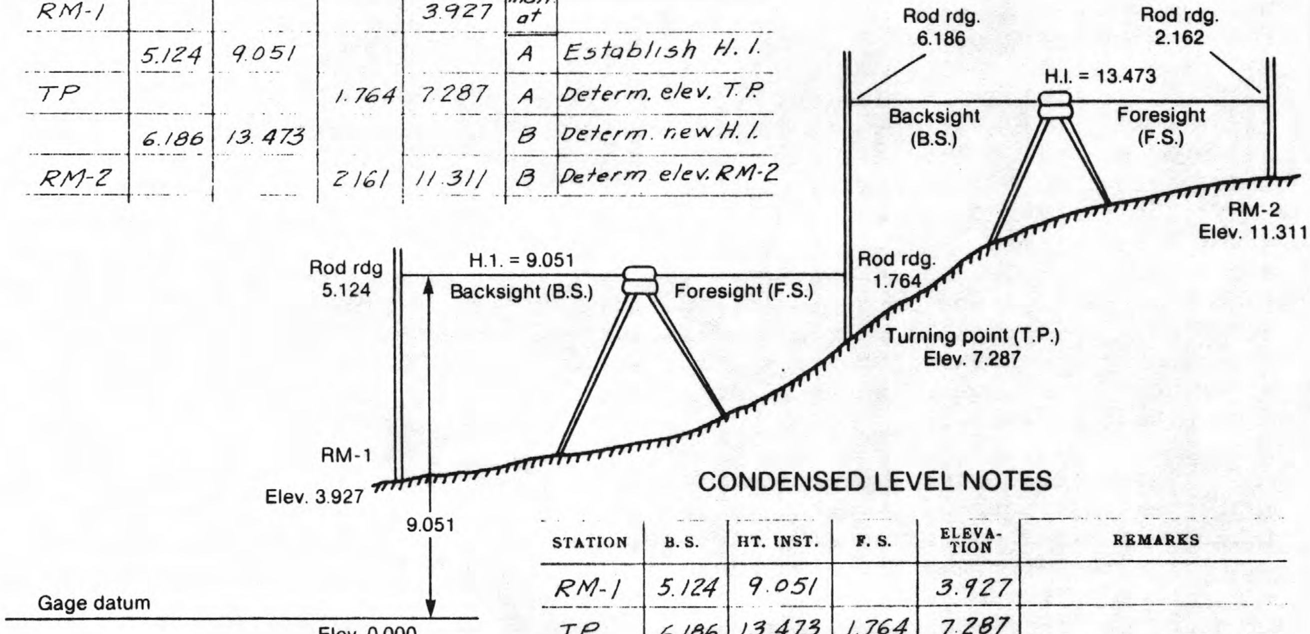
measured elevations by logical distribution of the measuring errors; and summarizing the results of leveling so they can be readily incorporated into the discharge record computations. The leveling techniques described agree with those outlined in surveying textbooks, with the U.S. Geological Survey's National Mapping Division Leveling Instructions (U.S. Geological Survey, 1966), and with instructions for gaging-station leveling developed by the U.S. Geological Survey, Water Resources Division.

LEVELING METHOD AND CONCEPTS

Differential leveling starts by obtaining a reading with the leveled instrument's telescope from a rod held over a point of known elevation. The reading of the telescope's crosshair on the rod's graduations is the backsight (BS), and it is added to the point's known elevation to obtain the elevation of the instrument's line of sight or height of instrument (HI). The rod is then held on the next point whose elevation is needed, and a foresight (FS) is read. The foresight is subtracted from the height of instrument, and the result is the elevation of the point under the rod. That point then becomes a point of known elevation, and the instrument may be moved to a new location, usually halfway between the last-leveled point and the next point to be turned on. The process is repeated as often as necessary until the line is complete. Elevations (Elev.) are computed by using the equations: Elev. + BS = HI, and HI - FS = Elev. Figure 2 illustrates the procedure and two notekeeping formats. The compressed version of the notes is commonly used.

EXPANDED LEVEL NOTES

STATION	B. S.	HT. INST.	F. S.	ELEVATION		REMARKS
RM-1				3.927	Instr at	
	5.124	9.051			A	Establish H. I.
TP			1.764	7.287	A	Determ. elev. T.P.
	6.186	13.473			B	Determ. new H. I.
RM-2			2161	11.311	B	Determ elev. RM-2



CONDENSED LEVEL NOTES

STATION	B. S.	HT. INST.	F. S.	ELEVATION	REMARKS
RM-1	5.124	9.051		3.927	
TP	6.186	13.473	1.764	7.287	
RM-2			2.162	11.311	

Figure 2.--Schematic of leveling procedure.

The principal potential source of error in gaging-station leveling is the instrument's line of sight varying from a true horizontal line, usually due to imperfect instrument adjustment. Few levels can be counted on to remain in close adjustment for much more than a week of normal use. Atmospheric refraction curves the line of sight downward, but errors from this source are usually negligible for the sight lengths used in gaging-station or ordinary bench-mark leveling.

The line of sight of an engineer's level in perfect adjustment generates a horizontal plane, slightly distorted by refraction, when the telescope is revolved about its vertical axis. The surface defined by revolving the line of sight of a badly adjusted leveled instrument (collimation error) in about its vertical axis is a shallow cone with its vertex at the top or bottom, depending on the direction of the collimation error. The cone corresponding to such a level is illustrated in figure 3. The instrument is set up at "B" and its line of sight tilts downward at a slope of 0.010 foot in 100 feet (or a collimation error factor of +0.010). A backsight on "A" 100 feet away would read 0.010 foot low, which would make the computed height of instrument 0.010 foot low. A foresight on "C" 50 feet from the level would read 0.005 foot low, which reading subtracted from the 0.010 foot low height of instrument would give an elevation for "C" 0.005 foot too high. If the foresight were made on "D" 100 feet from the level, the rod reading would be 0.010 foot low and, when subtracted from the 0.010 foot low height of instrument, would give the correct elevation for "D." Note that the effect of the slope in the line of sight is completely cancelled out, and no error in elevation results when the backsight and foresight distances are exactly balanced.

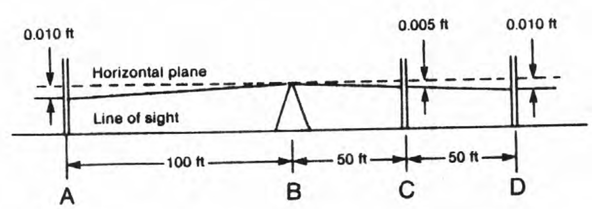
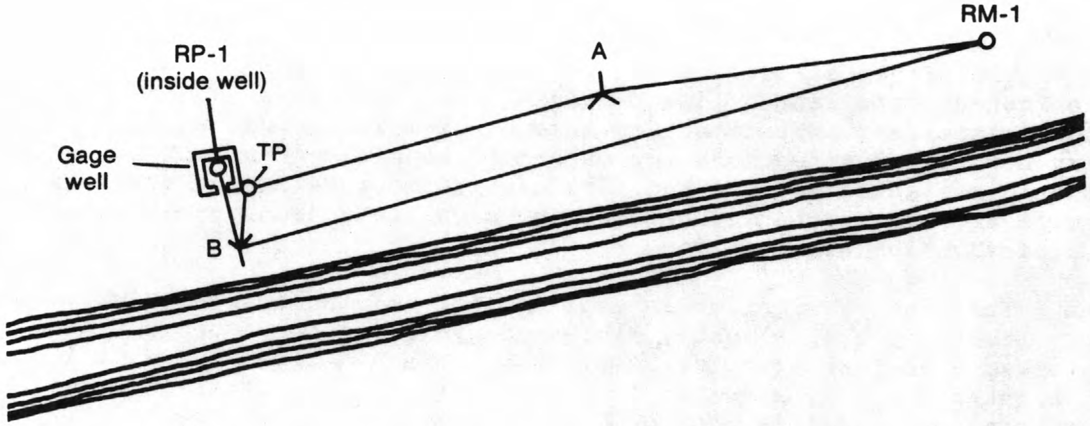


Figure 3.--Variation of line of sight misadjustment effect with length of sight.

A level, even one kept in close adjustment, is used knowing that it may have been knocked out of adjustment since its last checking, so all sight lengths are balanced as closely as possible. An extra turning point can be used to balance the sights at a gaging station where the instrument must be set up at a fixed location. Figure 4 illustrates a situation where the inside gages are checked from a reference point inside the well. Ordinarily the levels could be run from the reference mark directly to the reference point. However, a rod on the reference point can be sighted through the cleanout door, only from instrument setup "B." The backsight distance to the reference mark would be about 100 feet longer than the foresight distance to the reference point; and if the instrument were even slightly out of adjustment, the slope of the line of sight could cause a substantial error in the measured elevation of the reference point. The sight lengths can be closely balanced by using a turning point on the outside of the well and measuring its elevation by setting up the level at "A." The reference point elevation can then



Levels from RM-1 to RP-1, using an instrument whose line of sight slopes downward 0.0001 ft/ft

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS
Level set up at "B", 110 ft from RM-1 and 15 ft from RP-1					
RM-1	4.110	10.835		6.725	
RP-1	4.031	10.913	3.953	6.882	Measured elevation affected by instrument misadjustment
RM-1			4.188	6.725	closure 0
		——			
Level set up at "A", 55 ft from RM-1 and TP, and at "B", 15 ft from RP-1 and 10 ft from TP					
RM-1	4.092	10.817		6.725	
TP	3.817	10.623	4.011	6.806	
RP-1	3.882	10.774	3.731	6.892	True elevation, unaffected by instrument misadjustment
TP	4.102	10.908	3.968	6.806	closure 0
RM-1			4.183	6.725	closure 0
		——			

Figure 4.--Turning point used to avoid unbalanced lengths of sight.

be measured accurately with reasonably balanced sight lengths from the turning point and the reference point.

Curvature and Refraction

Horizontal light rays bend when they travel through varying densities of the atmosphere. The bending is erratic while the air temperature is changing rapidly and also near the ground when heat waves are noticeable. Refraction also bends a horizontal line of sight slightly and smoothly downward from the instrument. When the effect of this refraction is evaluated, it is usually combined with earth's curvature effect, the divergence of a horizontal surface from a level surface. In figure 1 the horizontal line of sight from a level set up at "A" and pointed at a rod held at "B" is refracted downward. If the earth's surface was flat, and the line of sight straight, the rod would read "a." The rod actually reads "b" but "b" appears to be at "c." The distance "ab" represents the combined curvature and refraction effect (CR), which for stable conditions can be estimated by the formula $CR = 0.0206\ F^2$, where F is the length of the line of sight in thousands of feet.

Curvature and refraction are both negligible as long as the sight lengths are less than 150 feet (110 feet for peg testing of a level) and there are no heat waves radiating from the ground that are visible through the telescope. The effect of heat waves can usually be eliminated by keeping the line of sight as high off the ground as is practical and by shortening the sight lengths. Where curvature and refraction effect is consequential, as when referencing a gaging-station datum to National Geodetic Vertical Datum of 1929 (NGVD of 1929) with sight lengths up to 300 feet, it is minimized in the same way as the effect of instrument misadjustment--by balancing the length of the backsight and foresight for each setup of the instrument.

Precision

Precision is the degree of refinement to which measurements are carried out. Leveling precision depends on the type and quality of the instruments used. Nearly all engineer's levels and rods support precision of rod readings to 0.001 foot for sight lengths up to about 125 feet, with less precision for longer shots. Use of less than the maximum precision afforded by the equipment usually saves nothing in time or cost of leveling, so maximum precision is recommended.

Accuracy

Accuracy is the degree of conformity of a measured value to its true value. In leveling it is usually expressed as plus or minus the square root of the length of the level line ($\sqrt{M}$), or number of instrument setups ($\sqrt{n}$), times a value that is measured as explained below.

Level lines start at a point of known elevation and follow a route that turns on all marks and points in the line until the farthest point is reached. The line then heads back to the starting point. The first backsight and last foresight are made on the starting point, thus completing a closed circuit. The difference between the starting elevation and the elevation computed from the final foresight is the error of closure, the principal measure of the accuracy of the levels in that circuit. Systematic leveling errors, such as those from faulty rod calibration, and some other errors related to unbalanced sights, may not be reflected in the closure error.

Leveling Classifications

Leveling is usually classified according to the use of the results, procedural specifications, and closure tolerance. The two classes of leveling used at gaging stations are as follow.

Gaging-Station Levels

These are levels run at a gaging station in order to set or check the gages. The levels are normally run with closures less than 0.003 $\sqrt{n}$ foot, where "n" is the total number of instrument setups in the circuit. Sight lengths, usually under 100 feet, are balanced by estimation where practical. The rod, checked with a steel tape daily, is read to 0.001 foot. The level's line of sight is checked about weekly and again whenever there is reason to doubt its performance. Closures larger than 0.003 $\sqrt{n}$ foot may be tolerable when conditions are unfavorable, but faulty equipment and technique should be considered as possible causes of excessive closure error.

Ordinary Levels

All levels between bench marks, run to less than third-order geodetic leveling specifications, are classified as fourth-order, or ordinary, levels. Gaging-station datums are usually tied to NGVD of 1929 by using ordinary leveling with sight lengths limited to 300 feet and balanced by pacing, rod readings to 0.01 foot, and closures kept under 0.05 $\sqrt{M}$ foot. The total length, M, of the circuit, out and back, is measured in miles. Closures as high as 0.10 $\sqrt{M}$ foot may be acceptable in rough or hilly country.

Adjusting Elevations

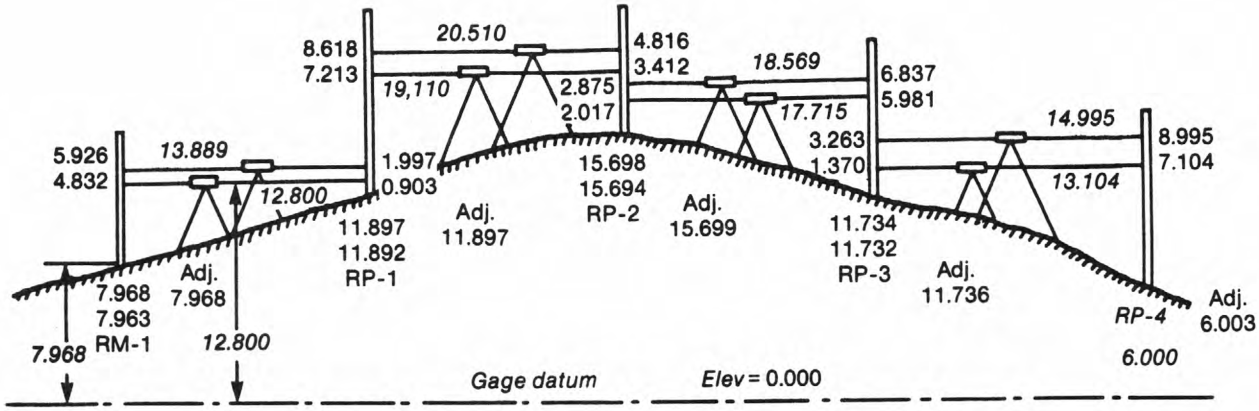
Adjust all elevations by distributing the closures of parts of circuits. The method used requires each mark, other than a starting mark, to be located on only one of the circuits used and to be leveled to on both the outward and return paths of only that circuit. Two differences in elevation between each pair of adjacent marks are determined, and the mean difference is used to compute each adjusted elevation. This procedure also identifies any faulty segment of a circuit that needs to be rerun. Figure 5 illustrates a level circuit beginning at reference mark 1, turning on reference points 1-4, and returning to reference mark 1 by turning on the same points. Notekeeping and adjustment formats also are illustrated.

ENGINEER'S LEVEL

Nearly all engineer's levels are automatic, tilting, or dumpy models; and each of these general types has many variations. Some of the more common models are illustrated in figure 6. Virtually all levels have stadia as standard or optional equipment. Levels can be run to any order of accuracy with all modern engineer's levels, but the proper choice of an instrument can have a profound effect on the time required to use and adjust it.

Automatic Level

An automatic, or self-leveling, instrument levels itself precisely after being manually leveled with its insensitive circular level. The precise leveling device, or compensator, is a system of prisms, one of which, suspended by wires, acts as a pendulum to keep the line of sight horizontal. Despite the level's delicacy, cost, and a tendency for its pendulum to hang up, the automatic level is a favorite for all kinds of leveling.



LEVEL NOTES

STATION	B. S.	HT. INST.	F. S.	ELEVATION
RM-1	4.832	12.800		7.968
RP-1	7.213	19.110	.903	11.897
RP-2	2.017	17.715	3.412	15.698
RP-3	1.370	13.104	5.981	11.734
RP-4	8.995	14.995	7.104	6.000
RP-3	6.837	18.569	3.263	11.732
RP-2	4.816	20.510	2.875	15.694
RP-1	1.997	13.889	8.618	11.892
RM-1			5.926	7.963

ELEVATION ADJUSTMENTS

Object	1st Diff.	2nd Diff.	Aver. Diff.	Elevation
RM-1				7.968
RP-1	3.929	3.929	+3.929	11.897
RP-2	3.801	3.802	+3.802	15.699
RP-3	3.964	3.962	-3.963	11.736
RP-4	5.734	5.732	-5.733	6.003

Error of closure = -0.005'

Allowable closure = $0.003\sqrt{8} = 0.008'$

Figure 5.--Schematic of leveling, notes, and adjustments.

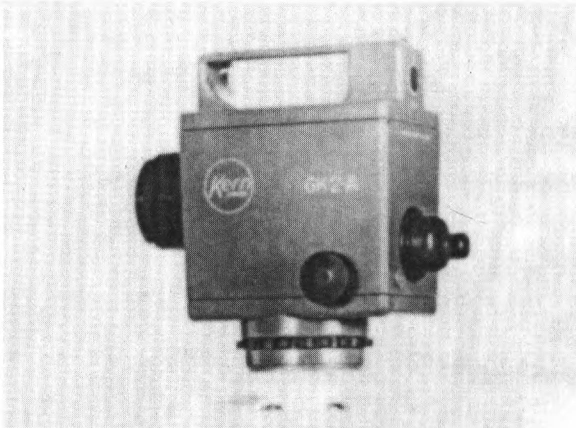
Tilting Level

A tilting level's telescope is supported by a hinge at one end and a tilting screw at the other. An insensitive circular level is fastened to the frame. The instrument is leveled approximately with the circular level and then precisely with the tubular level. The ungraduated tubular level vial is viewed through prisms and mirrors that make split images of the bubble ends coincide when the line of sight is horizontal. The bubble ends are matched exactly by turning a knob or micrometer dial on the tilting screw. On some models the bubble ends are visible through the telescope eyepiece while the rod is being read, as illustrated in figure 7. Tilting levels are at least as accurate as automatic levels, less costly, about as fast, and have no pendulums to stick.

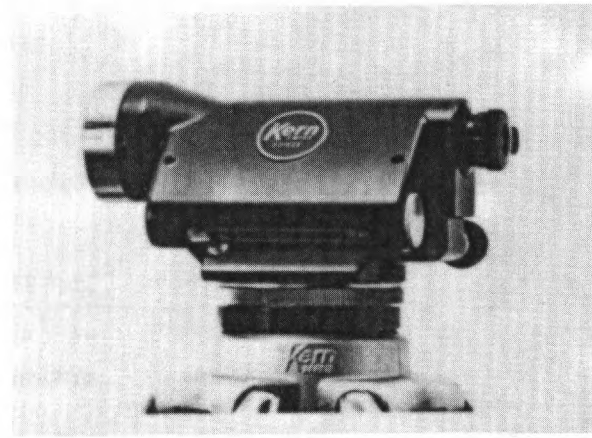
Dumpy Level

The dumpy level, a large, heavy, and obsolete instrument still in limited use, is time consuming to set up, to level, and to read. Its collimation is easily knocked out of adjustment and difficult to adjust. The sensitive tubular bubble is attached to the telescope and centered with a four-screw leveling head.

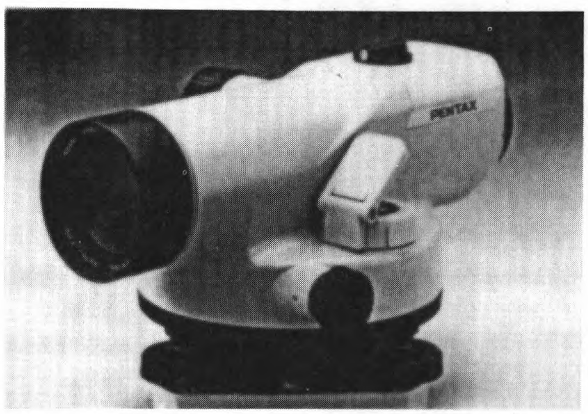
KERN GK2-A Automatic



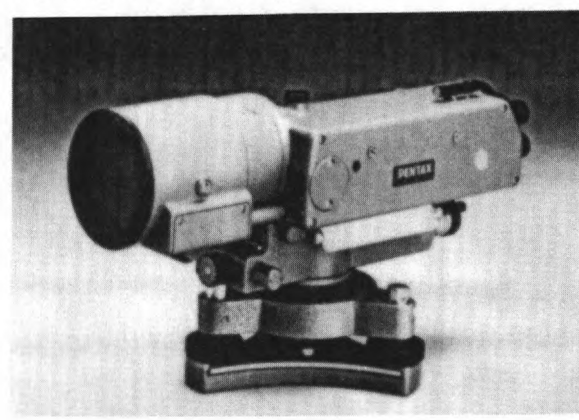
KERN GK23-E Tilting



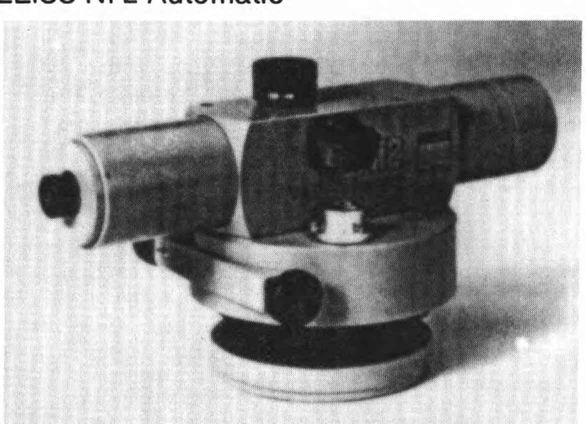
PENTAX ALM - 4 Automatic



PENTAX L-10 Tilting



ZEISS Ni 2 Automatic



Dumpy level

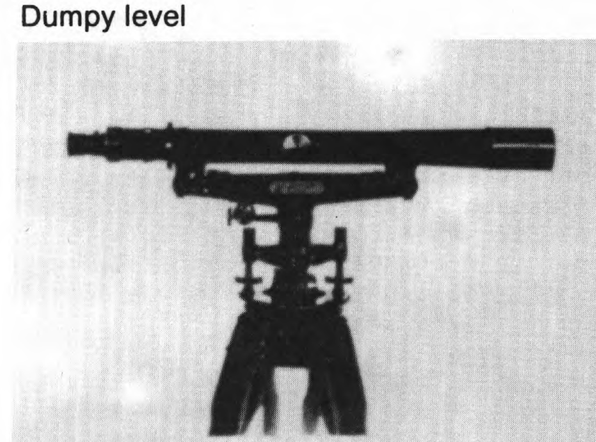


Figure 6.--Examples of engineer's levels.

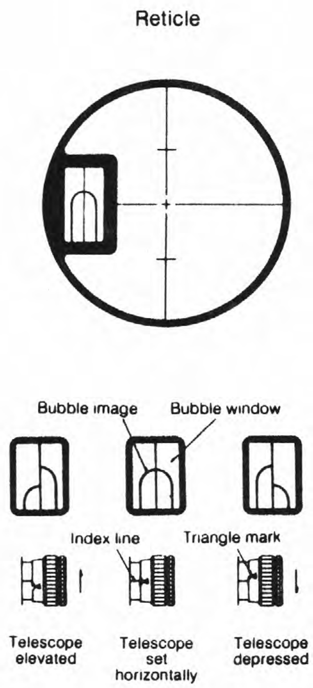


Figure 7.--Reticle and bubble windows as seen through a single-eyepiece tilting level.

Level Accessories

When a new level is ordered, the available features and options important to gaging-station leveling may warrant consideration, possibly with demonstrations in dealer's showrooms. The most important items to consider include:

Telescope.--Magnification of 30 times or more with even resolution from center to edge. Stadia ratio of 1:100 (avoid 1:30 or 1:60).

Collimation adjusting screw.--Must be easily accessible and should be spring loaded so turning it will not shake the level.

Eyepiece.--Should be "erecting" so the rod appears right side up. A single eyepiece tilting level, with rod and bubble ends visible simultaneously with the same eye, is much easier to use than one with a separate eyepiece for the bubble.

Horizontal circle.--Useful for reading horizontal angles.

Parallel-plate optical micrometer.--Allows the rod to be read directly to 0.001 foot and estimated to 0.0001 foot. Requires a wedge reticle (standard on some levels) and is an unnecessary but sometimes desirable luxury.

Automatic level components.--Most magnetic-dampened compensators are preferable to most air-dampened models. Close-fitting Styrofoam cover attachments, available for some models, minimize the effect of the sun on a bare instrument and offer some shock protection.

LEVELING ROD

Leveling rods are made in a great variety of types and styles, each with some advantages for specific applications. The rods most often selected for gaging-station levels include "Philadelphia," "Frisco," and "Chicago" rods, all with self-reading scales and illustrated in figure 8. The two-section version of the "Philadelphia" rod is a very popular general-purpose model. It is primarily self-reading but has a provision for an accessory target. The "Frisco" rod, preferably in two sections, is a targetless version of the "Philadelphia" that costs less because it has no parts to accommodate a target. A "Chicago" rod, in three or four wooden sections and with its graduations painted on the backing, is the easiest to use inside a gage well or instrument shelter. Its scales are adjustable to some extent, but only in a shop. The most practical rods to use at gaging stations have replaceable invar or steel ribbon scales riding loosely in slots in their wood or fiberglass backings. Each scale section is held in place by a spring at the top of the section and a screw at the bottom, adjustable up or down in the field. The backing material has no effect on the calibration of this type of rod, but the scale material is important in cold or hot weather.

Thermal expansion or contraction of the rod scale material affects rod readings by making the scale longer or shorter than when it was graduated. The resulting leveling error at a specific point depends on the material used for the scale, the difference between the temperature of the rod and the temperature at which it was calibrated, and the height of the mark being considered above or below the starting elevation. The leveling errors from expanded or contracted rod scales of various materials at a temperature 30 °F (17 °C) above or below the calibration temperature, usually 68 °F (20 °C), for a point 50 feet higher or lower than the starting point, are: invar, 0.001 foot; wood, 0.005 foot; steel, 0.010 foot; aluminum or magnesium, 0.02 foot.

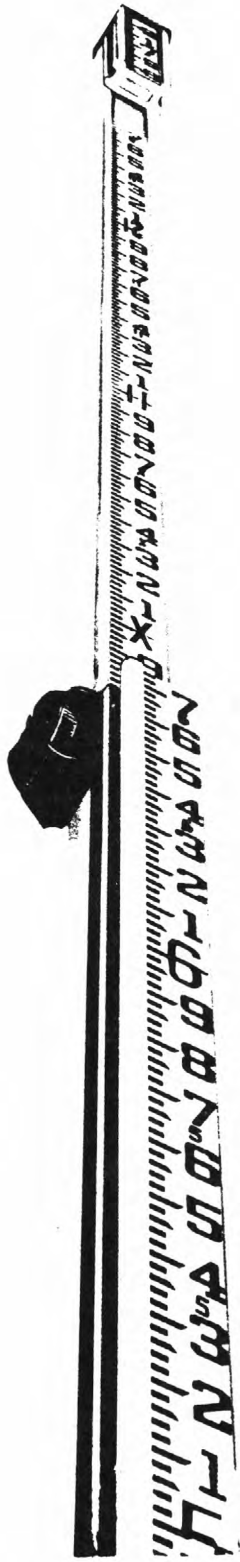
Most rods with invar scales are expensive, one-piece, metric models. "Philadelphia" type rods with invar scales, or replacement invar ribbon scales to fit such rods, usually must be specially ordered. Steel-scale replacement ribbons are generally satisfactory standard items. Scales painted on, cut or molded into, or cemented to fiberglass, magnesium, or aluminum, expand and contract too much for gaging-station leveling use in most climates. Scales painted on wooden backings, though unadjustable and short lived, are second only to invar for stability at varying temperatures.

A rod should be carefully stored, preferably in a protective case, when transported in a vehicle. The rods used for gaging-station leveling should be kept dry and never subjected to such rough use as construction work or cross sectioning. Walking with a fully extended rod over the shoulder, especially a "Chicago" type, flexes and strains the joints severely and shortens the rod's useful life.

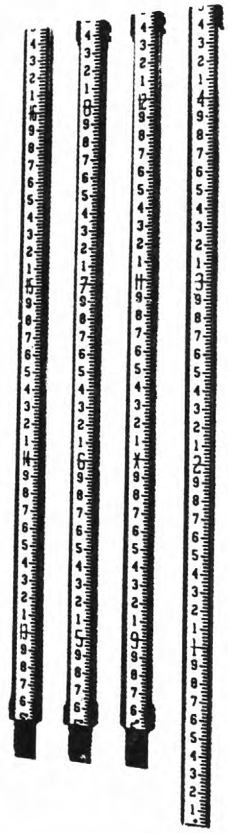
A 50-foot steel tape with a white face and black graduations, and a wooden 6-foot folding engineer's rule, are excellent auxiliary measuring equipment useful in performing gaging-station leveling.

Checking the Rod

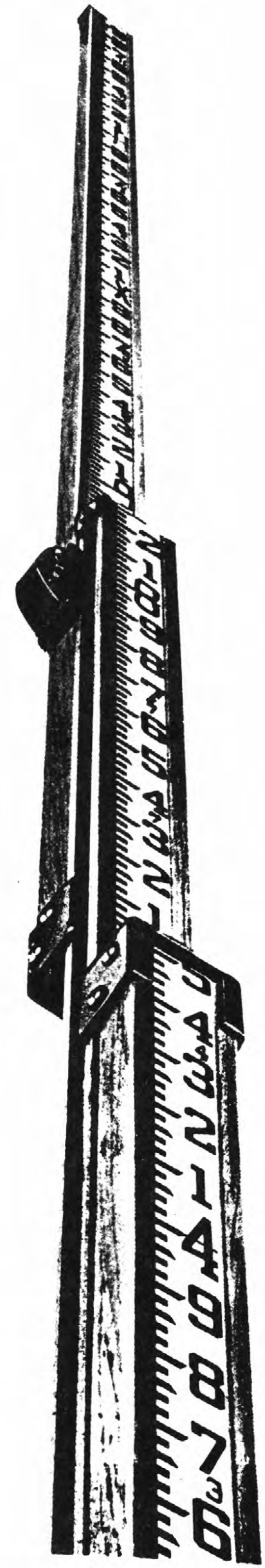
Measure the rod before use at each site. Match the 2-foot graduation of a steel tape with the 1-foot graduation of the rod, then read the tape at the bottom of the rod and at each foot mark. If all graduations are accurate within 0.002 foot, the rod is satisfactory. If the base of the rod is out of



Two-section "Philadelphia" Rod



Four-section "Chicago" Rod



Three-section "Frisco" Rod

Figure 8.--Leveling rods.

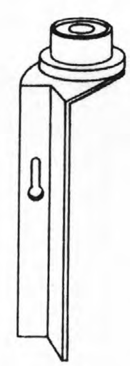
adjustment, the height-of-instrument values will be in error by the amount of the displacement. The errors will ordinarily cancel out without affecting the point elevations. However, if such a rod is used for a backsight, and the foresight is made on a tape, different rod, gage plate graduation, or the bottom of a gage weight, an appropriate correction may be necessary.

The scale plates and joints of some "Frisco" and "Philadelphia" rods can be adjusted in the field. A "Chicago" rod's calibration errors might be caused by dirt in the joints that can be cleaned off in the field. A worn joint or base plate can be shimmed in a workshop, but a new rod may be a more satisfactory solution.

Holding the Rod

The duties of a rod person are fairly simple but very important. First and most importantly, the rod must be plumb while it is being read. A rod level, similar to the one pictured in figure 9, is essential for fast and accurate levels. On a calm day, the rod can be plumbed without a rod level by balancing it over the marks with only a little loss of accuracy. The instrument operator can tell by looking at the vertical crosshair if the rod is in the vertical plane passing through the instrument. If the rod person slowly waves the top of the rod to and away from the instrument and the reading is well up on the rod, the lowest reading, which is the correct one, will occur when the rod is plumb. Waving a thick rod ("Philadelphia" or "Frisco") over a mark, such as a chiseled square in a flat concrete surface, causes the scale to rise when the back of the base rocks on the flat surface and could lead to serious errors in readings made low on the rod. This effect makes it advisable to have the tops of all reference marks and reference points high enough for the rod base to clear the surrounding surface.

Figure 9.--Rod level.



Where a portable turning point (such as a hammer-driven steel stake or steel trivet plate) is used, the rod person should set the rod on it gently. This prevents the turning point from being driven farther into the ground between sights by the impact of the rod being placed on it.

OPERATING THE LEVEL

Transportation

Even the most rugged level can be jolted seriously out of adjustment or damaged, especially while being carried inside a field vehicle or shipped.

Keep the instrument in its case, protected by heavy padding on all sides, while it is in a car or truck. When the level is mounted on its tripod, carry it under one arm with the instrument at the front in plain view. Be particularly careful while inside a building or moving through woods or brush. Carry a level over the shoulder only along roads or in open fields, and avoid leaving it unattended while it is set up in the field.

Checking the Tripod

Check the leg tension daily by setting the shoes about 3 feet apart and lifting the tripod by its head. The tension, adjustable by wing nuts on each leg or by special clamps under the tripod head, is satisfactory when each leg folds in slightly.

Setting up the Level

The ideal setup location is on firm, level ground. Avoid setting up on surfaces of tar, asphalt, ice, or frozen or marshy ground if at all possible. They are likely to soften and allow the tripod to settle enough to disturb the level or even change its height of instrument between readings. The instrument can be set up on a satisfactory surface and the bubble almost centered before the leveling screws are touched by setting two of the legs and moving the third leg from side to side or in and out until the tripod head looks level. Then push each leg firmly into the ground and use the leveling screws to center the bubble. When this procedure is used with a domed leveling head, a device for very rapid instrument leveling, an experienced surveyor can take a backsight within 30 seconds of the time the assembled level is placed on the ground.

Leveling the Instrument

Leveling is done in two steps: the preliminary leveling whose only effect on the setup is to level the horizontal crosshair, and the final leveling that makes the line of sight horizontal while the rod is being read. Most levels have leveling screws or a lever to center the bubble of a circular (bulls eye) level for the preliminary leveling and an automatic compensator or a tilting screw for the final leveling. For a dumpy level, the same level vial and leveling screws are used for both preliminary and final leveling.

To use a three-screw leveling head, rotate the telescope until the circular level vial is over one of the three screws. Center the bubble by turning the other two screws. The bubble will move toward any screw being turned clockwise and away from one turning counterclockwise. If a leveling screw runs to the limit of its threads, back if off a few turns, rotate the telescope to place the vial over that screw, then level with the other two screws. Once the bubble has been centered, further trials at other telescope positions are unnecessary. A self-leveling level is then leveled precisely by its compensator, or a tilting level by the operator turning the tilting screw until the bubble ends match.

Some instruments use a spherical or domed leveling head and are leveled by sliding the head around the spherical surface until the bubble is centered. The motion is controlled by a long lever that projects from the underside of the tripod and ends in a knob that is twisted tight to stop the movement. Most tripods can be equipped with a domed-head accessory that adapts any automatic or tilting level to this rapid-leveling method.

Use the four-screw leveling head of a dumpy level by setting up with one pair of opposing screws aligned in the general direction of the next back-sight. Turn the telescope over one pair of screws and twist them in opposite directions to center the bubble. Finish each adjustment by turning only one screw to ensure that the screw is tight enough to prevent rocking on that pair of screws and loose enough to prevent stiffening of the other pair. When the bubble is centered, turn the telescope 90 degrees to place it over the other pair of screws and center the bubble with those screws. Repeat until each screw has been adjusted no more than three times. At this stage the level is ready for the final centering of the bubble by using the one pair of screws nearest to the direction of the telescope, just before each rod reading.

Avoid touching the level, especially a dumpy, with fingers, clothing, or dangling equipment or notebook, while it is being read. Keep your feet well clear of the tripod shoes of any level, from the time of the first bubble centering until all readings are recorded.

Focusing

The knob on the top or side of the telescope controls the objective lens that brings the rod's graduations into focus at the plane of the crosshairs. The eyepiece is a small microscope that enlarges the images of the rod and crosshairs. Most eyepieces also rotate the images, which are upside down at the crosshairs, to make them appear upright to the operator. Before the instrument is leveled, point the telescope at the sky to eliminate all distracting background, then twist the eyepiece end until the crosshair image is sharpest. Do this at the start of the leveling, when a different level person takes over, or as one operator's eyes tire. Adjust the objective lens before each reading until it brings the rod into sharpest focus. Move your head up and down while sighting the rod. If the rod appears to move slightly in response to the eye movement, parallax is present, indicating that the rod is in focus either in front of or behind the crosshairs rather than at them. Parallax can usually be eliminated by adjusting the objective focus. If it persists, find some combination of eyepiece and objective focus adjustments that will keep the eyepiece setting constant from one sight to the next.

Reading Routine

Develop and habitually use a reading routine that will make certain that all rod readings are made under proper conditions. After the instrument is leveled, a good routine for reading all but automatic levels, in place with circular vial bubble centered, is:

1. Focus the objective lens.

2. Check for parallax and, if present, eliminate it by refocusing.

3. Center the telescope bubble precisely.

4. Check the rod against the vertical hair. If out of plumb, direct the rod person until the rod is vertical.

5. Read the rod.

6. See that the telescope bubble is still centered. If not, return to step 3.

7. Record the rod reading.

An automatic level, especially an air-dampened model, needs an occasional check of its compensator. When the instrument is first set up and leveled, test it by looking through the telescope at the rod and turning the leveling screw nearest to the eyepiece slightly in one direction, then in the other. If the crosshair returns to the same reading smoothly from both directions, the instrument is working properly. If there is a difference between the readings, repeat the test, but tap the telescope lightly before each reading. If that makes the readings agree, the level can still be used as long as it is tapped before each reading. Compensator sticking is usually intermittent and likely to go unnoticed for a long time unless the operator is alert. Tapping the telescope before each reading while looking for the telltale movement of the crosshair against the rod is an effective way to monitor the sticking. Some levels have a button-operated agitator. If the tapping or the agitator causes some movement, and additional agitation causes more movement, the level has a serious problem and must be repaired before it can be used.

Serious compensator sticking may be caused by a misadjusted circular level, dust particles in the compensator, or a stretched pendulum wire. The circular level can be adjusted in the field, but internal compensator problems must be corrected in a repair facility competent to clean, repair, or replace the mechanism.

A good reading routine for automatic levels, in place with the circular vial bubble centered, is:

1. Focus the objective lens.

2. Check for parallax and, if present, eliminate it by refocusing.

3. Tap the telescope and look for movement of the hair against the rod.

4. Check the rod against the vertical hair. If it is out of plumb, direct the rod person until the rod is vertical.

5. Read the rod and record the reading.

ADJUSTING THE ENGINEER'S LEVEL

A well-adjusted level can lose its adjustment during a single bumpy ride or from one incident of rough handling; or it may hold its adjustment through weeks of use. Misadjustment may show itself in the form of large circuit closures, or even as sticking of an automatic level's compensator. Check the level's collimation before the start of each week of use and again whenever there is reason to suspect its performance. Adjust the level when the collimation is found in error by more than 0.003 foot per hundred feet.

A pair of fixed-vertical scales installed at a permanent site and set to a common datum enables one person to check the collimation of any level in minutes and to adjust most models of automatic or tilting levels in a few additional minutes. A similar test and adjustment of the level in the field would take two people a great deal longer.

An automatic level's circular level and crosshairs are its only parts that a surveyor can adjust. A tilting level's adjustable components are its circular level and a prism that moves one of the bubble-end images. A dumpy level's crosshairs and bubble vial can be adjusted to collimate the instrument by a lengthy trial-and-error procedure, which is omitted from this manual but outlined in nearly all surveying texts and handbooks

Adjustment of levels involves capstan-head nuts and screws, some very delicate with easily stripped threads. The adjuster must develop an instinct for the proper degree of tightness. Capstans left too tight lead to metal creeping and loss of adjustment in a short time. Capstans left too loose may allow the first light jolt to change the level's adjustment. Turn capstans only with adjusting pins of proper length and diameter. Loose-fitting pins will deform the holes in the soft metal capstans and make them unusable. Replacements for lost pins can be bought from engineering-supply dealers for most levels.

Reticle

The reticle (crosshair ring) of a modern level is usually raised or lowered on rotation-preventing tracks by an adjusting device, often a spring-loaded capstan screw under a removable cover plate. A tilting level's reticle is unadjustable. A dumpy level's crosshairs can be rotated or moved up or down, somewhat awkwardly, by its capstan screws, but accidental rotation is a problem.

Circular Level Vial

A circular or bull's eye level is used for the preliminary leveling of an automatic or tilting level, and the adjustment of its vial could affect an automatic level's compensator operation. To test and, if necessary, adjust a circular level vial, center the bubble by using the main leveling screws or the domed leveling head on some instruments. Then rotate the telescope slowly until the bubble's distance from the center is greatest. If the bubble remains centered throughout the rotation, the vial needs no adjustment. If the bubble strays, bring it half way back to the center with the main leveling head and the rest of the way with the vial-adjusting screws. Repeat the process two or three times, if necessary, until the bubble stays centered through a complete revolution. This adjustment has no effect on the line of sight.

Some circular vials are held in place by three adjusting screws and a collar that compress an elastic washer between the vial and its seat. The screws may be visible or hidden under a removable cover. A screw in a three-screw set must be turned only clockwise for adjustment, and the bubble will move away from any screw being tightened. If an adjusting screw is turned to its limit, loosen all three screws, tighten each one until it moves the bubble slightly, and start adjusting again. Other circular vials use four-screw adjusting rings. Opposing screws are turned in opposite directions simultaneously and the bubble usually moves toward the screw turning clockwise.

Collimation

The inclination of a level's line of sight, when the telescope bubble is centered or the automatic compensator is operating, is its collimation error factor "c," in feet per 100 feet of sight length; it is positive when the line of sight points downward. The factor "c" is measured by leveling from one point to another and returning, using grossly unbalanced sight lengths. The resulting error of closure is a measurement of the instrument's misadjustment. One of two collimation tests can be used--a fixed-scale test or a peg test. The fixed-scale test is fast and accurate but requires a specially prepared location. The peg test is nearly as accurate and can be made anyplace but is more time consuming.

Fixed-Scale Test

Mount two short sections of vertical steel tape permanently and about 120 feet apart on trees, deeply set posts, or buildings at a reasonably level location. Set the tape sections, each about 1.5 feet long, to the same datum. Typical mounting details are shown in figure 10. Screw one of the tape sections "A" directly onto any flat vertical surface, and the other tape section

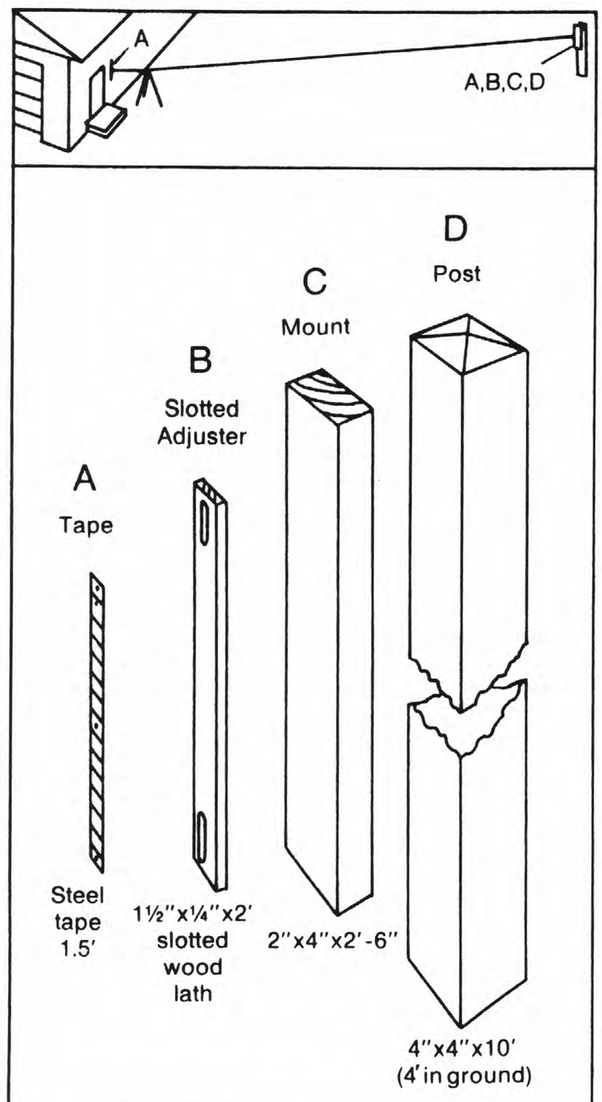


Figure 10.--Fixed-scale test apparatus.

onto the lath "B" for an adjustable mount. Attach the backing "C" to a tree at the opposite end of the test area, and shim it to make it vertical, or fasten "A" and "B" to the post "D." The equipment also can be installed indoors, attached to columns or doorframes, in a long basement corridor of a large building. To mount the equipment, set up a level equidistant from the scales and attach the fixed tape with its center at the height of instrument. Read the fixed tape and slide the adjustable tape up or down until the height of instrument reading on it agrees exactly with the fixed tape reading. Repeat this procedure from time to time, adjusting the movable tape if necessary to keep the scales to the same datum, usually at the start of a leveling season and before changing the adjustment of any instruments.

To test a level's collimation, set it up as close to one tape as the minimum focus distance will allow, usually about 11 feet. Read the near scale then the far one. Enter the readings and stadia distances on a form similar to figure 11. If the readings agree, the level is in perfect adjustment with a "c" of zero. If they disagree, compute "c." If the absolute value of "c" is more than 0.003, raise or lower the crosshair of an automatic level until its reading on the far rod agrees with the reading on the near one. For a tilting level, turn the tilting screw until the crosshair reading on the far rod agrees with the reading on the near rod, and then turn the collimation-adjusting device until the bubble ends match while the crosshair is at the correct reading.

Leave the completed test form in the instrument case in place of the form left there from the last test. Route the superseded form to a file of the instrument's service history.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

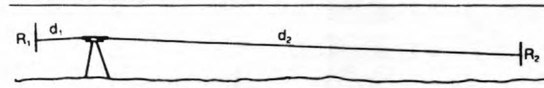
FIXED-SCALE COLLIMATION TEST OF ENGINEER'S LEVEL

Date 6-13-86 Tested by B.J. Johnson

Level type and ID Zeiss Auto W26093

Last test date 5-26-86 c found -0.003 Peg test ☐
c left -0.003 Fixed scale ☑

TEST AS FOUND



CR= 0

$$*c=100 \times \frac{(R_1-R_2-{**}CR)}{(d_2-d_1)}$$

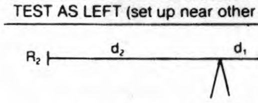
	R	d
1	0.761	11
2	.769	123

$$c=100 \times \frac{(0.761-0.769-0)}{(123-11)} = 100 \times \frac{-0.008}{112}$$

c= -0.007 As found

ADJUSTMENT (make R_2 read R_1+CR or 0.761 ft)

TEST AS LEFT (set up near other scale)



	R	d
1	0.612	11
2	.611	124

$$c=100 \times \frac{(0.612-0.611-0)}{(124-11)} = 100 \times \frac{+0.001}{123}$$

c = +0.001 As left

*c is the collimation error factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down.

**CR is the curvature and refraction effect for a sight length d_2. Its value, which increases the scale reading, is listed at right.

d_2 (ft)		CR (ft)
0	160	0.000
160	270	.001
270	350	

Figure 11.--Fixed-scale test notes and computations.

Several versions of the peg test, or two-peg test, are widely used. The system shown in figure 12 was adapted from the U.S. Geological Survey National Mapping Division instructions. To test and, if necessary, adjust a level, drive two stakes about 120 feet apart at a reasonably level site. Some surveyors prefer stakes as far apart as 300 feet in order to increase the total closure error. However, the rod readings are less precise at 300 feet than at 120 feet, and the curvature and refraction effect on the long sight is significant.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

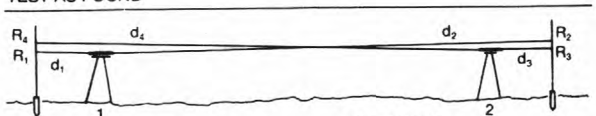
PEG TEST OF ENGINEER'S LEVEL

Date 6-7-86 Tested by K. L. Watts

Level type and ID Kern Tilting W 41762

Last test date 5-19-86 c found +0.002 Fixed scale ☑
c left +0.002 Peg test ☐

TEST AS FOUND



CR=0.003

$$* \; c = 100 \times \frac{(R_1+R_3) - (R_2+R_4-{**}CR)}{(d_2+d_4) - (d_1+d_3)}$$

	R	d
1	5.286	25
2	5.372	250
3	5.548	25
4	5.490	250

$$c = 100 \times \frac{(5.286 + 5.548) - (5.372 + 5.490 - 0.003)}{(250 + 250) - (25 + 25)}$$

$$c = 100 \times \frac{10.834 - 10.859}{500 - 50} = -0.006$$ As found

ADJUSTMENT (level remains set up at 2 and sighted at R_4)

Adjust cross hair to $R_4 \mp \frac{cd_4}{100} = 5.490 - \frac{0.006 \times 250}{100} = 5.490 - 0.015$

Cross hair setting = 5.475

REPEAT OF TEST AFTER ADJUSTMENT

$$c = 100 \times \frac{(5.284 + 5.546) - (5.357 + 5.475 - 0.003)}{(250 + 250) - (25 + 25)}$$

	R	d
1	5.284	25
2	5.357	250
3	5.546	25
4	5.475	250

$$c = 100 \times \frac{10.830 - 10.829}{500 - 50}$$

c = 0.000 As left

* c is the collimation factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down

**CR is twice the curvature and refraction correction for a sight of $\frac{d_2 + d_4}{2}$ ft. Its value, which increases the rod reading, is tabulated at right.

$(d_2 + d_4)/2$	**CR
0 - 110	0
110 - 190	.001
190 - 245	.002
245 - 290	.003
290 - 350	.004

Figure 12.--Peg-test notes and computations.

Set up as closely to one stake as minimum-focus distance will permit. Take backsight and stadia readings on the near stake and foresight and stadia readings on the far stake. Move the level close to the other stake and repeat the process. Enter the readings and distances in the first tabulation of a form similar to figure 12 and compute the collimation factor, C. If the absolute value of C is greater than 0.003, solve the second formula to compute the corrected rod reading for the last long shot. Raise or lower the crosshair of an automatic level to that reading. For a tilting level, turn the tilting screw until the crosshair is at the corrected reading, and then turn the collimation adjustment device until the bubble ends match while the crosshair is at the corrected reading. It is prudent to test a level at least twice before adjusting it, and always test it again after the adjustment.

Leave the completed test form in the instrument case, and route the form from the last test to a file of the level's service history.

GAGING-STATION DATUM CONTROL

Frequency of Levels

Check the individual gages at a site by measuring vertical distances from reference points when levels are run and also at the times of routine station visits whenever there are unexplained discrepancies between gage readings. If the discrepancies cannot be resolved from the reference point measurements, another set of levels, complete or partial, is necessary. A concrete gaging station, built with its foundation and reference marks set in rock, would be so unlikely to move that complete levels about every 10 years probably would be sufficient. A pipe well in an unprotected location on a bridge pier buffeted by debris during high water would need complete levels every year and at least a partial set after every major rise.

Prepare a leveling schedule each year to provide for complete levels at each regular gaging station that fits into one of the following categories:

1. has fewer than three sets of levels;
2. has gone 3 or more years without complete levels;
3. is movement prone and without complete levels during the past year; or
4. has unresolved gage-reading differences.

Establishing Gage Datum

If a new gaging station is being started where no other station has ever been operated, its datum should be set low enough to ensure that the lowest gage height ever likely to be recorded while the stream is flowing is at least 1 foot. One way to accomplish this is to set the gage to read a foot more than the maximum depth of water over the control plus a reasonable allowance for future scour. The scour allowance may be zero if the control is a sound artificial weir or ledge rock extending across the entire stream. A scour allowance of 10 feet or more might be needed for a very unstable alluvial channel in order to avoid future negative gage heights that will require a datum revision. If another gage was ever operated at a nearby equivalent site by a Federal, State, or municipal agency, consider using the previous gage's datum, adjusted for channel slope between the sites, for the new gage.

Reference Mark Installation

The objectives of gaging-station leveling are to define and maintain a datum, using reference marks installed in the most stable locations in the vicinity, and to adjust the gages as necessary to keep them in agreement with that datum. The most stable locations for reference marks are in ledge rock outcroppings and substantial masonry structures. The ground below the frost line in sandy soils is usually stable, but avoid reference mark sites in clay soils that expand and contract during seasonal variations in soil moisture. The stablest reference mark sites at gaging stations in expansive clay soil areas without nearby bridge piers are likely to be low and near the stream. There the base of a reference mark can usually be placed in permanently saturated soil.

Some commonly used types of reference marks are illustrated in figure 13. The gravel-filled pipe used in types C and D provides visibility to the mark and protects people, mower blades, and tires from the projecting rod. It also prevents frozen soil from adhering to the rod and lifting it. The earth anchor used for type D is sold in a wide range of sizes by major building-supply dealers. The device can be screwed into rock-free soil by using a shovel handle or crowbar as a lever. The ring on the shaft can be left in place or, if it seems likely to tempt vandals to raise or lower the anchor, the ring can be cut off and the shaft filed smooth. Large earth anchors have a separate auger, threaded so a length of pipe can be used as the shaft.

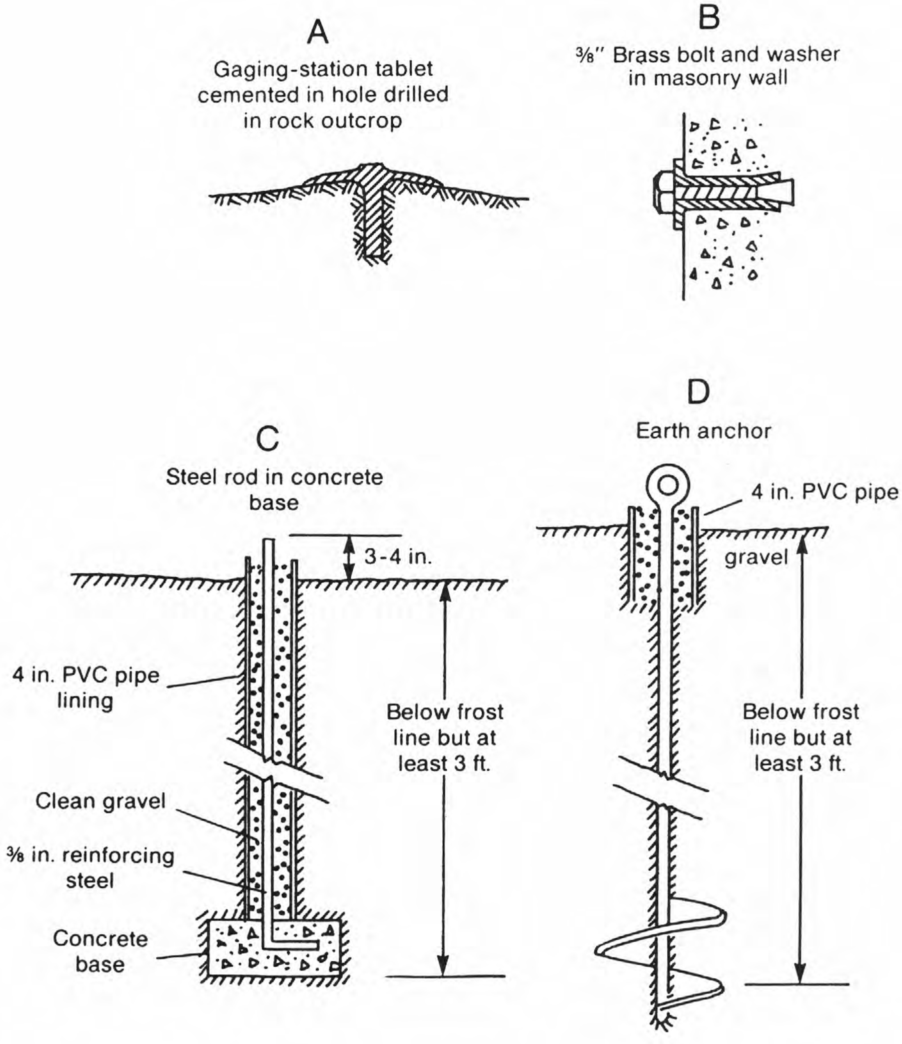


Figure 13.--Typical reference mark installations.

Each gaging station needs at least three reference marks: one, the most stable, as a starting point for levels, and the others to verify the elevation of the first mark. The reference marks should be independent in that only one should be on a single bridge pier or abutment; and at least one of the marks should be above the highest potential stage and located to survive any future construction or major floods that might wash out or bury the other marks.

Reference Point Installation

Install one reference point, preferably a 1/4-inch x 1-inch lag screw and washer, in the wooden gage-plate backing beside the plate for each set of enameled steel sections on a continuous backing. Install a similar reference point in a masonry anchor above water inside the gage well for taping down to the water surface. Keep one of the flat faces of the bolt head horizontal in order to facilitate reading of a vertical steel tape held against it. Two reference points in a vertical line may be more convenient for transferring elevations from ground level up to a high bridge deck or gage shelter by taping, than leveling up and down the stream bank. A reference point near the intake of a gage well, or the orifice or transducer of a pressure-type gage, is helpful when verifying low-flow stages. Consider the wire-weight check bar and electric-tape index as reference points.

RUNNING LEVELS

Schedule levels for a low-water period of favorable weather and postpone them if the weather is likely to prevent reliable results. Check the level and rod for proper adjustment and calibration before starting, and use a rod level and good reading routine. Keep the notes and computations on standard forms to facilitate checking and review. These forms can be reproduced from the blank forms at the end of this manual. Run the level circuit or series of circuits from the reference mark that appears to be most stable, turning on the other marks until the farthest one is reached. Then continue each circuit back to its starting point, turning on the same points in reverse order. Read each foresight as soon as possible after the backsight is made, and balance their lengths as closely as you can. Try to make all lines of sight clear the ground by a foot or more.

Side shots are foresights from a single height of instrument to points that are not turned on. They are generally avoided in high-quality leveling because they are unclosed, they may have unbalanced sight lengths, and their errors may be much greater than the circuit's error of closure. If a side shot is used, run it twice from different heights of instruments.

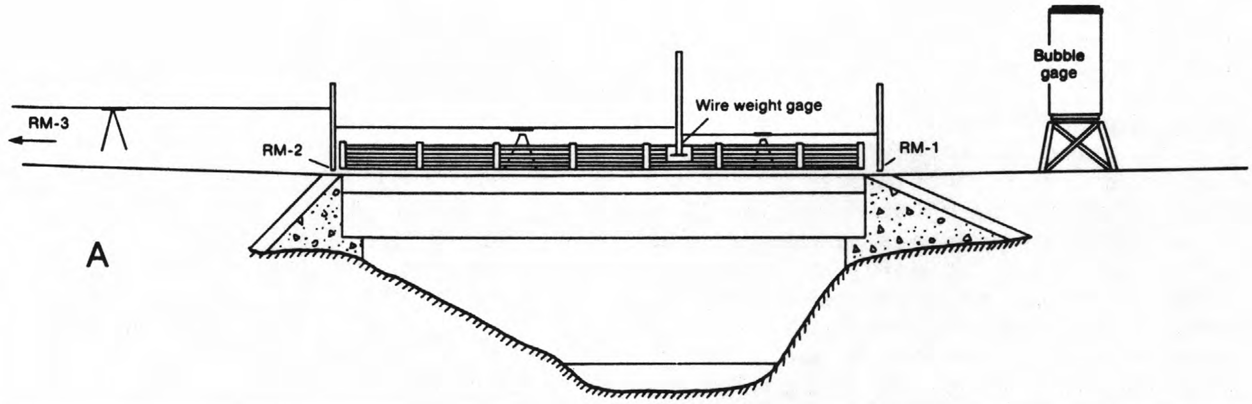
Check the levels for satisfactory closures in the spaces provided under "adjustment of elevations" on the level notes front sheet. List the differences between the measured elevations of adjacent points in the first half of each circuit and those from the return half as each circuit is completed. Where the first and second differences agree within 0.003 foot, the closure is satisfactory so enter the average difference. Rerun any segments that have larger discrepancies.

When all the circuits have been run, compute a tentative adjusted elevation for each point on the level notes' front sheet. Enter the starting elevation first and then add or subtract the average difference to obtain the next points' elevation. Compare these elevations with those tabulated from previous levels run at the station and see how well they agree. For instance, the current elevations might show that all marks and points, except the starting point, either rose by about 0.03 foot since the last levels, or the starting mark settled by that amount. The latter assumption is more reasonable than the first and indicates that the current adjusted elevations should probably have been computed by starting from a different reference mark. This can be tried by selecting the most logical of the other reference marks as a new starting point. Erase the originally computed adjusted elevations from the front sheet adjustment box. Enter the elevation of the new starting point from the last previous levels in the appropriate space. Working up and down the sheet from the newly entered starting elevation, add or subtract differences to compute a new set of adjusted elevations. If the new array of elevations compares logically with the levels from prior years, abandon the unsatisfactory reference mark, replace it with a new one, and run levels to the new mark. Use the newly adjusted elevations of the reference points as final results and to check the gages.

The simplest type of gaging-station leveling is illustrated in figure 14. A bubble gage referenced to a wire-weight gage has three reference marks nearby, and all are at about the same elevation. The layout of the station, and the locations of the reference marks and logical instrument setup sites, are indicated in figure 14A. The level notes are shown in figure 14B, and the adjustments and summary of results are listed in figure 14C. The levels were started from reference mark 1 and continued to the wire-weight gage, reference mark 2, and reference mark 3, turning on every point. The line then returned over the same route to close on reference mark 1.

A more complex station is illustrated in figure 15. Those levels cover a vertical range of 39 feet, and instrument setups on at least two levels are needed. The level notes' front sheet (figure 15C) indicates that the rod was checked and found essentially correct, so foresights can be made with either the rod or a tape. The electric-tape index elevation was measured by taping up from the height of instrument, using the tape on the station's electric-tape reel. The tape was read at the index and through the telescope at the height of instrument. The difference between the two readings, added to the height of instrument, is the elevation of the electric-tape index. A side shot was taken on reference point 1, and checked by another side shot from a different height of instrument during the return circuit. Levels were carried up to the bridge deck by taping between reference mark 1 and reference point 2 vertically above it. The total circuit closure (0.006 foot) was within the allowable limit ($0.003\sqrt{6} = 0.007$ ft). The adjustment process disclosed a faulty rod reading between reference mark 2 and reference point 2, so that portion was rerun.

The same station as the previous example is illustrated in figure 16. A weighted steel tape, temporarily suspended from the bridge, was used to transfer elevations from the ground near the stream up to the electric-tape index, and to the bridge deck. The side shot in the previous example was avoided by turning on reference point 1.



B

STATION	B.S.	HT. INST	F.S.	ELEVATION	REMARKS
RM-1	4.938	20.938		16.000	
ch. bar	2.320	21.246	2.012	18.926	ch. bar reads 18.925
RM-2	4.873	20.904	5.215	16.031	Tape to W.S. 16.115
RM-3	2.761	22.777	.888	20.016	W.S. reads 2.82
RM-2	5.162	21.191	6.748	16.029	
ch. bar	2.563	21.486	2.268	18.923	
RM-1			5.490	15.996	

C

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06927000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Red Creek near Waddell, Mo.

DATE June 18, 1986 PARTY O.R. Shinn, B.J. Johnson

ADJUSTMENT OF ELEVATIONS

Object	1st Diff	2nd Diff.	3rd Diff.	4th Diff.	Aver. Diff.	Elevation
RM-1						16.000
	2.926	2.927			+2.926	
ch. bar						18.926
	2.895	2.894			-2.894	
RM-2						16.032
	3.985	3.987			+3.986	
RM-3						20.018

WIRE WT.	Found	Left
Ch. Bar Rd.	18.925	18.925
Ch. Bar El.	18.926	18.926
Tape to W.S.	16.115	
W.S. El.	2.81	2.81
W. Wt. Rdg	2.82	2.82

BUBBLE GAGE	Found	Left
W. Wt. Rdg.	2.82	2.82
Bubb. Dial	2.82	2.82
Corr'n	0	0

DIGITAL RECORDER	Found	Left
Bubb. Dial ~~W.S. elev.~~	2.82	2.82
Gage rdg.	2.82	2.82
Corr'n	0	0

STAFF SECTIONS

Range	R.P. Ele	R.P. reading Found	R.P. reading Left	Gage corr'n

Level ID W 26093
Date of last check 6-10-86
Collimation error C -0.001
Tape reading on rod used

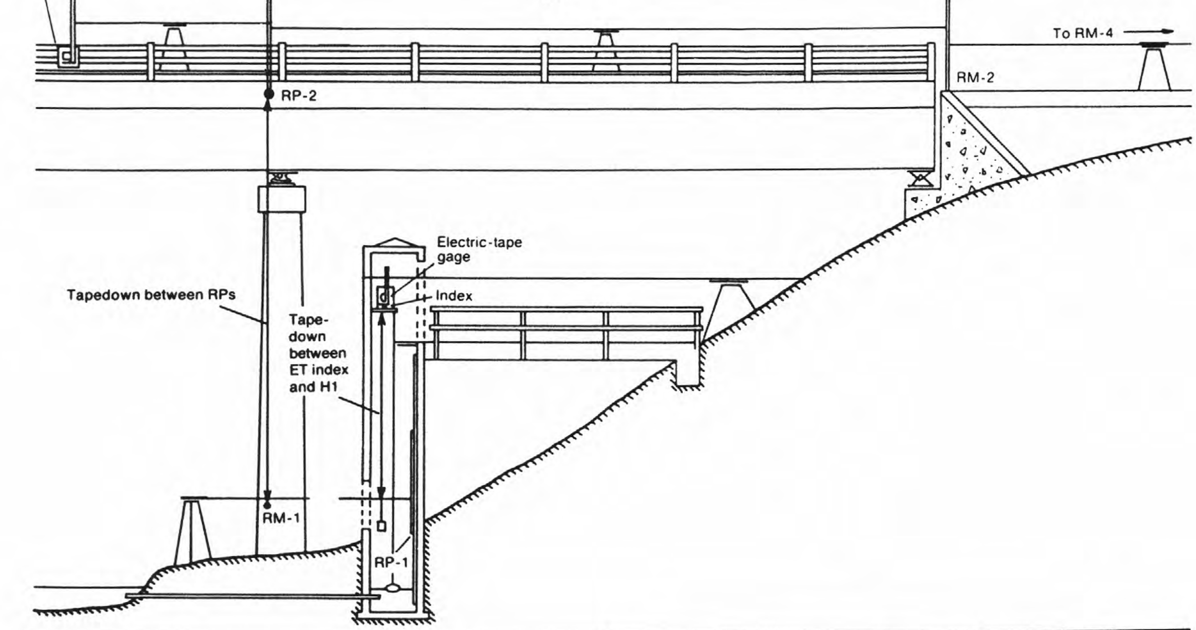
Base	
1.000	2.000
5.0	6.002
10.0	11.000

Temp 78°F
Cloudy
Calm

Sheet 1 of 2 Comp. by ORS Chk. by BJJ Date 6-18-86

Figure 14.--Instrument setup locations and field notes for simple gaging-station levels.

A



B

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS
RM-1	2.103	9.209		7.106	
RP-1			3.005	6.204	Reads 6.201 on a tape matched with gage plate
On tape			0	9.209	
Tape up H1 to Ind			—	+ * 15.699	= at H1 21.712 − at ET Ind. 6.013
ET Ind.			—	24.908	ET length 24.910; ET at W.S 1.370, Dig. rec 1.370
Tape down Ind. to H1			—	− * 17.103	= at H1 22.899 − at ET Ind. 5.796
On tape	0	7.805		7.805	
RP-1			1.602	6.203	
RM-1			.700	7.105	
Tape up RM-1 to RP-2			—	+ 35.720	
RP-2	5.037	47.862		42.825	
Wire-Wt. Ch. bar	2.918	47.656	3.124	44.738	
RP-2	4.994	47.822	4.828	42.828	
RM-2	3.874	46.672	5.024	42.798	Ch. bar elev 44.738; Tape to W.S. 43.315
RM-4	1.821	46.726	1.767	44.905	W.S. Elev 1.423; W.wt. reads 1.32
RM-2	5.105	47.905	3.926	42.800	Corr'n −0.10; Ch. bar reads 44.74
RP-2			5.086	42.819	Ch. bar reset 44.84; W.wt. reads 1.42
Tape down RP-2–RM-1			—	− 35.719	
RM-1			—	7.100	
	Rerun RP-2 to RM-2				
RP-2	5.218	48.043		42.825	
RM-2			5.238	42.805	

* Difference between readings of the hanging unreeled tape of the ET gage at the H1 and at the ET index mark

C

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06963000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Blue River at Elmont, Mo.

DATE June 16, 1986 PARTY B.J. Johnson, O.R. Shinn

ADJUSTMENT OF ELEVATIONS

Object	1st Diff	2nd Diff.	3rd Diff.	4th Diff.	Aver. Diff	Elevation
ET Ind.						24.908
RM-1	17.802	17.803			− 17.802	7.106
RP-1	.902	.902			− .902	6.204
RM-1						7.106
RP-2	35.720	35.719			+ 35.720	42.826
Ch. bar	1.913	1.910			+ 1.912	44.738
RP-2						42.826
RM-1	~~.030~~	.019	.020		− .020	42.806
RM-4	2.107	2.105			+ 2.106	44.912

W. WEIGHT	Found	Left
C. bar rdg	44.74	44.84 11:00 a
C. bar elev.	44.738	44.738
Tape to W.S.	43.315	
W.S. elev	1.42	1.42
Gage Rdg.	1.32	1.42
EL. TAPE		
Index elev	24.908	
Tape length	24.910	
Corr'n	−.002	−.002

DIGITAL RECORDER

	Found	Left
W.S. elev.	1.370	
Gage rdg	1.370	1.370
Corr'n	0	0

INSIDE STAFF SECTIONS

Range	RP Ele	RP reading Found	RP reading Left	Gage corr'n
0-21.0	6.204	6.201	6.201	+.003

Level ID W 26093
Date of last check 6-7-86
Collimation error C-0.001
Tape reading on rod used

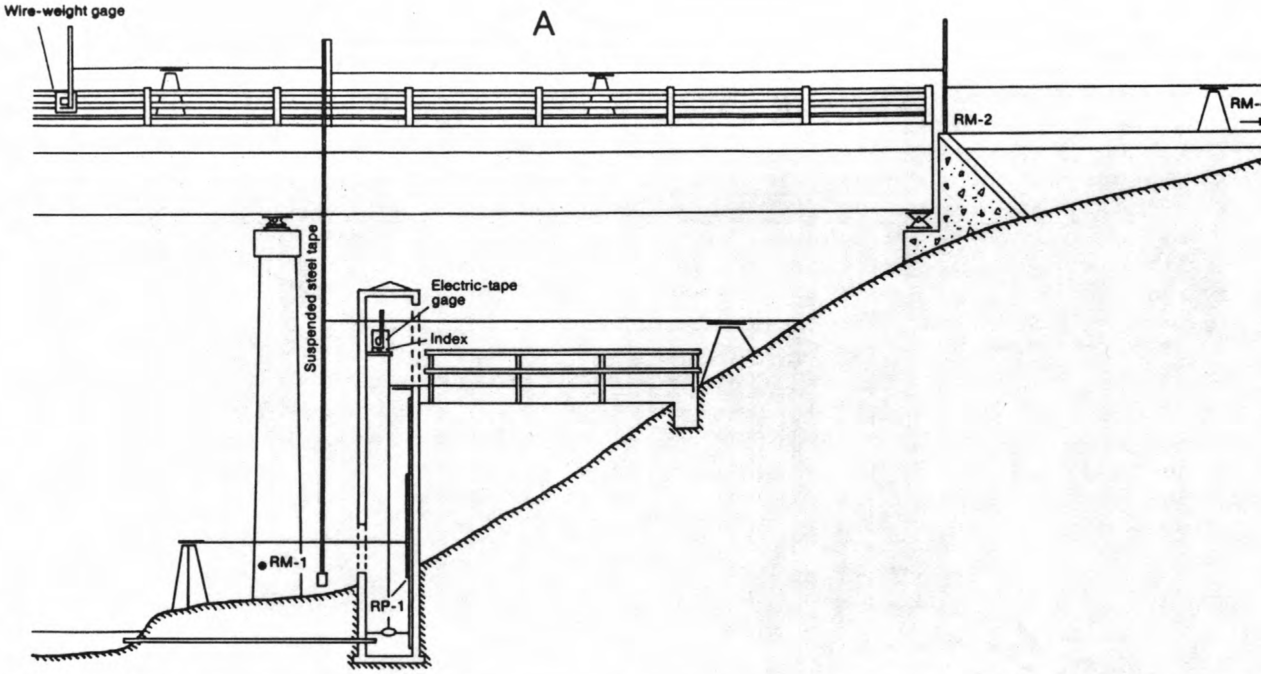
Base	
1.000	1.000
1.000	2.000
5.000	6.001
9.000	10.001
12.500	13.499

Temp 73°F
clear
calm

Sheet 1 of 2 Comp. by BJJ Chk. by ORS Date 6-16-86

Figure 15.--Instrument setup locations and field notes for complex gaging-station levels.

A



B

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS
RM-1	2.328	9.434		7.106	
RP-1	3.065	9.268	3.231	6.203	Reads 6.201 on tape matched with plates
Tape 0	5.846	9.219	5.895	3.373	
RP-1	3.127	9.332	3.014	6.205	
RM-1			2.227	7.105	
Tape 0	22.409	25.782		3.373	
ET Ind.	1.083	25.992	.873	24.909	ET Length 24.910 ws 1.37 Dig. Rec. 1.37
Tape 0			22.618	3.374	
Tape 0	41.483	45.216		3.373	
WW Ch.b.	.638	45.378	.476	44.740	Ch. bar reads 44.74 w.s. reads 1.32
RM-2	3.332	46.138	2.572	42.806	
RM-4	1.489	46.403	1.224	44.914	Ch. bar elev 44.741 Tape to w.s 43.315
RM-2	3.207	46.013	3.597	42.806	w.s. elev. 1.426 WWt. reads 1.32
WW Ch.b.	1.084	45.827	1.270	44.743	Corr'n + 0.11 Ch. bar reads 44.74
Tape 0			42.452	3.375	Ch. bar reset 44.85 WWt. reads 1.43

C

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06963000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Blue River at Elmont, Mo.

DATE June 16, 1986 PARTY B.J. Johnson, O.R. Shinn

ADJUSTMENT OF ELEVATIONS

Object	1st Diff.	2nd Diff.	3rd Diff.	4th Diff.	Aver. Diff.	Elevation
RM-1						7.106
RP-1	0.903	0.900			-0.902	6.204
Tape 0	2.830	2.832			-2.831	3.373
ET Ind	21.536	21.535			+21.536	24.909
Tape 0						3.373
W.W. Ch.b.	41.367	41.368			+41.368	44.741
RM-2	1.934	1.937			-1.936	42.805
RM-4	2.108	2.108			+2.108	44.913

WIRE-WT	Found	Left
Ch. bar rds.	44.74	44.85 (1100 hr.)
Ch. bar elev.	44.741	44.741
Tape to w.s	43.315	
w.s. elev.	1.426	1.426
Gage rds.	1.32	1.43
EL. TAPE		
Index Elev.	24.909	24.909
Tape length	24.910	24.910
Corr'n	- 0.001	- 0.001

DIGITAL RECORDER

	Found	Left
W.S. elev.	1.37	
Gage rdg.	1.37	1.37
Corr'n	0	0

STAFF SECTIONS

Range	R.P. Ele.	R.P. reading Found	R.P. reading Left	Gage corr'n
0-21.0	6.204	6.201	6.201	+0.003

Level ID W26093

Date of last check 6-7-86

Collimation error C -0.001

Tape reading on rod used

Base	1.000
1.000	2.000
5	6.001
9	10.001
12.5	13.499

Temp 71°F
cloudy
calm

Sheet 1 of 2 Comp. by BJJ Chk. by ORS Date 6-16-86

Figure 16.--Instrument setup locations and field notes for use with a suspended steel tape.

Checking the Gages

The first step at a float-operated station is to read all the inside gages and to check the floats and connectors. Shake each float to check it for leaks, and repair or replace it if necessary. Replace any kinked, twisted, or otherwise damaged tapes or cables. See that any surge protection devices (chains, float tunnels, and shafts) on digital recorder floats are clean and working. Put the floats back in the water, and read them again to determine the effect of any problems that were found and corrected.

Use the reference gage, generally an electric tape or independent float tape, to set the principal gage, which is usually the digital recorder dial to which the recorder and discharge measurements are referred. The reference gage is ordinarily reset when found in error by more than 0.005 foot. The other gages are reset using criteria that depend on the type and use of the gage and the effort needed to reset it.

Electric Tape

The electric-tape gage reads the water-surface elevation correctly when the length of the tape (distance between the zero of the tape and the bottom of the weight) is the same as the value of the tape-index elevation. When the tape length is too long, the reading of the water-surface elevation is too high and the correction is minus. Measure the tape length from a foot mark near the weight to the bottom of the weight, and add that distance to the foot mark used. In areas where gaging stations are not ordinarily equipped with electric-tape gages, a portable electric-tape unit with a tape length of 50 or 100 feet is useful for running station levels. A flat plate or washer mounted beside a hole in the instrument shelf can be used as an reference point and the portable electric-tape index. The portable unit also can be used to read the tape-down distance to the water surface inside a well visually or, with a ground connection and battery, electrically.

Float Tape

A float tape may be an independent gage or a driving tape for the recorder. If the station has an electric tape, read it after it has been checked by levels. That reading is the water-surface elevation in the well and should agree with the float tape. In order to read the electric tape to 0.001 foot, get an approximate reading, dry off the bottom of the weight, and, when the tape is 0.01 foot above the approximate reading, lower it in 0.001-foot increments until contact is made. If there is no electric tape, measure down from an appropriate reference point to the water surface; and compare that elevation to the float tape reading. Reset the float tape if it is found in error by more than 0.005 foot. The gage is best reset by loosening the connector screws near the float after noting the tape reading at the clamp. Slip the tape by the amount of the change, tighten the clamp, and note the tape reading after the change. A float tape also can be reset by moving its pointer. However, if it is later found that the gage has been reset in error and must be set again, the difference between the found and left readings cannot be checked.

The digital-recorder dial, the principal gage, may be driven by a beaded cable instead of a tape, but it is checked in the same manner as a float tape gage. However, the interpolation between hundredths of a foot is less certain.

Wire Weight

A wire-weight gage has several potential sources of error to be considered while checking it. The check-bar elevation may vary considerably during the day if the gage is mounted near the center of a long span of a modern slender bridge. Bridges arch upward when their top surfaces are warmer than the bottom ones and sag when the temperature differences are reversed. This effect is much greater for a modern slim girder bridge than for a deep trussed structure.

Drum and cable diameter variations cause wire-weight calibration errors as great as 0.10 foot per 60 feet of spooled-out cable. At the same check-bar setting, replacement of an old cable, stretched and made thinner by long use, with a new cable is likely to change the reading of a gage mounted high above the water by several hundredths of a foot. The weight spins rapidly when lowered a long distance. It reads much differently at the moment when the weight stops at the end of a spin in one direction than at the end of a spin in the other direction. These errors are usually negligible for gages mounted less than 15 feet above the water on short bridges. The errors may be tolerable for almost any wire-weight gage used at a station solely to ensure that the inside gages are operating properly.

Run levels to the check bar in its outer position. Further checking depends on how the gage is used. For most wire weights, let the weight down to the water, wait until the spinning stops, then wind the weight back up so that the wire is spooled evenly on the drum. Read the check bar. If the reading differs from the check-bar elevation by more than 0.005 foot, or 0.01 foot for a normal outside gage at a float-operated station, reset the dial.

For wire weights seriously out of calibration where accuracy at low stages is unusually important, follow the above procedure; and then determine the water-surface elevation by taping down from the check bar. Compare the gage reading to the water-surface elevation. Adjust the check bar by the difference (if the wire weight reads 0.06 foot low, adjust the gage until the check bar reads 0.06 foot higher than its elevation by levels). The gage should then be correct at low stages and in error at high stages.

If, for some special purpose, maximum accuracy at all stages is necessary, follow the above procedures but keep the check-bar reading at its correct elevation. Prepare a graph similar to figure 17, with zero correction plotted at the check-bar elevation and the water-surface elevation--gage reading difference plotted at the stage of the reading. Leave copies of the graph in the appropriate folders and in the metal pocket of the gage, so each reading made can be corrected by the amount indicated by the graph.

Vertical Staff

Each backing, usually a 2-inch x 6-inch board, for a series of enameled steel gage plates needs a reference point to be included in the level circuit. Stretch a steel tape along the entire range of all the gage plates on the backing, and adjust it up or down until the closest match between all gage-plate graduations on that series of plates and the tape graduations is made. Then read the reference point against the matched tape. The difference between the reference point reading on the tape and the reference point elevation by levels is the average error in that series of sections (RP Elev. - RP Reading = Correction).

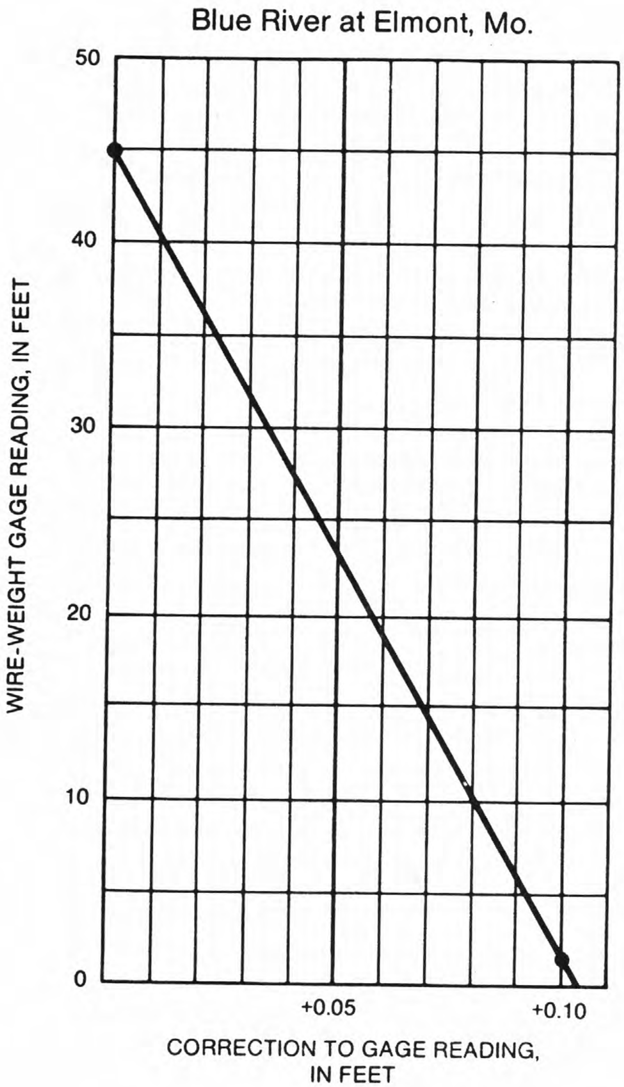


Figure 17.--Stage-related wire-weight gage corrections.

Staff gages are rarely reset for errors less than 0.02 foot. The lowest section, if used as a reference gage for a very small well or a bubble gage, may be reset for errors as small as 0.01 foot, or even less where a reading aid (foot-long point gage) is used to improve the precision of readings.

Inclined Staff

Check this type of gage by leveling from an reference point on or near it, whose adjusted elevation was included in the main level circuit. Use side shots to a sampling of foot marks throughout the gage's range, from one or more heights of instruments. Resetting of the scale markers on a long inclined staff is usually a major job, considered only where errors exceed 0.10 foot.

Bubble Gage

A bubble gage is best set to agree with the reference gage, usually an outside staff or wire weight, at low water and under optimum reading conditions, not necessarily at the time of levels. Reset it only under the same conditions.

Other Gages

A crest-stage gage is checked by leveling to its index. The index may be the top of the stick, or, more commonly, it may be the top of the lower fitting or stick-supporting bolt, which are usually built to be at the same elevation as the bottom of the stick.

An outside gage manometer (alcohol reservoir and transparent tubing) is checked by running levels to the reference points used with it.

Level Summary Sheets

Tabulate the results of the current levels and all prior levels and gage checks that have a bearing on current operations on forms similar to those shown on figures 18 and 19. All of the necessary information can be put on one sheet for a station with no staff gages and few reference points. Add the results of the levels to the summary each time they are run, and include a copy of the latest summary with the material usually carried in the field. Base the datum corrections used for the discharge record computations on these summary sheets.

NATIONAL GEODETIC VERTICAL DATUM

The NGVD of 1929, spheroidal in shape, is a level surface that approximates mean sea level. It is based on records from about 30 tidal stations in the United States and Canada and nearly 100,000 miles of first-order leveling. Earlier national datums, starting in about 1878, were known as "Sandy Hook Datum," "adjustments of 1903, 1907, 1912, 1927, special adjustment of 1929, general adjustment of 1929," and from 1937 to 1973 "Sea Level Datum of 1929." Some additional supplementary adjustments also have been used. Another general adjustment is planned for completion in about 1990.

Reference of every gage datum to the national datum is desirable, especially where flood profiles are likely to be needed. The tie-in ensures that the gage datum can be recovered in the future, even if the gaging station and its reference marks are destroyed. If a gaging station has not previously been tied into NGVD of 1929, run those levels as soon as it is feasible. In most areas this requires a bench mark or some other mark from a local network that was referenced to NGVD of 1929 within about 8 miles of the gaging station. Stations requiring longer or unusually difficult levels can wait until closer bench marks are installed or a pressing need develops for the data.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06963000

RESULTS OF GAGING STATION LEVELS

Station Blue River at Elmont, Missouri

Date of Levels	Party Chief	Elevations of reference marks and reference points									
		RM-1	RM-2	RM-3	RM-4	*L50	RP-1	RP-2	ET index	Check bar	
9-21-72	Herndon		42.809			61.72				44.740	
9-26-72	Herndon	7.106	42.806	44.926			6.207	42.825	24.910	44.745	
9-06-73	Herndon	7.106	42.806	44.921			6.205	42.824	24.907	44.743	
7-26-75	Lopez	7.106	42.803	44.906	44.914		6.206	42.826	24.909	44.748	
9-15-78	Harrigan	7.106	42.802		44.911		6.203	42.827	24.909	44.745	
7-26-82	Lentz	7.106	42.807		44.909		6.207	42.828	24.906	44.742	
6-16-86	Johnson	7.106	42.806		44.912		6.204	42.826	24.908	44.738	

*NGS bench mark. Line 17 MO. Elev. 1259.299 NGVD of 1929.

Figure 18.--Sample level summary sheet (marks and points).

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06963000

RESULTS OF GAGING STATION LEVELS

Station Blue River at Elmont, Missouri

Date of Levels	Party Chief	Electric tape			Wire-weight gage check bar				Inside staff		
		Index elev.	Tape length	Correction	Elev. found	Elev. left	Rdg. found	Rdg. left	R.P. Rdg.	Correction	
9-21-72	Herndon				--	44.740	--	44.74			
9-26-72	Herndon	24.910	24.910	0	44.745	--	44.74	44.74	6.199	+0.008	
9-06-73	Herndon	24.907	24.910	-.003	44.743	--	44.74	44.74	6.201	+.004	
7-26-75	Lopez	24.909	24.910	-.001	44.748	--	44.75	44.75	6.200	+.006	
9-15-78	Harrigan	24.909	24.910	-.001	44.745	--	44.75	44.75	6.200	+.003	
7-26-82	Lentz	24.906	24.910	-.004	44.742	--	44.74	44.74	6.201	+.006	
6-16-86	Johnson	24.908	24.910	-.002	44.738	--	44.74	*44.84	6.201	+.003	

*Adjusted to make low-water readings agree with water-surface elevations.

Figure 19.--Sample level summary sheet (gage corrections).

Some Federal, State, and municipal agency offices keep unpublished records of bench marks established to less than third-order accuracy for construction purposes. Some of these marks are near gaging stations, and their elevations are usually tied into old mean sea level datums that may be convertible to NGVD of 1929. Gage-datum elevations from such marks are usually credited to the organization that ran the network levels and can be used until a better tie is available.

The location of the nearest monumented bench mark is usually indicated on the most recent U.S. Geological Survey topographic quadrangle map. Descriptions and elevations of the marks shown on the maps, plus all others that are now in place, are published in lists or booklets by the National Geodetic Survey (NGS), and the U.S. Geological Survey. The NGS "Vertical Control Data" booklets are published separately by 30-minute quadrangles and can be ordered from:

The Director
National Geodetic Survey
NGS Information Center
Rockville, Maryland 20852

An index to U.S. Geological Survey "Vertical Control Lists" can be obtained from:

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, Virginia 22092

Identify the 15-minute quadrangles of interest from the index, and order the lists from the National Cartographic Information Center (NCIC) office listed for your State:

Arizona, California, Hawaii, Idaho, Nevada, Oregon, and Washington

Western Mapping Center-NCIC
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

Alaska, Colorado, Montana, New Mexico, Texas, Utah, and Wyoming

Rocky Mountain Mapping Center-NCIC
U.S. Geological Survey
Stop 504, Box 25046, Federal Center
Denver, Colorado 80225

All other States

Mid-Continent Mapping Center-NCIC
U.S. Geological Survey
1400 Independence Road
Rolla, Missouri 65401

Bench Mark Level Tie

The following approach is suggested for surveying a long level line to a selected bench mark. This method requires only a two-person party and minimizes the distance between that party and its vehicle.

Start from a gaging-station reference mark and run all elevations to gage datum, which, unlike the national datum, will probably never be changed. Make sight lengths as long as possible up to 300 feet, and balance them by pacing. Read the rod to 0.01 foot. Select a route, preferably along roads, to the bench mark. Consider the time available for the work, and level toward the bench mark until half that time has been used. Set a temporary reference mark at the stopping point, and level back to the starting point and vehicle. If the closures are satisfactory ($0.012\sqrt{n}$ or $.05\sqrt{M}$), drive to the previously set temporary reference mark, and repeat the process to and from another temporary reference mark. Continue until the NGVD of 1929 bench mark is tied in.

Mark and number about every third turning point with chalk, plastic or cloth flags, or lightly with a spray can of paint so they can be found in the event of an unsatisfactory closure. Then only the short segment between the inconsistent turning points will need rerunning. Use the same notekeeping format as for gaging-station levels. Figure 20 illustrates bench-mark leveling notes and adjustments.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. 06963000

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION Blue River at Elmont, Mo.

DATE Sept 21, 1972 PARTY G.K. Herndon, P.R. Crump

ADJUSTMENT OF ELEVATIONS

Object	1st Diff.	2nd Diff.	3rd Diff.	4th Diff.	Aver. Diff.	Elevation
RM-4						44.91
TP-1	3.53	3.53			3.53	48.44
TP-2	2.73	2.70			2.72	51.16
TP-3	3.88	3.87			3.88	55.04
TP-4	3.15	3.17			3.16	58.20
TP-5	3.16	3.17			3.16	61.36
TP-6	1.85	1.85			1.85	63.21
BM L-50	1.49	1.49			1.49	61.72

DIGITAL RECORDER

	Found	Left
W.S. elev.		
Gage rdg.		
Corr'n		

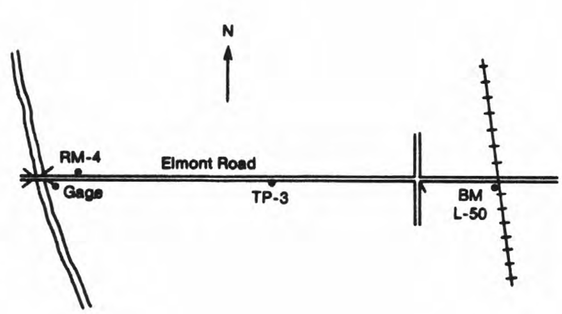
STAFF SECTIONS

Range	R.P. Ele.	R.P. reading Found	R.P. reading Left	Gage corr'n

Level ID W 17618
Date of last check 9-14-72
Collimation error C -0.003
Tape reading on rod used

Base	1.000	Temp 78°F cloudy light breeze
1.000	2.000	
5	6.001	
9	10.001	
12.5	13.499	

Sheet 1 of 3 Comp. by GKH Chk. by PRC Date 9-21-72



STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS
RM-4	5.06	49.97		44.91	
TP	5.13	51.16	3.94	46.03	
TP	5.08	52.36	3.88	47.28	
TP-1	4.91	53.35	3.92	48.44	℄ Road-painted
TP	5.00	54.25	4.10	49.25	
TP	4.97	55.21	4.01	50.24	
TP-2	5.12	56.29	4.04	51.17	N.Edge road-painted
TP	5.20	57.61	3.88	52.41	
TP	5.13	58.93	3.81	53.80	
TP-3	3.71	58.76	3.88	55.05	Flagged nail in oak root - S of road
TP	3.93	57.39	5.30	53.46	
TP	3.94	56.25	5.08	52.31	
TP-2	3.91	55.09	5.07	51.18	
TP	4.19	54.18	5.10	49.99	
TP	4.06	53.43	4.81	49.37	
TP-1	4.01	52.49	4.95	48.48	
TP	3.71	51.21	4.99	47.50	
TP	4.04	49.95	5.30	45.91	
RM-4			5.00	44.95	closure to .04 in 1.1 mi.
TP-3	5.03	60.07		55.04	
TP	4.97	61.07	3.97	56.10	
TP	5.01	62.17	3.91	57.16	
TP-4	5.05	63.24	3.98	58.19	S.edge road-painted
TP	5.06	64.36	3.94	59.30	
TP	4.91	65.32	3.95	60.41	
TP-5	4.01	65.36	3.97	61.35	℄ road-painted
TP	5.52	67.66	3.22	62.14	
TP	5.18	67.88	4.96	62.70	
TP-6	4.23	67.43	4.68	63.20	S.edge road-painted
TP	5.07	67.06	5.44	61.99	
TP	4.75	66.46	5.35	61.71	
BM-L50	4.99	66.70	4.75	61.71	
TP	5.13	67.36	4.47	62.23	
TP	5.31	68.12	4.55	62.81	
TP-6	5.14	68.34	4.92	63.20	
TP	4.66	67.19	5.81	62.53	
TP	5.04	66.90	5.33	61.86	
TP-5	5.35	66.70	5.55	61.35	
TP	4.21	64.77	6.14	60.56	
TP	4.61	64.04	5.34	59.43	
TP-4	3.95	62.13	5.86	58.18	
TP	3.96	61.03	5.06	57.07	
TP	4.01	59.99	5.05	55.98	
TP-3			4.98	55.01	closure-0.03 in 1.3 mi

Figure 20.--Sample bench mark leveling field notes and adjustments.

CHECKLIST OF EQUIPMENT FOR GAGING-STATION LEVELS

Consider the following equipment, in addition to that ordinarily carried in a stream-gaging vehicle, when loading for a field trip involving levels:

- Level
- Tripod Rod
  - Old rod for use in stream
- Rod level
- 24-inch carpenter's level
- 50- or 100-foot tape with weight
  - Portable electric tape set
- 6-foot folding engineer's rule
- Gaging station reference mark tablets
- Post hole digger
- Earth anchors
  - 3- or 4-inch PVC pipe for reference mark use
- Assorted brass or galv. bolts
  - Masonry anchors for bolts
- 1/4- x 1-inch lag screws and washers
  - Masonry anchors for screws
- Hand drill and bit assortment
- Colored chalk
- Spray paint
- Star drill and hammer
- Small container of Portland cement
- Fresh sack of concrete mix
- Machete or brush hook
- Turning points
  - Steel stake
  - Wooden stakes
  - Trivet
  - Rubber hammer
- Note forms
  - Level notes and front sheets
  - Summary sheets
- Field station descriptions
  - Bench-mark elevation and descriptions
- Summary sheets of past levels

SELECTED REFERENCES

Brinker, R.C., 1969, Elementary Surveying (5th ed.): Scranton, Pennsylvania, International Textbook Company, 620 p.

Davis, R.E., Foote, F.S., and Kelly, J.W., 1966, Surveying Theory and Practice (5th ed.): New York, McGraw-Hill, 1,096 p.

Kissam, P., 1978, Surveying Practice (3rd ed.): New York, McGraw-Hill, 502 p.

McCormac, J.C., 1983, Surveying Fundamentals: Englewood Cliffs, New Jersey, Prentice-Hall, 522 p.

Thomas, N.O., and Jackson, N.M. Jr., 1981, Manual for Leveling at Gaging Stations in North Carolina: U.S. Geological Survey Open-File Report 81-1104, 37 p.

U.S. Geological Survey, 1966, Topographic Instructions of the U.S. Geological Survey: Book 2, Part 2E-Leveling, 63 p.

MASTER COPIES FOR NOTEKEEPING AND LEVEL SUMMARY FORM DUPLICATION

The notekeeping and level-summary forms used in this manual are printed on the last four sheets and can be duplicated by an office copier if printed forms are unavailable.

1. Front sheet and level notes. This sheet can be folded to provide a front page (summary and adjustments) and one page of level notes, which is adequate for gaging stations with an average number of reference marks and reference points.

2. Two pages of level notes. This form can be printed on the reverse sides of the above sheets to provide two additional pages of level notes for stations with numerous reference marks and reference points, or for long lines of cross-country levels.

3. Peg test and fixed-scale test forms.

4. Results of gaging-station levels.

The first three forms are screened, to make notes written with a hard pencil stand out, and should be printed lightly or with a light-colored toner.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Sta. No. ________

SUMMARY AND ADJUSTMENTS OF GAGING STATION LEVELS

STATION ______________________________

DATE _______ PARTY ______________________

ADJUSTMENT OF ELEVATIONS

Object	1st Diff.	2nd Diff.	3rd Diff.	4th Diff.	Aver. Diff.	Elevation

DIGITAL RECORDER

	Found	Left
W.S. elev.		
Gage rdg.		
Corr'n		

STAFF SECTIONS

Range	R.P. Ele.	R.P. reading Found	R.P. reading Left	Gage corr'n

Level ID

Date of last check

Collimation error C

Tape reading on rod used

Base ______

1.000 ______

Sheet ___ of ___ Comp. by ______ Chk. by ______ Date _______

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS

STATION	B.S.	HT. INST.	F.S.	ELEVATION	REMARKS

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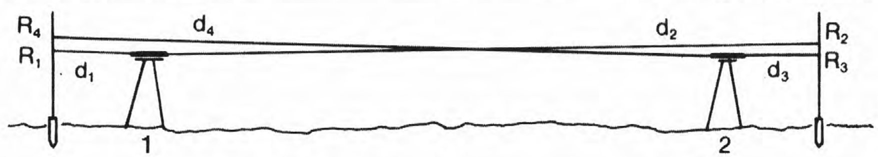
PEG TEST OF ENGINEER'S LEVEL

Date _________ Tested by ______________________

Level type and ID ___________________

Last test date _______________ c found _________ Fixed scale ☐
c left ___________ Peg test ☐

TEST AS FOUND



$$* \ c = 100 \times \frac{(R_1+R_3) - (R_2+R_4-{**}CR)}{(d_2+d_4) - (d_1+d_3)}$$

	R	d
1		
2		
3		
4		

c=100 x (+) – (+ –) / (+) – (+)

c=100 x – / – = ________ As found

ADJUSTMENT (level remains set up at 2 and sighted at R_4)

Adjust cross hair to $R_4 \mp \frac{cd_4}{100}$ = ________ / 100 =

Cross hair setting = ________

REPEAT OF TEST AFTER ADJUSTMENT

c=100 x (+) – (+ –) / (+) – (+)

	R	d
1		
2		
3		
4		

c=100 x – / –

c = ________ As left

* c is the collimation factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down.

**CR is twice the curvature and refraction correction for a sight of $\frac{d_2 + d_4}{2}$ ft. Its value, which increases the rod reading, is tabulated at right.

$(d_2 + d_4)/2$	**CR
0 – 110	0
110 – 190	.001
190 – 245	.002
245 – 290	.003
290 – 350	.004

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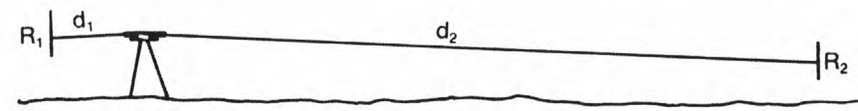
FIXED-SCALE COLLIMATION TEST OF ENGINEER'S LEVEL

Date ________ Tested by ___________________________

Level type and ID __________________

Last test date ______________ c found __________ Peg test ☐
c left ____________ Fixed scale ☐

TEST AS FOUND



CR= --------

$$*c = 100 \times \frac{(R_1-R_2-{**}CR)}{(d_2-d_1)}$$

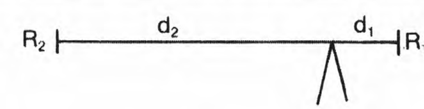
	R	d
1		
2		

c=100 x (– –) / (–) =100 x ________

c= ________ As found

ADJUSTMENT (make R_2 read R_1+CR or ________ ft)

TEST AS LEFT (set up near other scale)



	R	d
1		
2		

c=100 x (– –) / ( ) = 100 x ________

c = ________ As left

* c is the collimation error factor, the inclination of the line of sight in ft/100 ft, minus when up from the instrument, and plus when down.

**CR is the curvature and refraction effect for a sight length d_2. Its value, which increases the scale reading, is listed at right.

d_2 (ft)		CR (ft)
0	160	0.000
160	270	.001
270	350	

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Sta. No ____________________

RESULTS OF GAGING STATION LEVELS

Station____

Date of Levels	Party Chief										