Levels at Gaging Stations

Chapter 19 of
Section A, Surface-Water Techniques
Book 3, Applications of Hydraulics

Techniques and Methods 3–A19

U.S. Department of the Interior
U.S. Geological Survey

Cover: View of levels being run at U.S. Geological Survey streamflow-gaging station 10156000, Snake Creek near Charleston, Utah.
Photograph taken by K. Michael Nolan, U.S. Geological Survey, June 30, 2010.

Back Cover: USGS topographic field party, circa 1925, with a Wye level on a tripod and two stadia rods. Photograph by U.S. Geological Survey.

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By Terry A. Kenney

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U.S. Geological Survey
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Preface

This series of manuals on techniques and methods (TM) describes approved scientific and data-collection procedures and standard methods for planning and executing studies and laboratory analyses. The material is grouped under major subject headings called “books” and further subdivided into sections and chapters. Section A of book 3 is on surface-water techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. These publications are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment, and this format permits flexibility in revision and publication as the need arises. Chapter A19 of book 3 (TM 3–A19) deals with levels at gaging stations. The original version of this chapter was published in 1990 as U.S. Geological Survey (USGS) Techniques of Water-Resources Investigations, chapter A19 of book 3. New and improved equipment, as well as some procedural changes, have resulted in this revised second edition of “Levels at gaging stations.”

This edition supersedes USGS Techniques of Water-Resources Investigations 3A–19, 1990, “Levels at streamflow gaging stations,” by E.J. Kennedy.

This revised second edition of “Levels at gaging stations” is published on the World Wide Web at http://pubs.usgs.gov/tm/tm3A19/ and is for sale by the U.S. Geological Survey, Science Information Delivery, Box 25286, Federal Center, Denver, CO 80225.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32)/1.8

Levels at Gaging Stations

By Terry A. Kenney

Abstract

Operational procedures at U.S. Geological Survey gaging stations include periodic leveling checks to ensure that gages are accurately set to the established gage datum. Differential leveling techniques are used to determine elevations for reference marks, reference points, all gages, and the water surface. The techniques presented in this manual provide guidance on instruments and methods that ensure gaging-station levels are run to both a high precision and accuracy. Levels are run at gaging stations whenever differences in gage readings are unresolved, stations may have been damaged, or according to a pre-determined frequency. Engineer's levels, both optical levels and electronic digital levels, are commonly used for gaging-station levels. Collimation tests should be run at least once a week for any week that levels are run, and the absolute value of the collimation error cannot exceed 0.003 foot/100 feet (ft).

An acceptable set of gaging-station levels consists of a minimum of two foresights, each from a different instrument height, taken on at least two independent reference marks, all reference points, all gages, and the water surface. The initial instrument height is determined from another independent reference mark, known as the origin, or base reference mark. The absolute value of the closure error of a leveling circuit must be less than or equal to $0.003\sqrt{n}$ ft, where n is the total number of instrument setups, and may not exceed |0.015| ft regardless of the number of instrument setups. Closure error for a leveling circuit is distributed by instrument setup and adjusted elevations are determined. Side shots in a level circuit are assessed by examining the differences between the adjusted first and second elevations for each objective point in the circuit. The absolute value of these differences must be less than or equal to 0.005 ft. Final elevations for objective points are determined by averaging the valid adjusted first and second elevations. If final elevations indicate that the reference gage is off by |0.015| ft or more, it must be reset.

Introduction

At gaging stations where water-surface elevation or stage is measured, the U.S. Geological Survey (USGS) sets gages to read the stage above a specified reference surface called the gage datum (Kennedy, 1990). Equipment in most gaging stations measures and records stage at a frequency of 15 minutes. At streamflow gaging stations, discrete measurements of streamflow, made by hydrographers, are paired with a representative stage value. Over time, these pairings define a site-specific stage-discharge relation to which recorded stage values are applied to obtain a continuous streamflow record. To provide accurate and relevant data, it is imperative that gages agree with the established gage datum for the life of the station. To check and ensure that gages are properly set to gage datum, differential leveling techniques are used. Levels are run at gaging stations according to a standard set of frequency requirements, when unresolved gage reading differences have been identified, or when the station has been damaged.

Purpose and Scope

The purpose of this manual is to document the procedures that should be followed when running levels to check that gages are set to the established gage datum. Leveling equipment is discussed, along with specific precision requirements, desired accuracy, and calibration requirements. The required frequency for running gaging-station levels is outlined and presented in an easy to follow decision tree. The procedure for running levels at gaging stations is described in detail and illustrated in example level circuits. Specific error tolerances for both circuit closure and objective-point elevation differences are presented. Methods for taking foresights to various types of gages are discussed, and finally, office procedures associated with gaging-station levels are outlined. This manual describes new procedures for running levels at gaging stations that supersede those described by the previous USGS Techniques of Water-Resources Investigations Report "Levels at Streamflow Gaging Stations" by E.J. Kennedy (1990).

Differential Leveling and Leveling Equipment

Differential leveling is the process of measuring the vertical difference between a point of unknown elevation and a point of known elevation (McCormac, 1983). By measuring this difference, an elevation can be determined for the point of unknown elevation. At gaging stations, this measurement is most commonly made using an engineer's level and a calibrated leveling rod (fig. 1). The engineer's level is set up about equidistant from the point of known elevation and the point(s) of unknown elevation. A shot from the engineer's level is first made to a leveling rod that is held on the known elevation point. This reading on the leveling rod is called a backsight (BS). The BS, which is the vertical distance of the engineer's level above this point, is added to the known elevation of that point to determine the elevation of the engineer's level, or the height of the instrument. Shots are then made from the engineer's level to the leveling rod that is held on point(s) of unknown elevation. These readings are called foresights. A foresight (FS) is the distance of the engineer's level above the point and is subtracted from the instrument height to determine elevation.

Differential leveling techniques are used at gaging stations to determine elevations for reference marks, reference points, gages, and the water surface. Reference marks are objects (for example, brass tablets, steel rods, or bolts) that are installed in the most stable locations near the gage and are used to adjust the gages as necessary to keep them in agreement with the gage datum (Kennedy, 1990). Reference points are objects (for example, bolts, nails, or screws) that are installed in locations to facilitate the determination of gage heights by measuring their distance from the water surface. A variety of engineer's levels and leveling rods can be used to run levels at streamflow-gaging stations. The USGS reports stage at most gaging stations in increments of 0.01 ft. Therefore, gaging-station levels, which are used to verify that gages agree with the gage datum, must be measured at a higher level of precision and accuracy. Precision describes the closeness of one measurement to another while accuracy describes how close a given measurement is to the true value (McCormac, 1983). The precision required of gaging-station levels is 0.001 ft, while the desired accuracy is less than 0.010 ft. Instruments selected for running levels at gaging stations must be capable of meeting these precision and accuracy requirements.

Level Instruments

Many surveying instruments are available that have several different equipment options and can perform a variety of surveying tasks. Levels at gaging stations require measurements of vertical distance and do not need measurements of horizontal distance or horizontal angle. Engineer's levels are the most common instruments used for running levels at gaging stations. Most engineer's levels meet the desired accuracy of less than 0.010 ft and the required precision of 0.001 ft for gaging-station levels. Surveying technology is continually changing, and other types of surveying instruments, such as tilting instruments, may be capable of meeting these accuracy and precision standards.

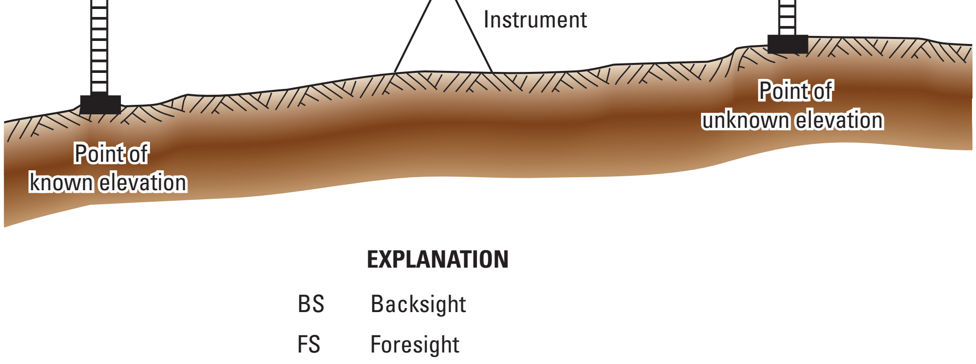


Figure 1. Differential leveling using an engineer's level and leveling rods.

The techniques and methods presented in this manual provide guidance on using engineer’s levels that ensures gaging-station levels are run to a high level of precision and accuracy. Before other types of surveying instruments are used for running gaging-station levels, techniques and methods specific to those instruments that ensure precision and accuracy requirements are met must be rigorously documented. Engineer’s levels, which are sometimes referred to as line or spirit levels, can be classified in two general categories: optical levels and electronic digital levels.

Optical Levels

Optical levels (fig. 2) are used to manually read the leveling rod that is held on an objective point. When using an optical level, the operator reads the value off the rod at the cross hair of the level. Self-reading rods used in gaging-station levels are graduated to 0.01 ft. Precision requirements call for the operator of an optical level to estimate measurements within 0.001 ft. The ability to accurately estimate to 0.001 ft is determined by the distance from the instrument to the rod, the magnification power of the level’s optics, and environmental conditions, such as the presence of heat waves. In general, the magnification of optical levels is about 30 times and allows readings as precise as 0.001 ft up to a distance of about 150 ft. Most modern optical levels are automatic, or self-leveling — the instrument levels itself precisely after being leveled manually with its circular (bull’s eye) level (Kennedy, 1990). Many older optical levels, such as the Dumpy level, are not self-leveling and are time-consuming to set up and level. These older instruments are also easily knocked out of level, which can introduce unquantified errors into the leveling circuit.

Electronic Digital Levels

Electronic digital levels (fig. 3) automatically read a bar-code leveling rod (fig. 4) held on an objective point. When using an electronic digital level, the operator sights in the bar-code leveling rod using the optical view finder and then interrogates the instrument to make a measurement. The instrument then shows the value on its digital display screen. Many electronic digital levels are equipped with logging and computational functions that can be used when running levels. Electronic digital levels contain optical systems that also allow the level to be used manually. Like optical levels, distances to objective points and environmental conditions can limit the utility of electronic digital levels. Electronic digital levels provide some distinct advantages over optical levels; for example, because the instrument automatically reads the leveling rod, any subjectivity in manually estimating the measurement to 0.001 ft is removed. Similarly, the potential for misreading the leveling rod is eliminated when using electronic digital levels. When using data-logging features common to many electronic digital levels, errors associated with manually transcribing measurements can also be eliminated. A disadvantage of electronic digital levels is that the electronic nature of these instruments introduces the potential for system failures to occur while in the field. Fortunately, the optical capability serves as a backup to the electronic system. It is common when running levels at gaging stations to use a secondary device, such as a steel tape, to take shots on objects located in places where a rod cannot be placed. Further, FSs to some objects (such as wire-weight gages) are made by sighting in the object at the cross hair of the instrument. Digital systems, which require a bar-code rod, cannot be used for such shots. For these reasons, both the optical and the digital systems of electronic digital levels must be maintained and tested frequently.

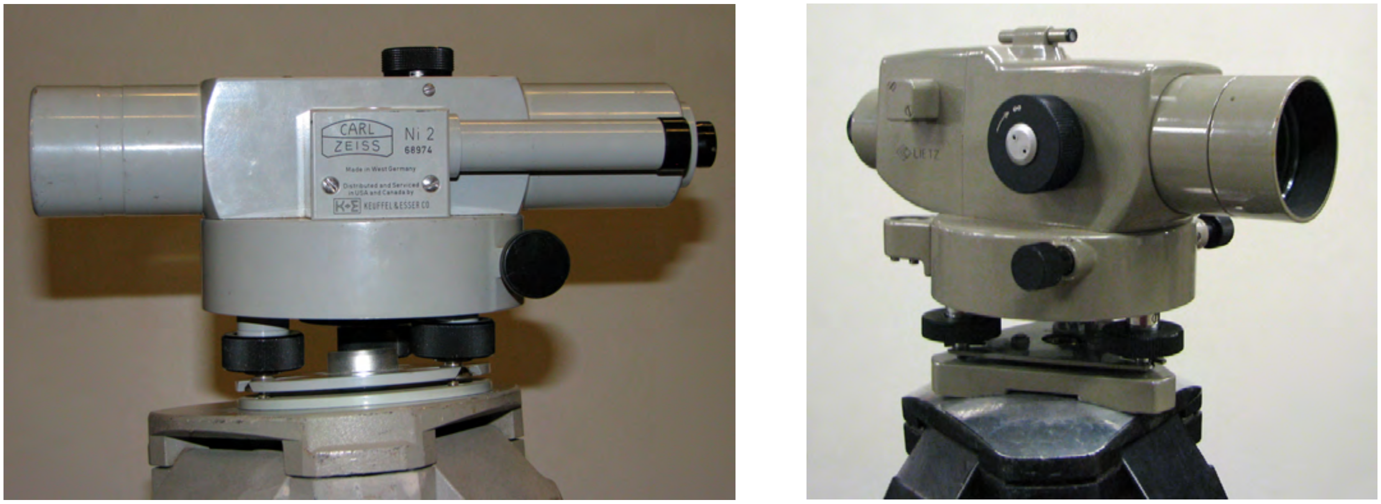


Figure 2. Optical levels.

Figure 3. Electronic digital levels.

Parallax

A sharply focused level is important for accurate readings of the leveling rod. A properly focused instrument locates the graduations of the leveling rod at the plane of the cross hairs. Parallax is the relative movement of the image of the leveling rod with respect to the cross hairs as the observer's eye moves. This is caused by the objective lens not being focused on the leveling rod (Kennedy, 1990). To check for parallax, slightly move your eye up and down while sighting in a leveling rod. If the rod appears to move with respect to the cross hair, parallax is present. Parallax usually can be eliminated by adjusting the objective focus. Diligence in refocusing the instrument for all readings and checking for parallax will eliminate erroneous measurements associated with improper focus.

Checking the Engineer's Level

An engineer's level is set up to measure the vertical distance from objective points to the level plane of the instrument. When applying the techniques of differential leveling, a properly leveled instrument is assumed to be on a horizontal plane at the determined elevation of the instrument or instrument height. Collimation error is a measurement of the inclination of a level's line of sight (Breed and others, 1970; McCormac, 1983; Kennedy, 1990), or the deviation from the horizontal plane. Collimation error is reported as a vertical deviation over a set distance, such as 0.xxx ft per 100 ft. If horizontal distances from the instrument to each object that a FS or BS is taken on are known, collimation corrections can be computed and applied. However, levels at gaging stations do not require measurements of horizontal distance, and therefore, the collimation error of the instrument is preserved in all measurements and is not corrected for.

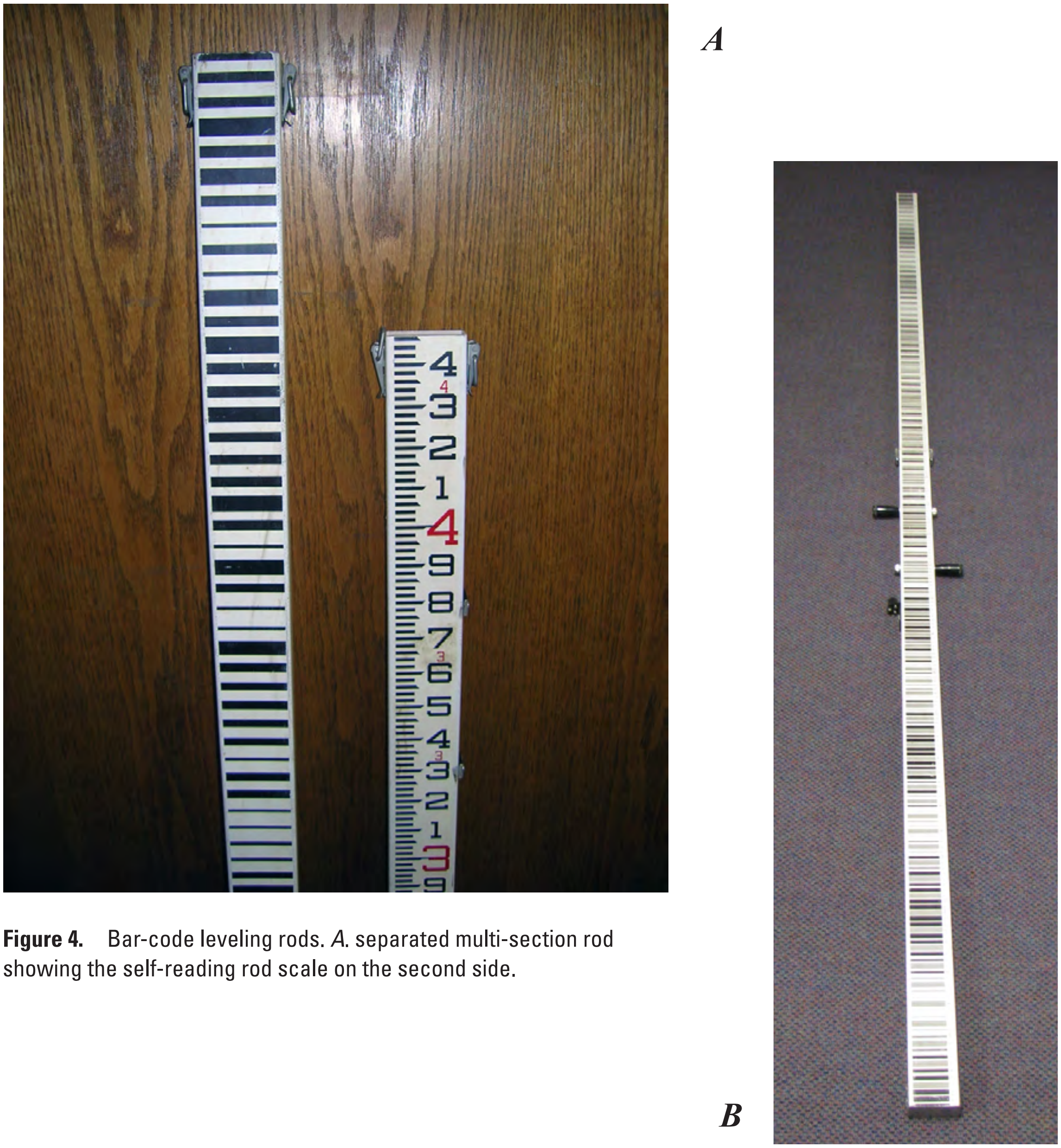


Figure 4. Bar-code leveling rods. *A*. separated multi-section rod showing the self-reading rod scale on the second side.

Collimation error of an engineer's level is determined by running a fixed-scale test, a two-peg test, or another accepted collimation test. These tests check how true the instrument is sighting on a horizontal plane. Given the precision with which gaging-station levels are run (0.001 ft) and the criteria that determine a valid level run at a gaging station (these are outlined in detail in the section on "Assessing a Level Circuit and Adjusted Elevation"), the tolerance for the collimation error of an instrument cannot exceed the absolute value (| |) of 0.003 ft/100 ft. Instruments possessing collimation errors greater than |0.003| ft/100 ft should be adjusted by qualified personnel or by a certified facility. Following any adjustments made to an instrument, a collimation test must be performed and documented to verify that the instrument was adjusted correctly.

The criteria for an acceptable level run include a limit on circuit-closure error and a maximum difference between the first and second elevations of any objective point in the level circuit. Conditions exist that can cause an instrument with a collimation error greater than |0.003| ft/100 ft to yield results that meet the criteria for an acceptable level circuit and yet still produce final elevations that are incorrect because of the collimation error (see section on "Collimation Error and Balanced Sightline Distances"). In order to minimize errors associated with instrument calibration, a collimation test (fixed-scale, peg, or other accepted test) must be performed and documented at least once per week (National Oceanic and Atmospheric Administration, 1981; Federal Geodetic Control Committee, 1984) for each week that gaging-station levels are run. There should not be more than 7 days between a collimation test and a set of levels. If a level is found to have a collimation error greater than |0.003| ft/100 ft, all gaging-station levels run since the previous collimation test must be discarded and re-run. For this reason, it is recommended to run collimation tests more frequently. When electronic digital levels are used, these tests should be done for both the optical and digital systems.

Fixed-Scale Test

A fixed-scale test uses two mounted rod scales set to the same datum and spaced about 120 ft apart to determine the collimation error of an instrument (fig. 5). A fixed-scale test can be set up outdoors between trees, deeply set posts, or buildings at a reasonably level location, or can be set up indoors; for example, between columns or doorframes in a long corridor of a large building (Kennedy, 1990). To install the scales, place the instrument equidistant from the mounting locations. Install each scale such that the readings from the level to each scale are equal. To test the collimation of the level, set it up as close as possible to one scale. Read each scale from this location, and measure the horizontal distances to each scale. The length of d_2 should not exceed 110 ft to avoid curvature and refraction effects. Horizontal distances can be determined using the stadia hairs of the level, the distance reported by an electronic digital level, or a measuring tape. From these readings, the collimation error can be computed using the equation (Kennedy, 1990):

$$c = 100 * \left[\frac{(R_1 - R_2)}{(d_2 - d_1)} \right], \qquad (1)$$

where

c is the collimation error, in unit length per 100 unit lengths,

R_1 is the reading obtained from the near rod scale, in unit length,

R_2 is the reading obtained from the far rod scale, in unit length,

d_1 is the distance to the near rod scale, in unit length, and

d_2 is the distance to the far rod scale, in unit length, which should be less than 110 ft.

If the absolute value of the collimation error is greater than 0.003 ft/100 ft, the level must be adjusted. A diagram of a fixed-scale test showing the variables of equation 1 is shown in figure 5. A fixed-scale test form is provided in appendix A.

Peg Test

A peg test does not require scales to be mounted and can be run with the instrument and rod in any reasonably level location. Several versions of peg tests are used. The one described here, commonly referred to as a two-peg test, was adapted from the USGS Geography Discipline, formerly known as the USGS Survey and National Mapping Division (Kennedy, 1990). Two pegs or marks should be established and spaced about 120 ft apart (fig. 6). The instrument is set up as close as possible to one of the pegs. Shots are taken to the rod held on the near peg and the far peg. Distances from the instrument to the pegs are measured, using the stadia hairs, the digital system, or a measuring tape. The instrument is then moved as near as possible to the other peg, and again shots are taken to each and distances are measured. From these measurements the collimation error can be computed using the equation (Kennedy, 1990):

$$c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right], \qquad (2)$$

where

c is the collimation error, in unit length per 100 unit lengths,

R_1 is the reading taken on the near peg from the first instrument setup, in unit length,

R_2 is the reading taken on the far peg from the first instrument setup, in unit length,

R_3 is the reading taken on the near peg from the second instrument setup, in unit length,

R_4 is the reading taken on the far peg from the second instrument setup, in unit length,

d_1 is the distance to the near peg from the first instrument setup, in unit length,

d_2 is the distance to the far peg from the first instrument setup, in unit length,

d_3 is the distance to the near peg from the second instrument setup, in unit length, and

d_4 is the distance to the far peg from the second instrument setup, in unit length.

The average of d_2 and d_4 should be less than 110 ft to avoid curvature and refraction effects. If the absolute value of the collimation error is greater than 0.003 ft/100 ft, the instrument must be adjusted. A diagram of a peg test showing the variables of equation 2 is shown in figure 6. A peg test form is provided in appendix B and is also contained in the Gaging Stations Level Notes form (appendix C).

Manufacturer-Recommended Collimation Test

Some manufacturers of level instruments provide a recommended method for testing and adjusting for collimation error. Some of the electronic digital levels contain preprogrammed tests and adjustment routines that provide for efficient and convenient collimation checks. Some preprogrammed checks may require the instrument to be located a specified distance from the rod. If manufacturer-recommended methods meet the 0.001-ft precision and the less than 0.010-ft accuracy requirements for gaging-station levels and report collimation error as a vertical deviation over a specified distance, they can be used as the weekly collimation test. Weekly tests are required for both the optical and digital systems of the electronic instruments.

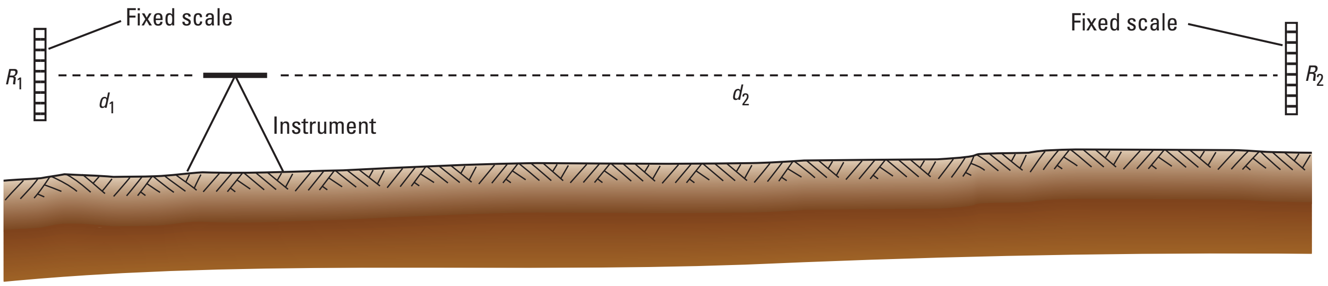


Figure 5. Engineer's level and rod scales set up for the fixed-scale test. *R*, the reading obtained from a rod scale; *d*, the distance to a rod scale. Modified from Kennedy (1990).

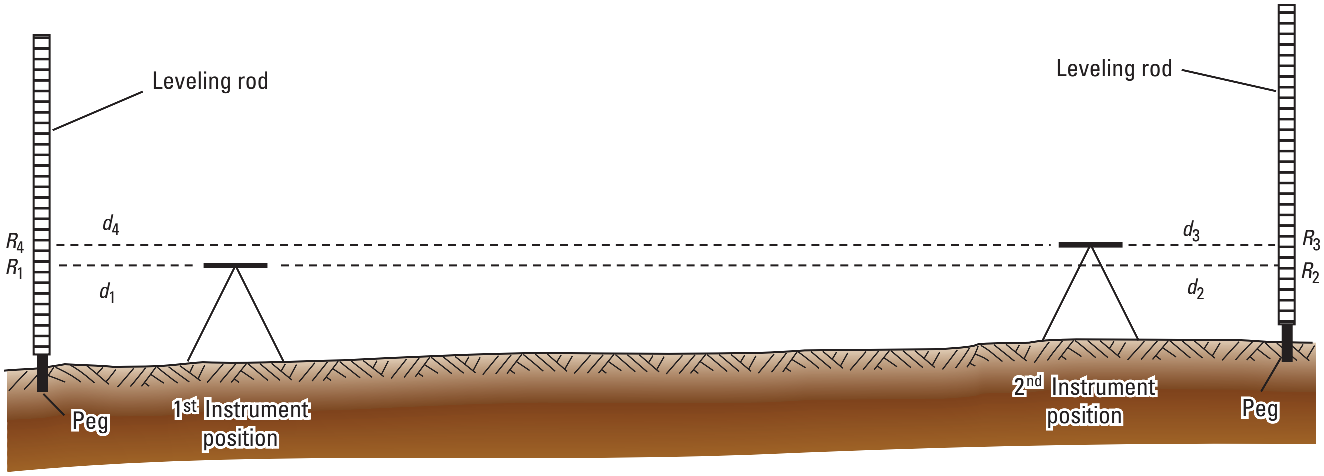


Figure 6. Engineer's level and leveling rods set up for the two-peg test. *R*, the reading obtained from a leveling rod; *d*, the distance to a peg. Modified from Kennedy (1990).

Collimation Error and Balanced Sightline Distances

Collimation error is a measure of the inclination of a level's line of sight. Unless corrected using measurements of horizontal distance, this systematic error is preserved in all measurements made with the level. Balancing the sightline distances to all objects to which shots are taken minimizes the effects of collimation error on final elevations. However, balancing sightline distances in a gaging-station level circuit is often not feasible. Under ideal conditions when sightline distances are perfectly balanced, collimation error preserved in FSs and BSs does not affect the final computed elevations. An example is an instrument that has a high collimation error of 0.010 ft/100 ft and sightline distances that equal 100 ft (table 1). Each BS and FS shows an error of 0.010 ft, because the instrument has a collimation error of 0.010 ft/100 ft and the distances are all 100 ft. Even though each shot contains collimation error, because the horizontal distances are equal, the error in each shot is equal. The collimation error indicates that the line of sight of the level is angled downwards causing readings of the leveling rod to be 0.010 ft low. Because the errors are equal for each shot, the true differences in elevation between the objective points can be accurately determined, and therefore, the final elevations of the objective points are the true elevations and the circuit-closure error is 0.000 ft. If this were a level circuit, ideally the level would not be used because the absolute value of the collimation error is greater than |0.003| ft; however, because the sightline distances are perfectly balanced, the collimation error does not adversely affect the final elevations because the true differences in elevation between the objective points are determined in this circuit.

Collimation error begins to have a profound effect on final elevations when sightline distances are extremely unbalanced. However, the effect of collimation error can be masked when the distances between the instrument and the objective points remain the same for the second instrument setup. Table 2 provides an example of how the effects of collimation error can go unnoticed. This example uses the same level circuit as the previous example, but sightline distances range from 10 to 200 ft. In this circuit, the distance to each of the objects remained the same for the second instrument setup. Errors contained in each BS and FS ranged from 0.001 to 0.020 ft. In a real gaging-station level circuit, these errors would not be known because horizontal distances are not measured. The two elevations acquired for each objective point differ from the true elevations, yet the closure error is 0.000 ft. In this example circuit, an instrument with a large unknown collimation error was used, and unless a comparison was made with the historical elevations, one would assume that the level circuit met the criteria for a valid level circuit of closure error and the difference between adjusted first and second objective point elevations (discussed in detail below). This introduces the potential for gages to be set or adjusted incorrectly during a level run.

The sightline distances should be inverted in order to reveal collimation errors in a circuit consisting of unbalanced sightline distances, which, as shown above, can produce erroneous final elevations. In the previous example with unbalanced sightline distances, the second instrument setup was located in the same position as the first instrument setup. The level circuit appeared to be valid, as evidenced by a closure error of 0.000 ft and no differences between first and second elevations for each objective point, yet the final

Table 1. Notes for gaging station levels run when all sightline distances are equal and the instrument used has a collimation error of 0.01 foot per 100 feet.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. BS, backsight; HI, height of instrument; FS, foresight; RM, reference mark; TP, turning point; NA, not applicable]

Object	Distance from instrument to object	BS error [1]	BS	HI	FS error [1]	FS	Elevation	Closure error	1st and 2nd elevation differences	True elevations	Difference from true elevation
RM1 (origin)	100	0.010	5.260	105.260	0.010	NA	[2] 100.000	NA	NA	100.000	NA
RM2	100	NA	NA	NA	0.010	7.121	98.139	NA	NA	98.139	0
RM3	100	NA	NA	NA	0.010	2.042	103.218	NA	NA	103.218	0
TP	100	NA	NA	NA	0.010	3.343	101.917	NA	NA	101.917	0
Instrument moved and re-leveled											
TP	100	0.010	4.343	106.260	0.010	NA	101.917	NA	NA	101.917	0
RM3	100	NA	NA	NA	0.010	3.042	103.218	NA	0	103.218	0
RM2	100	NA	NA	NA	0.010	8.121	98.139	NA	0	98.139	0
RM1	100	NA	NA	NA	0.010	6.260	100.000	0.000	NA	100.000	0

[1] Computed from the collimation error and the distance from the instrument to the object.

[2] Given elevation in the level circuit.

Table 2. Notes for gaging station levels run when sightline distances between the instrument and objects vary in the same order for two setups and the instrument used has a collimation error of 0.01 foot per 100 feet.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. Distances from the instrument to each object remained the same after the instrument was moved. BS, backsight; HI, height of instrument; FS, foresight; RM, reference mark; TP, turning point; NA, not applicable]

Object	Distance from instrument to object	BS error[1]	BS	HI	FS error[1]	FS	Elevation	Closure error	1st and 2nd elevation differences	True elevation	Difference from true elevation
RM1 (origin)	10	0.001	5.251	105.251	0.001	NA	[2]100.000	NA	NA	100.000	NA
RM2	100	NA	NA	NA	0.010	7.121	98.130	NA	NA	98.139	–0.009
RM3	150	NA	NA	NA	0.015	2.047	103.204	NA	NA	103.218	–0.014
TP	200	NA	NA	NA	0.020	3.353	101.898	NA	NA	101.917	–0.019
Instrument moved and re-leveled											
TP	200	0.020	4.353	106.251	0.020	NA	101.898	NA	NA	101.917	–0.019
RM3	150	NA	NA	NA	0.015	3.047	103.204	NA	0.000	103.218	–0.014
RM2	100	NA	NA	NA	0.010	8.121	98.130	NA	0.000	98.139	–0.009
RM1	10	NA	NA	NA	0.001	6.251	100.000	0.000	NA	100.000	0.000

[1] Computed from the collimation error and the distance from the instrument to the object.

[2] Given elevation in the level circuit.

elevations were incorrect, because the FS errors caused by the collimation error of the instrument were equal for the two shots taken to each objective point.

Table 3 shows an example of the same level circuit run with an instrument with the same collimation error of 0.010 ft/100 ft, but with the sightline-distances inverted so that the object farthest from the initial instrument setup is closest to the instrument for the second setup. The range of error contained in the FSs and BSs associated with the collimation error of the instrument is similar to those in the previous example because the same distances were used. Again, these errors would not be known because the horizontal distances are not measured when levels are run at gaging stations. By inverting the sightline distances a significant closure error is revealed. If this example were an actual level circuit and the instrument had a large (unknown) collimation error, the sightline distances were unbalanced, but the sightline distances were inverted for the second instrument setup, the closure error criterion for a valid level circuit would have indicated a problem with the circuit. By inverting the sightline distances in a circuit that has unbalanced sightline distances, unknown collimation errors of an instrument can be reflected in the closure error. If the location of objective points and the locations for setting up the instrument cause unbalanced sightline distances to be unavoidable, it is recommended that these distances be inverted so that the object that was farthest from the first instrument setup becomes closest to the second instrument setup. The technique of inverting the sightline distances is designed to expose any unknown instrument error in the circuit closure error, thus alerting the user of possible systematic instrument error.

Leveling Rods

Many kinds of leveling rods are available for use in running levels at gaging stations. Rods come in different lengths, many are expandable, and they are made of different materials. Many rods, such as the “Philadelphia” or “Chicago” style rods, are made of a structural material, often wood or fiberglass, and a rod-scale material, such as Invar or steel. Invar is a nickel steel alloy, commonly used for precise measuring equipment and has a very low coefficient of thermal expansion (CTE). Self- reading rods with numeric scales (fig. 7) are used with optical engineer’s levels, while electronic digital levels use leveling rods with bar-code scales (fig. 4). The scales of self-reading rods are typically divided into feet and tenths and hundredths of feet by means of alternating black and white spaces (McCormac, 1983) (fig. 8). Bar-code leveling rods often have a self-reading scale on the second side of the rod to use with the optical system of the instrument (fig. 4*A*). For gaging-station levels, self-reading rods must be graduated to 0.01 ft and readings are visually interpolated in order to meet the measurement-precision requirement of 0.001 ft. Regardless of the type of engineer’s level, when running levels at gaging stations, it is good practice to not extend a rod more than about 16 ft because of the difficulty in holding a tall rod steady and level on an objective point. A leveling rod should always be used in conjunction with a rod level.

Table 3. Notes for gaging station levels run when sightline distances between the instrument and objects vary inversely for two setups and the instrument used has a collimation error of 0.01 foot per 100 feet.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. BS, backsight; HI, height of instrument; FS, foresight; RM, reference mark; TP, turning point; NA, not applicable]

Object	Distance from instrument to object	BS error [1]	BS	HI	FS error [1]	FS	Elevation	Closure error	True elevations	Difference from true elevation
RM1 (origin)	200	0.020	5.270	105.270	0.020	NA	[2] 100.000	NA	100.000	NA
RM2	150	NA	NA	NA	0.015	7.126	98.144	NA	98.139	0.005
RM3	100	NA	NA	NA	0.010	2.042	103.228	NA	103.218	0.010
TP	10	NA	NA	NA	0.001	3.334	101.936	NA	101.917	0.019
Instrument moved and re-leveled										
TP	200	0.020	4.353	106.289	0.020	NA	101.936	NA	101.917	0.019
RM3	150	NA	NA	NA	0.015	3.047	103.242	NA	103.218	0.024
RM2	100	NA	NA	NA	0.010	8.121	98.168	NA	98.139	0.029
RM1	10	NA	NA	NA	0.001	6.251	100.038	-0.038	100.000	0.038

[1] Computed from the collimation error and the distance from the instrument to the object.

[2] Given elevation in the level circuit.

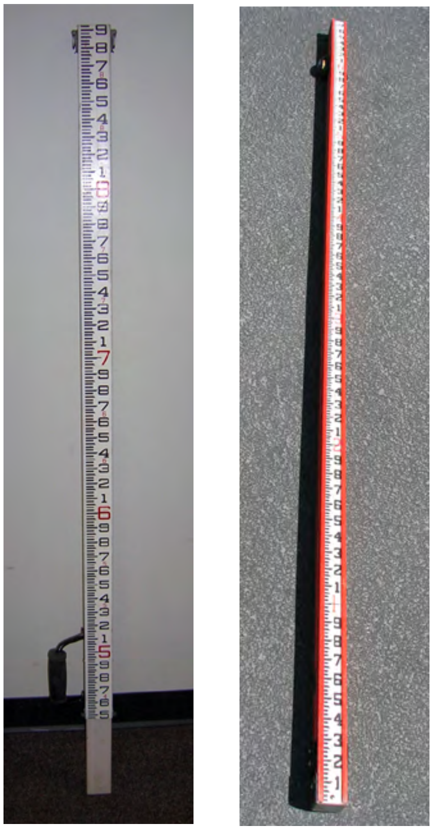


Figure 7. Self-reading leveling rods.

Inspection of Leveling rod

Leveling rods should be examined regularly to ensure that their scales are set correctly and that their structure, specifically the bottom surface, is free of damage or debris. If a leveling rod is found to be damaged it should be removed from service. Thermal expansion or contraction of the material of the rod scale should be considered when the rod is used for gaging-station levels. The most common materials for leveling-rod scales include Invar, fiberglass, steel, and wood. Most rod scales are calibrated at the standard temperature of 68°F. The entire scale length for a self-reading rod should be verified with an independent measuring tape from the bottom of the rod. Similar independent verification checks of all other measuring devices used when running levels should also be done. All verifications should be made indoors at the standard temperature of 68°F. Rods should be checked with a measuring tape at each foot marking along the length of the scale and at both sides of any joints between scale sections. If all graduations are accurate to within |0.002| ft, the rod is satisfactory (Kennedy, 1990). If a rod scale is found to be outside of the |0.002|-ft tolerance, adjust the scale if possible or remove the leveling rod from service. At temperatures greater than the calibration or standard temperature, the rod scale will expand causing measurements to be lower than they actually are, and at temperatures less than the calibration temperature, contraction of the rod scale will have the opposite effect. To minimize both errors in shots taken to leveling rods, and the need to apply corrections to measurements due to thermal expansion or contraction, it is recommended that leveling rods (including all devices used as rods during level

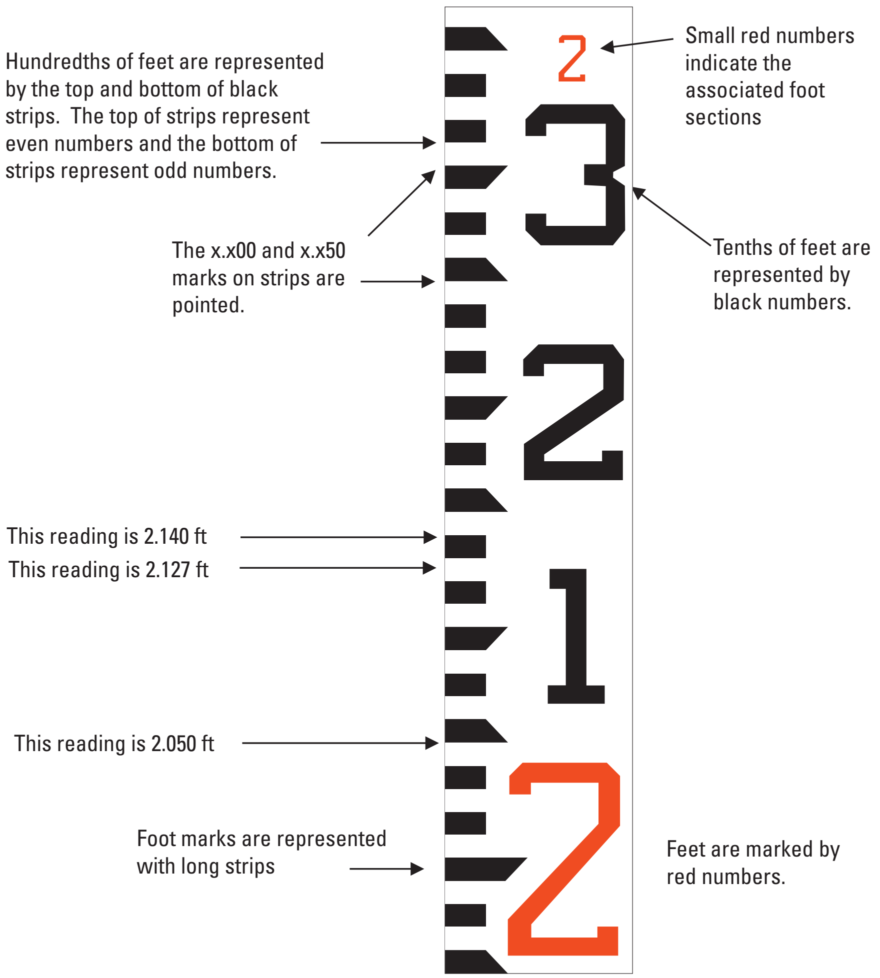


Figure 8. Scale of a self-reading Philadelphia rod.

runs) be used at temperatures near the calibration temperature of the rod scale whenever possible. Determining the need for and computing temperature corrections is discussed in the section on "Correcting for Rod Scale Expansion or Contraction Due to Temperature Variations."

Proper Care and Use of a Rod Level

It is important that the leveling rod be held vertical when levels are run at gaging stations. To ensure that the leveling rod is vertical, a rod level should always be used. Rod levels are either stand alone (fig. 9*A*) and are used with multiple leveling rods, or permanently attached and dedicated to a single leveling rod (fig. 9*B*). The stand-alone rod levels consist of a bull's eye bubble level mounted on a 90-degree or square channel material. The 90-degree channel allows the rod level to be held along the vertical axis of either a square or round leveling rod. Rod levels should be checked for plumb regularly and adjusted if necessary. To test the rod level, any corner such as a wall corner that has been verified to be level using a carpenter's level can be used. Most rod levels have screws that are used to adjust how the bubble level is seated in its mount. When checking for plumb, the bubble should be examined for expansion. If the bubble has expanded beyond the circular level indicator line, the rod level should be discarded.

Correcting for Rod Scale Expansion or Contraction Due to Temperature Variations

At constant temperatures, measurements can be precisely corrected for expansion and contraction of the rod-scale material due to temperature variation. All materials have a determined coefficient of thermal expansion (CTE), and the CTE for the rod scale should be readily available from the manufacturer of the rod. Material compositions of rod scales vary, particularly for fiberglass rods; therefore, it is recommended that the rod scale CTE be obtained directly from the manufacturer. For reference, CTE ranges for some common leveling rod-scale materials are provided in table 4.

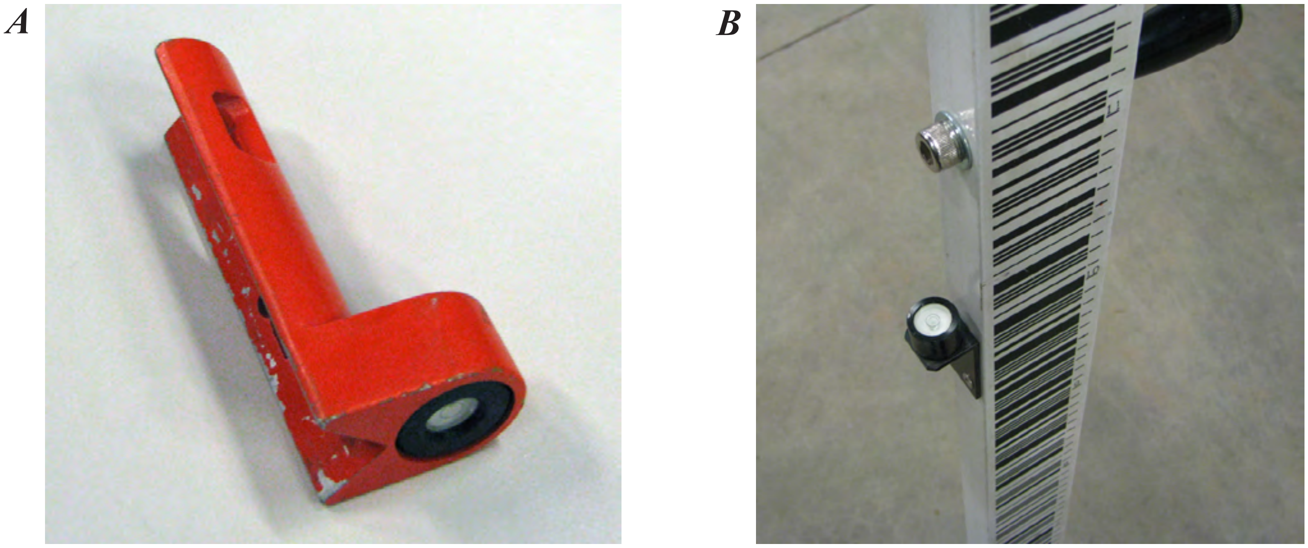


Figure 9. Stand-alone *A*. and permanently attached *B*. rod levels.

The rod-scale material-specific CTE, the standard temperature, and the rod-scale temperature at the time the leveling rod is used for a measurement are used in the following equation to determine the correction for expansion or contraction due to temperature variation:

$$C_t = \text{CTE} * L(T - T_o), \tag{3}$$

where

C_t is the correction for expansion or contraction due to temperature variation, in unit length,

CTE is the rod – scale material – specific coefficient of thermal expansion, in 1 / degrees Fahrenheit or 1 / degrees Celsius (examples contained in table 4),

L is the length of the measurement, in unit length,

T is the rod – scale temperature at the time of the measurement, in degrees Fahrenheit or degrees Celsius, and

T_o is the standard temperature, in degrees Fahrenheit (usually 68°F) or degrees Celsius (usually 20°C).

The rod-scale temperature, *T*, can be measured directly by an infrared thermistor, or if the rod is not in the direct sun, air temperature can be used as a surrogate for the rod temperature. To determine whether corrections are needed for a given level circuit, first compute or estimate the maximum elevation difference between the origin reference mark and any point in the level circuit. This is the difference between the elevation of the origin and either the highest or the lowest point that a FS will be taken on. Substitute this difference for *L* in equation 3 and compute C_t. If the absolute value of C_t is greater than 0.003, all FSs and BSs of the circuit should be corrected for temperature-related expansion or contraction. Individual FSs and BSs taken during a level run can be corrected by adding the rod reading to the computed expansion or contraction correction value by using the equation

$$S_{\text{corrected}} = S_{\text{read}} + (\text{CTE} * S_{\text{read}}(T - T_o)), \tag{4}$$

where

$S_{\text{corrected}}$ is the sight (backsight or foresight) corrected for expansion or contraction due to temperature variation, in unit length,

S_{read} is the sight (backsight or foresight) obtained from the leveling rod, in unit length,

CTE is the rod-scale material-specific coefficient of thermal expansion, in 1/degrees Fahrenheit or 1/degrees Celsius (examples contained in table 4),

T is the rod-scale temperature at the time of the measurement, in degrees Fahrenheit or degrees Celsius, and

T_o is the standard temperature, in degrees Fahrenheit (usually 68°F) or degrees Celsius (usually 20°C).

Table 4. Approximate coefficients of thermal expansion for common leveling rod-scale materials.

Rod-scale material	Approximate coefficient of thermal expansion	
	in length/length/degree Fahrenheit (1/°F)	in length/length/degree Celsius (1/°C)
Invar [1]	0.8×10^{-6}	1.4×10^{-6}
Wood [1]	2.1×10^{-6} to 2.8×10^{-6}	3.8×10^{-6} to 5×10^{-6}
Steel tape [2]	6.45×10^{-6}	12×10^{-6}
Fiberglass [1]	17×10^{-6} to 22×10^{-6}	30.6×10^{-6} to 39.6×10^{-6}

[1] From http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html.

[2] From Breed, Hosmer, and Bone (1970).

Considerations for Secondary Devices Used for Vertical Measurements

When running levels at gaging stations, a secondary measuring device other than a leveling rod might be required to take FSs on gages or to carry elevations over a large vertical distance. The CTE for the materials that compose secondary devices used in a level circuit should be obtained and used to correct FSs and BSs when appropriate. Any secondary devices used must meet the precision and accuracy requirements of gaging-station levels. When using a measuring tape to carry elevations between a bridge deck and a low water bank, the tape should be weighted so that the tape is not stretched and the tension applied by the weight should ensure that the tape is suspended vertically. Figure 10 is a photograph of a steel tape with a 1-pound weight that is commonly used for measuring water levels in wells. This same equipment can be used for tape-down measurements or for carrying elevations over a large vertical distance. The practical limit of measurement precision for this tape-down method is ±0.01 ft (U.S. Geological Survey, 1980). If used when running levels at gaging stations to carry elevations between a bridge deck and a low water bank, the FSs or BSs should be estimated to 0.001 ft.

Wind can have a profound effect on suspended measuring devices, particularly those suspended from a bridge. Wind will cause a suspended tape to bend and artificially increase the vertical distance the tape is spanning. Wind effects cannot be accounted for, so vertical measurements using a suspended measuring tape affected by wind should be avoided.

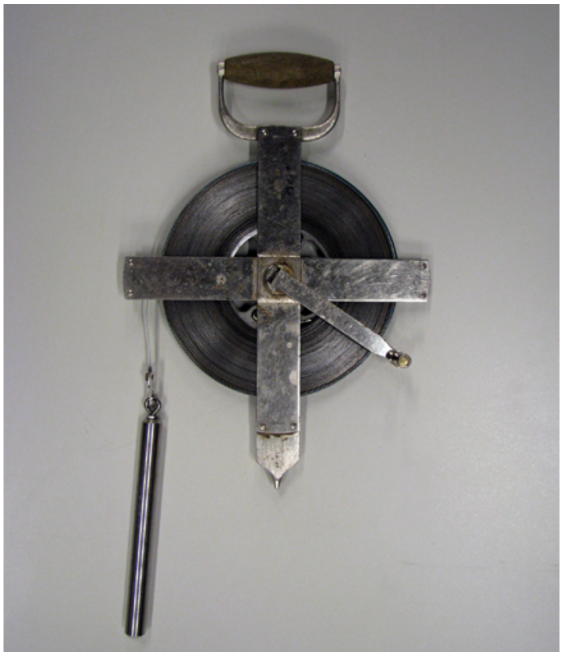


Figure 10. Steel tape with 1 pound of tension.

Establishment of Gage Datum

The gage datum is the reference surface at a gaging station to which all gages are set (Corbett and others, 1943) (fig. 11). The reference surface is represented by the 0.000-ft mark on the gages and should be located well below the streambed, below any likely gage height of zero flow (GZF). The gage datum is usually an arbitrary reference but it can be tied to an established datum, such as the North American Vertical Datum of 1988 (NAVD 88), through the use of established benchmarks. When a gaging station is being established where no station has existed previously, the gage 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 ft (Kennedy, 1990). When establishing the gage datum, the current water depth over the hydraulic control of the gage pool should be known and the potential maximum streambed scour should be considered. Experience with stream channels of similar materials, geometry, and basin characteristics may provide some indication of the potential magnitude of streambed scour. Because negative gage heights are undesirable, the gage datum reference surface that is selected should be well below the estimated maximum scour depth to avoid negative gage heights over the life of the station.

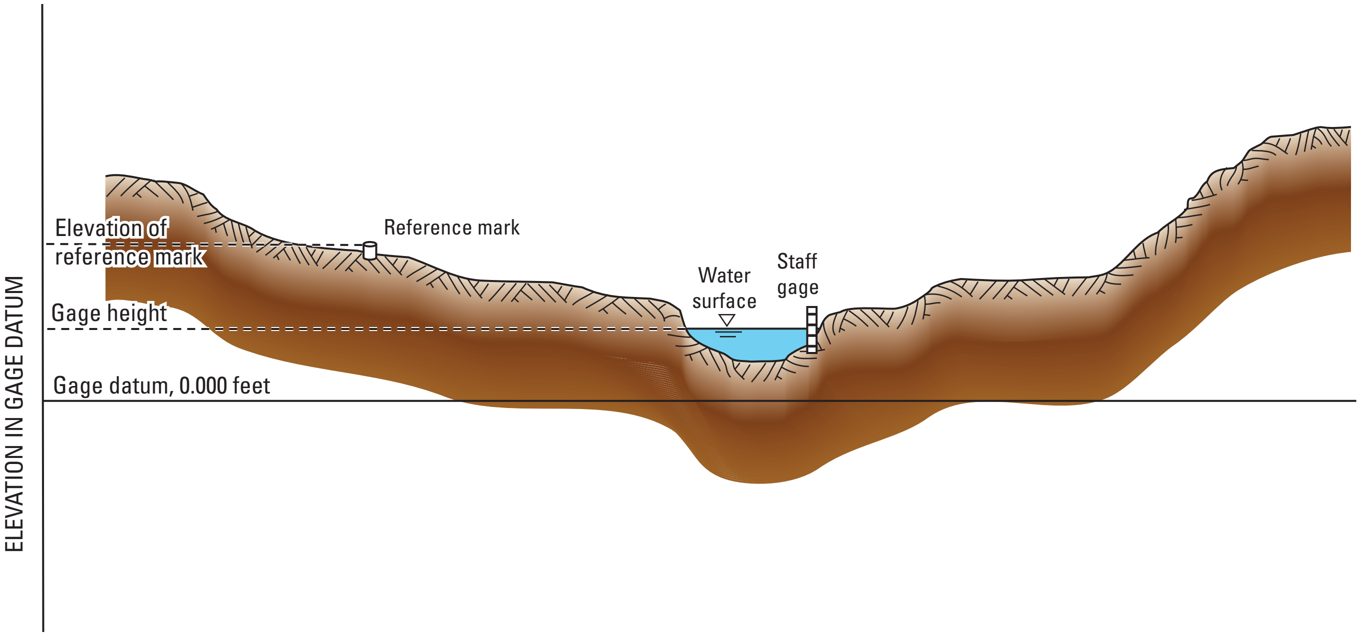


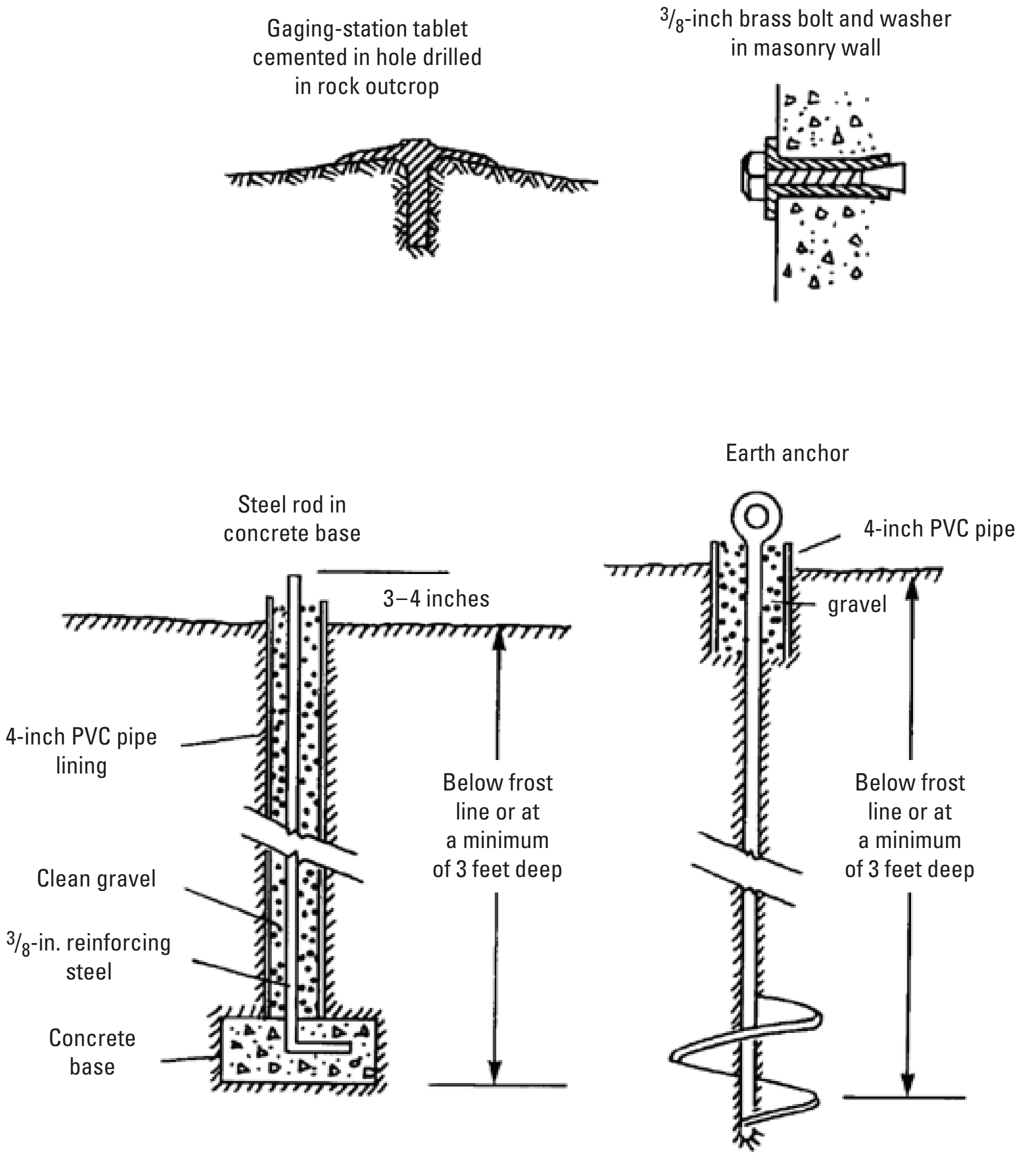
Figure 11. Gage datum at a station.

Installation of Reference Marks

Reference marks are installed and elevations are determined in the gage datum when gaging stations are established. Stable and permanent reference marks facilitate maintaining that the gages at a station are set to the gage datum over the life of the station. Typical reference marks include gaging-station tablets cemented and drilled into rock outcrops, bolts drilled into masonry walls, steel rods driven and cemented into stable ground, and other earth anchors located below frost lines (fig. 12). Reference marks provide a means for recovering the gage datum if the gaging station is destroyed or is removed and reactivated sometime later. The most stable locations for reference marks are often rock outcrops and substantial masonry structures. Bridges often provide a stable environment for reference marks; however, bridges that sway or have a high traffic volume may not be desirable because precise measurements are difficult to make with a level and rod. In the absence of rock outcrops and stable masonry structures, reference marks can be anchored at depths below the local frost depth in stable soils (fig. 13). The methods used by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Ocean Survey for establishing geodetic benchmarks (Floyd, 1978) can provide guidance for installing reference marks. Clay soils that expand and contract during seasonal variations in soil moisture should be avoided (Kennedy, 1990).

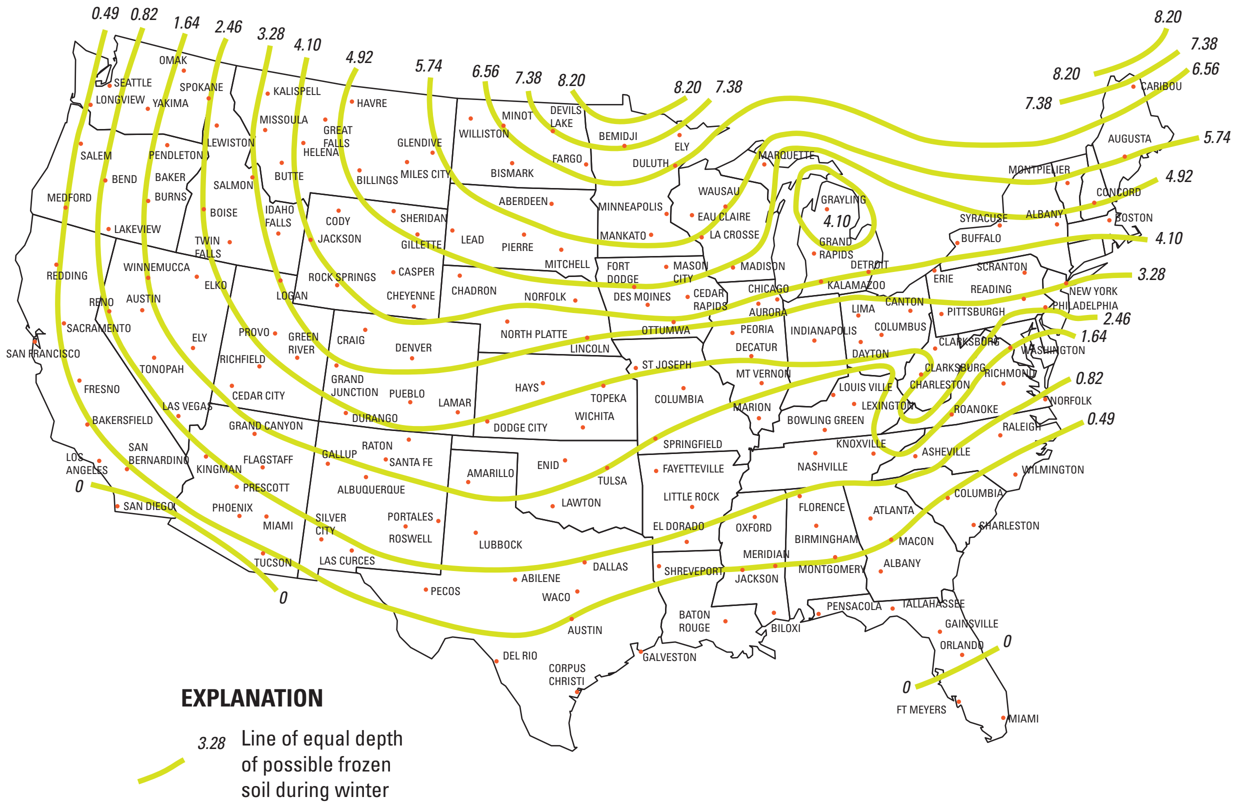
Gaging stations should have a minimum of three independent reference marks; more than three are recommended whenever possible in case one (or more) proves to be unstable or is destroyed. These marks should be located independently of one another. For example, if one or more reference marks are installed on a bridge structure, at least two others should be installed somewhere away from (and independent of) the bridge. Furthermore, reference marks should be located independently of any gage, gage infrastructure, or instream control structure, because reference marks are used to track vertical changes over time to the gages and to the other marks. If reference marks and gages are not independent of one another, determining vertical differences becomes difficult.

When locating reference marks, other considerations should be made. Access to reference marks during flood conditions is important to verify that the recorder is accurately set to the gage datum in case the reference gage is inaccessible. Ideally, at least one reference mark should be located outside of the floodplain. When determining the locations of reference marks, running levels should be considered and, if possible, marks should be located so that sightline distances are balanced and levels can be run in an efficient manner. The potential for damage or destruction of reference marks related to construction, specifically road construction or future land development, should be considered. Finally, reference marks should be easily found from descriptive statements in the station description document. As discussed later, site sketches showing the location of reference marks should be prepared. If vegetation is likely to obscure marks over time, exact measurements from local objects should be provided and a witness post should be installed.



Modified from Kennedy (1990).

Figure 12. Typical reference marks.



Modified from Floyd (1978).

Figure 13. Extreme depth of frost map.

Referencing a Gage Datum to an Established Datum

It is desirable to reference an arbitrary gage datum to a commonly used established datum, such as NAVD 88, at all gaging stations. This is especially important at stations used by the National Weather Service for flood forecasting or at locations where flood profiles are likely to be needed (Kennedy, 1990). Generally, two methods are used to tie a gage datum to an established datum - running a traditional survey line and using a survey grade Global Positioning System (GPS).

The first method is to run a traditional survey line consisting of a closed level circuit or a series of closed level circuits from an established survey control point to the origin or base reference mark of a gaging station. The National Geodetic Survey (NGS) maintains a database of established and maintained survey control points or benchmarks throughout the United States that are available at http://www.ngs.noaa.gov/cgi-bin/datasheet.prl. This database can be used to find the location of the nearest control point and its elevation in NAVD 88. The distance between the gaging station and an established survey control point may be considerable and therefore the survey line will consist of a number of different instrument setups and turning points. Techniques for running survey lines from established benchmarks outlined by the National Oceanic and Atmospheric Administration (Schomaker and Berry, 1981) should be used to tie gage datums to established datums.

The second method is to use a survey-grade GPS to determine the elevation of a gaging station reference mark above an established datum. Usually, the GPS is set up over the reference mark of interest and allowed to collect positional data over a set time interval. The uncertainty of the positional data decreases with increased occupation time over the reference mark. GPS technology and therefore the recommended methods for collecting positional data using a GPS, is continually changing. Follow currently accepted agency guidelines and methods for determining elevations with a survey-grade GPS.

After determining the elevation of a gaging station reference mark above an established datum, the gage datum can then be referenced, or tied, to the already established datum. The gage datum is the 0.000 ft reference surface at a gaging station. To determine the elevation of this surface above the desired established datum, subtract the elevation of the reference mark above the gage datum from the elevation for the same reference mark above the established datum. All other reference marks, reference points, and gages can then be assigned elevations above the established datum by adding the elevation of the gage datum above the established datum to their elevation above the gage datum.

Frequency of Gaging-Station Levels

Gaging-station locations and environments vary widely as do the factors affecting the stability of reference marks and gages. The relative stability of a gaging station needs to be considered when determining the frequency at which levels should be run. For example, a station affected by ground freezing and thawing may require levels to be run annually in the spring, while a station with gages and reference marks fixed to bedrock that has demonstrated stability may require levels to be run only every 5 years. Gaging-station levels should be run frequently enough to capture any gage movement that may occur. A decision tree is provided (fig. 14) to help determine when levels need to be run at a gaging station.

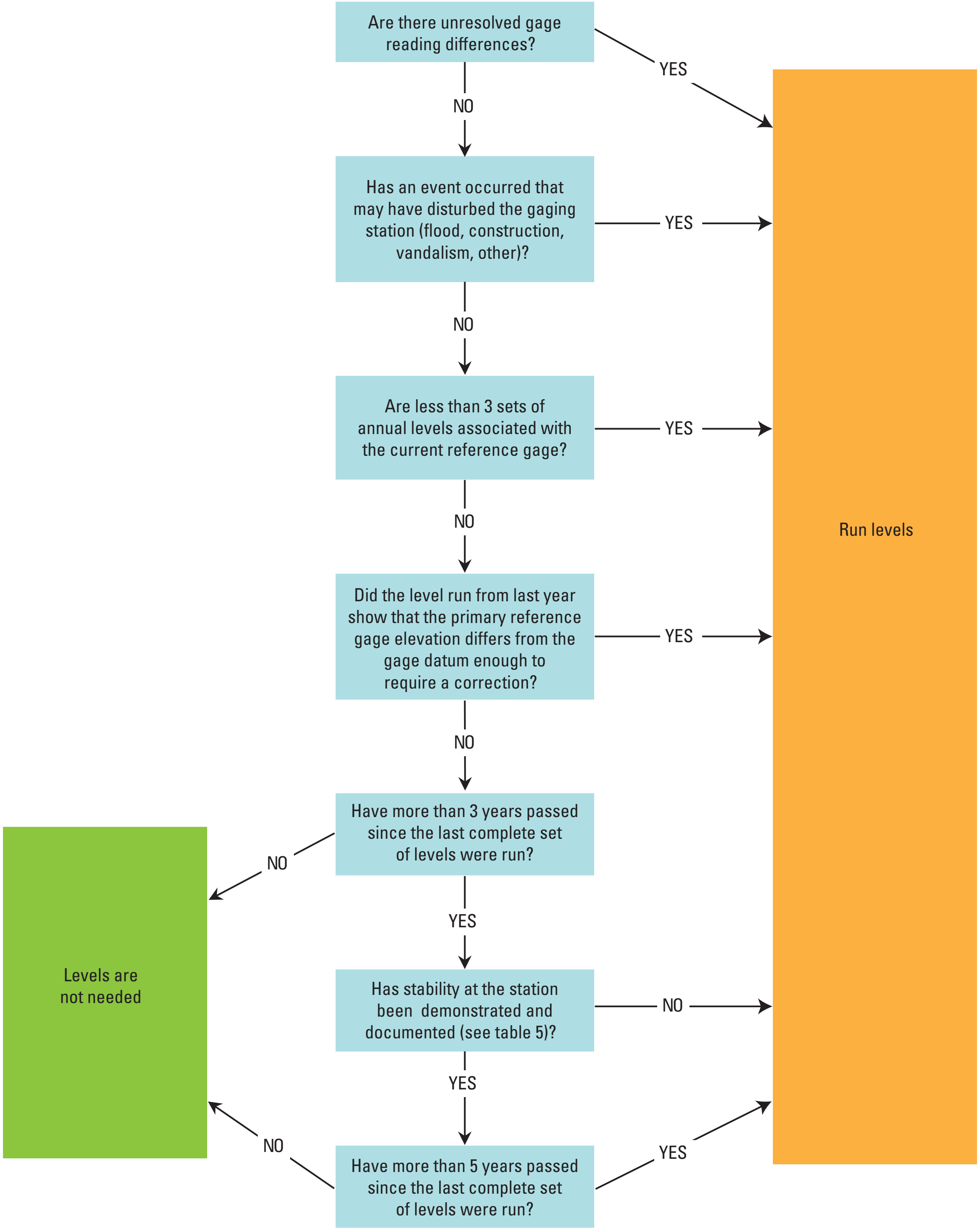


Figure 14. Decision tree for determining if levels are needed.

In addition to running levels according to the site-specific determined frequency, levels should be run whenever a difference in gage readings cannot be resolved or damage is suspected. Suspected damage to a gage may be associated with flooding, ice, vandalism, nearby construction, or other events that may disturb some part of the gaging station. A new gage installation (including the installation of a new reference gage at an existing station) should have three sets of annual levels, including the initial establishment set, acquired during the first 3 years of operation. After the first three sets of levels are acquired, a level frequency of once every 3 years may be adopted. A level frequency of at least every 5 years may be adopted if stability is shown to exist. Stability is demonstrated if the maximum elevation difference from the initial elevations for the primary reference gage and three reference marks is less than |0.015| ft for a minimum of five sets of levels and a period of at least 10 years (table 5). This means that for any set of levels run during a 10-year period, the elevations for the primary reference gage and the three reference marks (these must be the same three marks measured over the minimum five consecutive sets of levels) cannot differ from the initial elevation (as determined at the beginning of that 10-year period) by |0.015| ft or more. If elevations for any of these four objective points change by |0.015| ft or more, the site is not considered stable and the frequency that levels are run cannot exceed 3 years. An example of a summary of levels for a station where the stability criterion was not met is shown in table 6. If during any level run, regardless of the determined frequency of levels, the elevation of the primary reference gage differs from the gage datum by |0.015| ft or more (requiring the gage to be reset and the recorded and (or) observed stage values to be corrected), levels must be run again the following year. If no correction is required the following year, the level frequency can be reset to a 3-year cycle, until stability can be demonstrated.

Table 5. Requirements for demonstrating gaging station stability.

Minimum years that a reference gage and three reference marks have been active	10
Minimum number of sets of levels	5
Maximum difference in elevation from the initial elevation (as determined at the beginning of a 10-year time period), in feet, of a reference gage and three reference marks	<|0.015|

Preparation for Running Levels

Running levels at gaging stations is important for accurate measurements of stage and subsequent computation of streamflow over the life of the station. Uncertainties related to measurement error during the leveling process can be minimized if adequate preparations are made. Equipment should be properly tested and calibrated, and site-specific information important to the leveling process should be gathered. Crews assigned to run levels should be properly trained in the procedures explained in this manual and be familiar with the equipment they will be using. Levels should be run in favorable weather conditions and site-specific environmental conditions; safety hazards that may be encountered should be understood and discussed before traveling to the site.

Determining the Need for Levels

The first step in preparing to run levels is to determine whether or not levels are needed at a specific gaging station. The need for levels should be assessed using the decision tree (fig. 14) at least once a year for each station and more frequently if differences in gage readings cannot be resolved or damage to the gage is suspected. Offices are encouraged to implement a tracking system to determine when levels are due to be run at each of their stations. It is beneficial operationally

Table 6. Example summary of levels where the stability criterion is not met.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. RM, reference mark; adj., adjustment; NA, not applicable; ft, foot]

<table>
<tr><th rowspan="3">Date</th><th colspan="6">Elevations</th><th colspan="3" rowspan="2">Differences in elevation</th><th rowspan="3">Remarks</th></tr>
<tr><th rowspan="2">RM1 (given)</th><th rowspan="2">RM2</th><th rowspan="2">RM3</th><th colspan="3">Reference gage</th></tr>
<tr><th>Water surface found</th><th>Water surface left</th><th>Adj. made</th><th>RM1 (given)</th><th>RM2</th><th>RM3</th></tr>
<tr><td>04/01/1999</td><td>12.525</td><td>8.623</td><td>10.226</td><td>4.234</td><td>4.234</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td></td></tr>
<tr><td>04/14/2000</td><td>12.525</td><td>8.621</td><td>10.228</td><td>4.325</td><td>4.325</td><td>0</td><td>0</td><td>–0.002</td><td>0.002</td><td></td></tr>
<tr><td>03/28/2001</td><td>12.525</td><td>8.622</td><td>10.224</td><td>3.999</td><td>3.999</td><td>0</td><td>0</td><td>–0.001</td><td>–0.002</td><td></td></tr>
<tr><td>04/02/2004</td><td>12.525</td><td>8.635</td><td>10.242</td><td>4.177</td><td>4.177</td><td>0</td><td>0</td><td>0.012</td><td>0.016</td><td>RM3 different by 0.016 ft</td></tr>
<tr><td>04/15/2007</td><td>12.525</td><td>8.635</td><td>10.240</td><td>4.440</td><td>4.440</td><td>0</td><td>0</td><td>0.012</td><td>0.014</td><td></td></tr>
<tr><td>04/02/2010</td><td>12.525</td><td>8.635</td><td>10.244</td><td>4.013</td><td>4.013</td><td>0</td><td>0</td><td>0.012</td><td>0.018</td><td>RM3 different by 0.018 ft</td></tr>
</table>

for an office to schedule level runs for about one-third of its stations each year. This will ensure that the leveling workload in an office is balanced and will allow additional stations that have an immediate need for levels to be run to be more readily incorporated. The time of year that levels are run at stations should follow the likely factors that cause changes to the reference gage. For example, if stations are susceptible to frost heave, it is best to run levels as soon as possible after the spring thaw, ideally at temperatures near the standard temperature of the leveling rod-scale material (usually 68°F).

Compiling Historic Level Notes and Site Sketch Maps

Past level notes for the station where levels are to be run should be reviewed. These notes show the previous composition of the level circuit(s), which can assist in planning the new level circuit(s). The past level notes can be used to determine the maximum elevation difference between the origin and any point in the circuit (L in equation 3). This information is needed to determine whether or not the leveling-rod scale must be corrected for expansion or contraction. The historic level summary should be examined for any stability issues related to reference marks and reference points. Finally, copies of the past set of level notes and the site sketch map should be made and taken to the site.

Considerations for Site Conditions

The expected environmental conditions at the site where levels are to be run should be considered. The river stage should be amenable to determining accurate water-surface elevations from the low water bank and taking FSs to all reference marks, reference points, and gages. Levels should be run in favorable weather conditions; wind, rain, and snow should be avoided if at all possible. Air temperature and its affect on leveling-rod scales needs to be considered. Vegetation located in sightlines is undesirable and may be avoided through maintenance or running levels during times when leaves are off trees and shrubs. The survey crew should be briefed on all safety hazards specific to the site where the levels are to be run. These hazards should be documented and available in the site-specific job hazard analysis document.

Running Levels

After determining that levels are needed at a gaging station and making the necessary preparations, levels should be run following the procedures outlined below. Ideally, the leveling instrument should be set up in a location that allows for balanced sightline distances to the objects to be shot from this instrument setup. The instrument should be placed upon a firmly set tripod in a stable location at a height that allows for a comfortable position for the instrument operator and accurate readings of the rod on the objects to be shot. The instrument should be properly leveled using the leveling tools of the instrument. Before beginning the level run, the time should be noted and all of the gages and recorders at the station should be read. The temperature of the leveling rod should be equilibrated to the air temperature. Rod-scale and air temperatures should be measured and noted. The rod-scale temperature can be measured directly using an infrared thermistor, or if the rod is not in the direct sun, air temperature can be used for the rod-scale temperature. Equation 3 should be used to determine the maximum expansion or contraction correction for the level circuit. For this determination, L in equation 3 should be set equal to the maximum elevation difference expected between the origin and either the highest or the lowest point to be surveyed. If the absolute value of the correction for expansion or contraction due to temperature variation is greater than 0.003 ft, all FSs and BSs of the level circuit should be corrected using equation 4.

To describe the procedures for running levels at a gaging station, a very simple level circuit with two instrument setups is presented here. Determine the order in which the reference marks, reference points, gages, water surface, and other objects are to be shot. The initial instrument height is determined from a BS to the origin, as determined from historical levels at the station. The BS value, measured to the nearest 0.001 ft, should be corrected for expansion or contraction of the rod scale if needed and then added to the given elevation of the origin reference mark to obtain the instrument height. Foresights read to the nearest 0.001 ft should then be taken to the reference marks, reference points, gages, water surface, and other objects that were planned to be shot from the current instrument setup. If appropriate, FSs should be corrected for temperature-related expansion or contraction of the rod scale. The corrected FS values should be subtracted from the corresponding instrument height to obtain elevations in the gage datum. All gages and recorders should be read and noted with corresponding times just before or immediately after the FS on the water surface.

After taking a FS on all objective points that were planned to be shot from the current instrument setup, a turning point should be established. The turning point should be a stable, independent object that is not an objective point of the level circuit. This point will be used to establish a new instrument height from which second elevations will be determined for the objects previously shot. Take a FS on the turning point, and if necessary, correct for expansion or contraction, and then determine its elevation. Following this FS, the instrument should be moved and re-leveled in a location that again balances the distances to the objective points. However, if the sightline distances to the objective points were unbalanced in the initial instrument location, the new instrument location should invert the sightline distances by being set up closer to the objective point that was farthest from the initial setup. Take a BS to the turning point, and if required, correct for expansion or contraction of the rod scale and add it to the determined elevation of the turning point to determine a new instrument height. From this new instrument height, take FSs to the same objective points, correcting for expansion or contraction if conditions require it, and obtain second elevations for each. To close the leveling circuit, the final shot should be a FS taken on the origin reference mark that, if necessary, should be corrected for expansion or contraction of the rod scale.

If a FS on the water surface cannot be taken directly using the leveling rod, a measurement using a measuring tape may be made from a reference point from which two FSs were taken. The length of the tape up or down measurement should be as short as possible by measuring from a temporary or permanent reference point on the low water bank from which two FSs were taken. Tape downs from a bridge or similar structure should not be used to obtain the water-surface elevation during a level run.

The procedure presented above describes a simple gaging station level circuit in which all FSs to objective points can be taken from a single instrument setup. To help illustrate the procedures for running levels at gaging stations, a complete set of level notes from a level circuit that required only two instrument setups is shown in figure 15. The turning point that was used to determine the second instrument height was not an objective point of the circuit. In order to ensure that two FSs were taken on each objective point of the circuit, an independent turning point was required. If an objective point was used as the turning point in this circuit, that objective point would not have two FSs taken from two different instrument heights from which elevations could be compared.

Quite often, level circuits are more complex than the one presented above and require multiple instrument setups, and thus more than one turning point, to be able to take two FSs on all objective points. Intermediate turning points, those used to carry elevations to different instrument setup locations on either the “out” or the “back” parts of the level circuit, can be objective points if, when the circuit is completed, they have two FSs taken on them. Because these objective points are being used as turning points, they will also have at least one BS taken on them as well. However, regardless of circuit complexity, the turning point ascertained after determining all first elevations and before determining second elevations must be independent (not one of the objective points). This independent turning point marks the termination of the out part and the beginning of the back part of the level circuit, or loop. To help illustrate the procedures for running levels at gaging stations using multiple turning points, a complete set of level notes from a level circuit that required eight instrument setups is provided in figure 16. A level notes form, available for printing and downloading, is provided in appendix C.

Standards and Requirements for Gaging-Station Levels

Three orders of vertical control classification are accepted by the Federal Geodetic Control Committee (1984). In this classification scheme, first- and second-order leveling can be applied to the vertical control for National geodetic surveys, and second- and third-order leveling can be applied to engineering projects of varying size and scope. Selected requirements associated with the three classifications that are pertinent to gaging-station levels are presented in table 7. Gaging-station levels generally are classified as third-order levels with the adoption of some first- and second-order requirements. Table 8 shows adopted standards and requirements for gaging-station levels.

Circuit-Closure Error

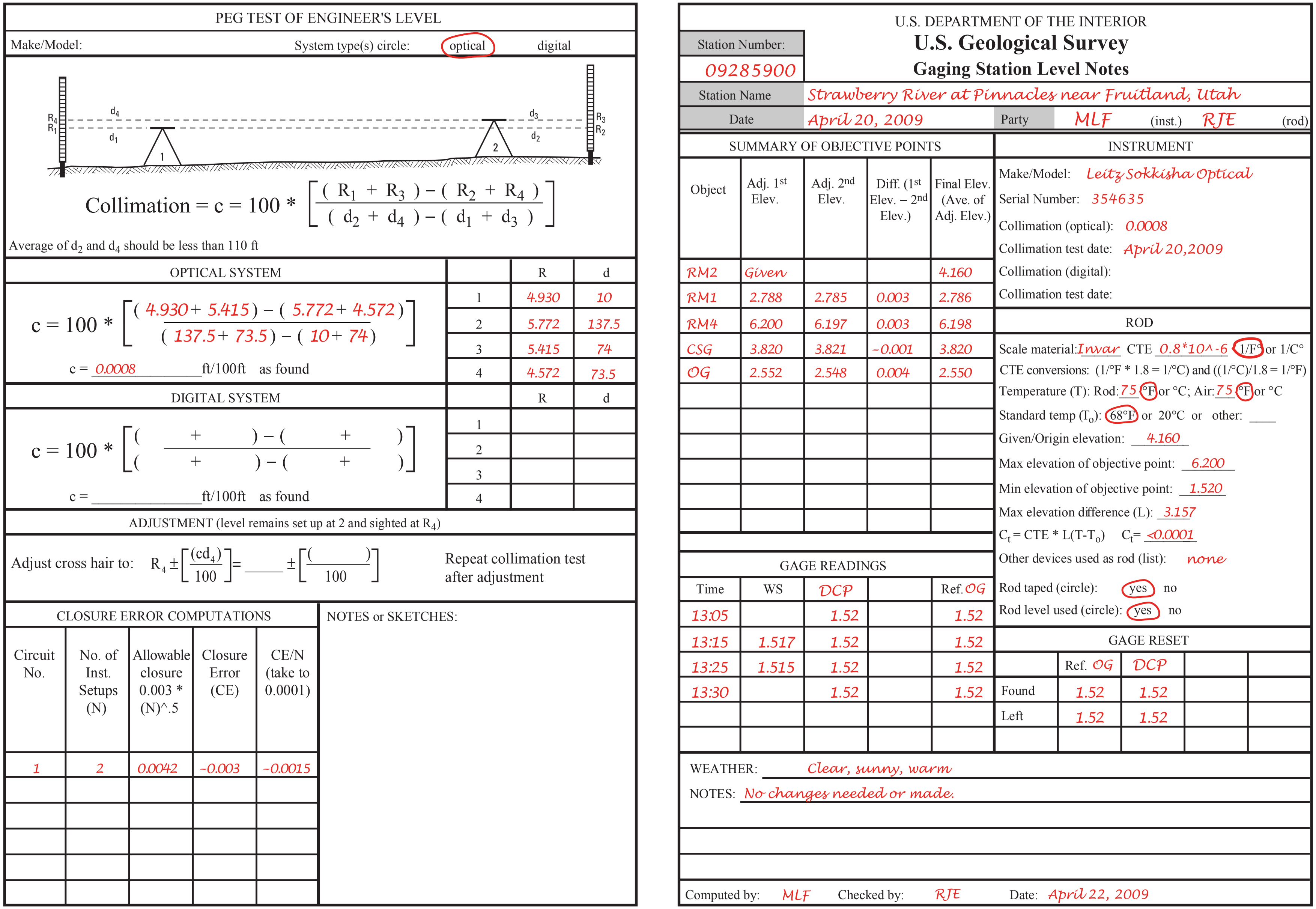
The closure error of a leveling circuit is the difference between the given elevation for the origin reference mark and the elevation for that reference mark associated with the final instrument height of the level circuit. Closure error is computed as the given elevation minus the final elevation. Assigned vertical closure-error limits define the desired and acceptable accuracy, or error, for the intended use of the survey data. The random acquisition of error in a level circuit tends to vary with the square root of the number of opportunities or instrument setups (Davis and others, 1966). Therefore, a vertical closure-error limit for differential levels can be determined by multiplying an acceptable uncertainty constant by the square root of the total number of setups. This acceptable uncertainty depends on how the data will be used and should be amenable to the desired accuracy and precision requirements of the levels. For gaging-station levels, the uncertainty constant is 0.003 ft (Kennedy, 1990). The vertical closure-error limit for gaging station level circuits is computed using the equation

$$CE_{\text{limit}} = 0.003\sqrt{n}, \quad (5)$$

where

CE_{limit} is the closure-error limit, in feet, and

n is the total number of instrument setups in a level circuit.



PEG TEST OF ENGINEER'S LEVEL

Make/Model: System type(s) circle: [✓ optical] digital

$$\text{Collimation} = c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)}\right]$$

Average of d_2 and d_4 should be less than 110 ft

OPTICAL SYSTEM		R	d
$$c = 100 * \left[\frac{(4.930 + 5.415) - (5.772 + 4.572)}{(137.5 + 73.5) - (10 + 74)}\right]$$	1	4.930	10
	2	5.772	137.5
	3	5.415	74
c = 0.0008 ft/100ft as found	4	4.572	73.5

DIGITAL SYSTEM		R	d
$$c = 100 * \left[\frac{(\quad + \quad) - (\quad + \quad)}{(\quad + \quad) - (\quad + \quad)}\right]$$	1		
	2		
	3		
c = ______ ft/100ft as found	4		

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

Adjust cross hair to: $R_4 \pm \left[\frac{(cd_4)}{100}\right] = \_\_\_\_ \pm \left[\frac{(\quad)}{100}\right]$

Repeat collimation test after adjustment

CLOSURE ERROR COMPUTATIONS

Circuit No.	No. of Inst. Setups (N)	Allowable closure 0.003 * (N)^.5	Closure Error (CE)	CE/N (take to 0.0001)
1	2	0.0042	-0.003	-0.0015

NOTES or SKETCHES:

U.S. DEPARTMENT OF THE INTERIOR

U.S. Geological Survey

Gaging Station Level Notes

Station Number: 09285900

Station Name: Strawberry River at Pinnacles near Fruitland, Utah

Date: April 20, 2009 Party: MLF (inst.) RJE (rod)

SUMMARY OF OBJECTIVE POINTS

Object	Adj. 1st Elev.	Adj. 2nd Elev.	Diff. (1st Elev. – 2nd Elev.)	Final Elev. (Ave. of Adj. Elev.)
RM2	Given			4.160
RM1	2.788	2.785	0.003	2.786
RM4	6.200	6.197	0.003	6.198
CSG	3.820	3.821	-0.001	3.820
OG	2.552	2.548	0.004	2.550

INSTRUMENT

Make/Model: Leitz Sokkisha Optical

Serial Number: 354635

Collimation (optical): 0.0008

Collimation test date: April 20,2009

Collimation (digital):

Collimation test date:

ROD

Scale material: Invar CTE 0.8*10^-6 [✓ 1/F°] or 1/C°

CTE conversions: (1/°F * 1.8 = 1/°C) and ((1/°C)/1.8 = 1/°F)

Temperature (T): Rod: 75 [✓ °F] or °C; Air: 75 [✓ °F] or °C

Standard temp (T_o): [✓ 68°F] or 20°C or other: ____

Given/Origin elevation: 4.160

Max elevation of objective point: 6.200

Min elevation of objective point: 1.520

Max elevation difference (L): 3.157

C_t = CTE * L(T-T_o) C_t= <0.0001

Other devices used as rod (list): none

Rod taped (circle): [✓ yes] no

Rod level used (circle): [✓ yes] no

GAGE READINGS

Time	WS	DCP		Ref. OG
13:05		1.52		1.52
13:15	1.517	1.52		1.52
13:25	1.515	1.52		1.52
13:30		1.52		1.52

GAGE RESET

	Ref. OG	DCP		
Found	1.52	1.52		
Left	1.52	1.52		

WEATHER: Clear, sunny, warm

NOTES: No changes needed or made.

Computed by: MLF Checked by: RJE Date: April 22, 2009

Figure 15. Complete set of level notes for a level circuit with two instrument setups.

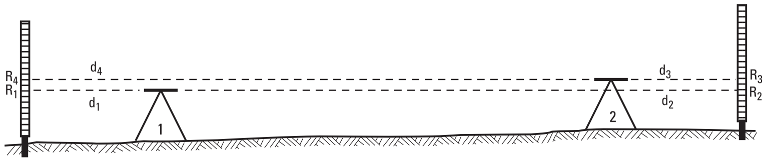
OBJECT	BS	CORRECTED BS	HEIGHT OF INSTRU-MENT (HI)	FS	CORRECTED FS	ELEVATION	Remarks	CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
		BS+(CTE* BS*(T−T_0))			FS+(CTE* FS*(T−T_0))									
RM2	5.017		9.177			4.160	Given; Cap 15' NE gage	-0.0015					4.160	Given, Origin
RM1				6.388		2.789	Cap in concrete pier		2.788		0.003	2.786	2.788	
RM4				2.976		6.201	Bolt in tree 10' SE gage		6.200		0.003	6.198	6.200	
CSG				5.356		3.821	Index top lower cap		3.820		-0.001	3.820	3.822	
OG				6.624		2.553	Ref. gage (staff plate)		2.552		0.004	2.550	2.550	Nail at 2.55
WS	@13:15			7.660		1.517	OG=1.52, DCP=1.52		1.516					Held on rock, +/-.01
TP1				8.195		0.982								
		Moved Instrument												
TP1	8.335		9.317					-0.0030						
WS	@13:25			7.802		1.515	OG=1.52, DCP=1.52			1.512				Held on rock, +/-.01
OG				6.766		2.551				2.548				Nail at 2.55
CSG				5.493		3.824				3.821				
RM4				3.117		6.200				6.197				
RM1				6.529		2.788				2.785				
RM2				5.154		4.163								
	CLOSURE ERROR = 4.160 - 4.163 = -0.003													
	CElimit = |0.003*(√2setups)| = |0.004|													

Figure 15. Continued.

PEG TEST OF ENGINEER'S LEVEL

Make/Model:

System type(s) circle: [✓ optical] [✓ digital]



$$\text{Collimation} = c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right]$$

Average of d_2 and d_4 should be less than 110 ft

OPTICAL SYSTEM

$$c = 100 * \left[\frac{(4.834 + 4.715) - (2.643 + 6.901)}{(109.4 + 108.9) - (9.6 + 10.2)} \right]$$

c = 0.0025 ft/100ft as found

	R	d
1	4.834	9.6
2	2.643	109.4
3	4.715	10.2
4	6.901	108.9

DIGITAL SYSTEM

$$c = 100 * \left[\frac{(4.940 + 4.559) - (2.748 + 6.747)}{(109.1 + 108.7) - (9.9 + 10.2)} \right]$$

c = 0.002 ft/100ft as found

	R	d
1	4.940	9.9
2	2.748	109.1
3	4.559	10.2
4	6.747	108.7

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

Adjust cross hair to: $R_4 \pm \left[\frac{(cd_4)}{100}\right] = \_\_\_\_ \pm \left[\frac{(\quad\quad)}{100}\right]$

Repeat collimation test after adjustment

CLOSURE ERROR COMPUTATIONS

Circuit No.	No. of Inst. Setups (N)	Allowable closure 0.003 * (N)^.5	Closure Error (CE)	CE/N (take to 0.0001)
1	8	0.008	-0.004	-0.0005

NOTES or SKETCHES:

U.S. DEPARTMENT OF THE INTERIOR

U.S. Geological Survey

Gaging Station Level Notes

Station Number: 09261000

Station Name: Green River near Jensen, Utah

Date: April 19, 2009

Party: MLF (inst.) TAK (rod)

SUMMARY OF OBJECTIVE POINTS

Object	Adj. 1st Elev.	Adj. 2nd Elev.	Diff. (1st Elev. – 2nd Elev.)	Final Elev. (Ave. of Adj. Elev.)
RM1	Given			15.410
RM3	25.685	25.688	-0.003	25.686
RM4	16.290	16.290	0.000	16.290
ChkBar	26.471	26.472	-0.001	26.472

INSTRUMENT

Make/Model: TopCon DL-102C

Serial Number: 1202

Collimation (optical): 0.0025

Collimation test date: April 19, 2009

Collimation (digital): 0.0020

Collimation test date: April 19, 2009

ROD

Scale material: Fiberglass CTE 20*10^-6 [✓ 1/F°] or 1/C°

CTE conversions: (1/°F * 1.8 = 1/°C) and ((1/°C)/1.8 = 1/°F)

Temperature (T): Rod: 70 [✓ °F] or °C; Air: 70 [✓ °F] or °C

Standard temp (T_o): [✓ 68°F] or 20°C or other: ____

Given/Origin elevation: 15.410

Max elevation of objective point: 26.472

Min elevation of objective point: 3.114

Max elevation difference (L): 12.296

C_t = CTE * L(T-T_o) C_t = <0.0005

Other devices used as rod (list): none

Rod taped (circle): [✓ yes] no

Rod level used (circle): [✓ yes] no

GAGE READINGS

Time	WS	DCP		Ref. WW
12:05		3.11		3.11
12:30	3.114	3.11		3.11
12:35	3.114	3.11		3.11
12:55		3.11		3.11

GAGE RESET

	Ref. WW	DCP		
Found	3.11	3.11		
Left	3.11	3.11		

WEATHER: Clear, sunny, warm

NOTES: No changes needed or made.

Computed by: MLF Checked by: TAK Date: April 22, 2009

Figure 16. Complete set of level notes for a level circuit with eight instrument setups.

OBJECT	BS	CORRECTED BS	HEIGHT OF INSTRUMENT (HI)	FS	CORRECTED FS	ELEVATION	Remarks	CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
		BS+(CTE*BS*(T−T_0))			FS+(CTE*FS*(T−T_0))									
RM1	3.111		18.521			15.410	Brass cap rt. Anchor block	-0.0005					15.410	Given, Origin
RM4				2.230		16.291	Top of bolt d/s leg A-frame		16.290		0.000	16.290	16.290	
TP1	1.552		9.964	10.109		8.412	screwdriver	-0.0010						
WW				0		9.964	Direct read		9.963					Dial =9.96
WS	@12:30			6.850		3.114	WW(ref) = 3.11, DCP=3.11		3.113					+/ – 0.02
TP2	4.616		10.028	4.552		5.412		-0.0015						
WS	@12:35			6.914		3.114	WW(ref) = 3.11, DCP=3.11			3.112				+/ – 0.02
WW				0		10.028	Direct read			10.026				Dial =10.03
TP1	9.880		18.292	1.616		8.412		-0.0020						
RM4				2.000		16.292				16.290				
TP3	8.670		25.464	1.498		16.794		-0.0025						
TP4	5.069		28.590	1.943		23.521		-0.0030						
RM3				2.902		25.688	Brass cap us right brdg abut		25.685		-0.003	25.686	25.690	
CHKBR				2.116		26.474	Dial = 26.47		26.471		-0.001	26.472	26.470	
TP5	2.417		28.692	2.315		26.275		-0.0035						
CHKBR				2.217		26.475	Dial = 26.47			26.472				
RM3				3.001		25.691				25.688				
TP6	1.682		21.344	9.030		19.662		-0.0040						
RM1				5.930		15.414				15.410				
	Closure Error is (15.410-15.414) = -0.004													
	Acceptable closure is 0.003*√8 = |0.008| ft													

Figure 16. Continued.

Table 7. Standards and select requirements for leveling.

[Modified from Federal Geodetic Control Committee (1984) and McCormac (1983). *D* is distance in kilometers. ft, foot]

Order	**First**		**Second**		**Third**
Class	**I**	**II**	**I**	**II**	
Recommended uses	Basic framework of the National Network and metropolitan area control. Regional crustal movement studies. Extensive engineering projects. Support for subsidiary surveys.		Secondary framework of the National Network and metropolitan area control. Local crustal movement studies. Large engineering projects. Tidal boundary reference. Support for lower order surveys.	Densification within the National Network. Rapid subsidence studies. Local engineering projects. Topographic mapping.	Small-scale topographic mapping. Establishing gradients in mountainous areas. Small engineering projects. May or may not be adjusted to the National Network.
Maximum collimation error (ft/100 ft)	0.005	0.005	0.005	0.005	0.01
Maximum time interval (days) between collimation error determinations	1	1	1	1	7
Rod level verticality maintained to within (ft)	10	10	10	10	10
Maximum sight length (ft)	164	197	197	230	295
Minimum ground clearance of line of sight (ft)	1.6	1.6	1.6	1.6	1.6
Maximum circuit misclosure (circuit-closure error limit) (ft)	$\lvert 0.010\sqrt{D}\rvert$	$\lvert 0.013\sqrt{D}\rvert$	$\lvert 0.020\sqrt{D}\rvert$	$\lvert 0.026\sqrt{D}\rvert$	$\lvert 0.039\sqrt{D}\rvert$

Table 8. Standards and adopted requirements for gaging station levels.

[*n* is the total number of instrument setups in a circuit. ft, foot]

	Adopted standards and requirments
Order	**Third**
Use	**Gaging station levels**
Maximum collimation error (ft/100 ft)	|0.003|
Maximum time interval (days) between collimation error determinations	7
Rod level verticality maintained to within (ft)	10
Maximum sight length (ft)	164
Minimum ground clearance of line of sight (ft)	1.6
Maximum circuit misclosure (circuit-closure error limit) (ft)	$\lvert 0.003\sqrt{n}\rvert$

Assessing a Level Circuit and Adjusting Elevations

An acceptable set of gaging-station levels has two FSs, each from a different instrument height, to a minimum of two independent reference marks, all reference points, all gages, and the water surface. A third independent reference mark is the origin, or starting point, with a given elevation from which the initial instrument height is determined. The origin reference mark is considered to be the most stable and should be explicitly identified as such in the current station description for the gaging station. The first criterion for a valid level circuit is that the absolute value of the closure error for the leveling circuit must be less than or equal to the closure error limit computed using equation 5 and must not exceed |0.015| ft regardless of the number of instrument setups. If the closure error exceeds the closure error limit, the entire level circuit must be re-run.

Following the completion of a level circuit for which the closure error falls within the specified limit, elevations of objective points are adjusted by distributing the determined closure error of the circuit to each instrument setup. Closure error is associated with instrument setups made throughout a leveling circuit and instrument (collimation) error if present and sightline distances are not balanced. Closure error is introduced into a circuit during the determination of instrument heights because of errors in FS readings taken on the turning points, or errors in BS readings taken on the turning points or origin. Closure error is not affected by side shots, shots taken on objective points from a given instrument setup. In the levels methods and techniques presented in this manual, the specific instrument setup(s) where error is incurred cannot be determined; therefore, closure error is distributed in a manner that assumes the error accumulates with each instrument setup. The methods described by Thomas and Jackson (1981) should be used to adjust the elevations of objective points by distributing the circuit closure error uniformly to the different instrument setups of the level circuit. To determine adjusted elevations for any objective point in a circuit, use the equation

$$E_{adj} = [(HI_{seq})(CE / n)] + E_{unadj}, \tag{6}$$

where

E_{adj} is the adjusted elevation of an objective point,

HI_{seq} is the sequential instrument setup number associated with the foresight taken to that objective point (the first instrument setup is 1, second instrument setup is 2),

CE is the closure error for the circuit computed as the given origin elevation minus the final elevation of the origin from the final instrument setup,

n is the total number of instrument setups in the circuit, and

E_{unadj} is the unadjusted elevation of the objective point.

Table 9 gives an example of a four-instrument setup level circuit where a closure error of -0.005 ft is distributed to the four instrument setups and the applied error is accumulated with the sequence of instrument setups. The absolute value of the closure error of the circuit, 0.005 ft, is less than the closure error limit, |0.006| ft, computed using equation 5. The closure error of -0.005 ft shows that the final elevation of the origin reference mark was 0.005 ft higher than the given elevation. The adjustment, calculated by dividing the closure error by the number of instrument setups and multiplying by the sequential instrument setup number should be rounded to a precision of 0.0001 ft. This adjustment should be added to the unadjusted elevations to obtain adjusted elevations that should then be rounded to a precision of 0.001 ft. Rounding should follow the technique shown in table 10 (U.S. Geological Survey, 1991).

The closure-error criterion of a valid level circuit discussed above ensures that systematic errors associated with instrument setups are not introduced into a leveling circuit. The second criterion of a valid level circuit is that the absolute value of the difference between the adjusted first and second elevations for each objective point must be less than or equal to 0.005 ft. This criterion, based on the examination of side shots, ensures that systematic errors specific to each objective point are not present in their final elevations. If the absolute value of the difference between the adjusted first and second elevations for an objective point is greater than 0.005 ft, two new FSs, each from independent instrument heights, must be taken. A new closure error for this abbreviated circuit is determined, and the closure error must fall within the previously specified tolerance. The new elevations of the objective points are adjusted, as described above, and the absolute value of the difference between the adjusted first and second elevations must be less than or equal to 0.005 ft. Elevations for some objects are determined by sighting them in at the cross hair of the level, such as the bottom of a wire weight or an electric tape gage weight. When running levels to these types of objects, they are either lowered or raised until they are at the cross hair of the level. Therefore, determined elevations, which are equal to the instrument height, vary from one instrument setup to another. For this reason, these types of objects are not subject to the elevation difference criterion. Although it may be possible to compare the difference between the height of the instrument and the dial reading for the 2 FSs, the 0.01 ft precision of the gages prohibits a comparison that can be held to the |0.005| ft tolerance. Because taking precise FSs on the water surface is often difficult, water-surface elevations are not subject to the |0.005| ft elevation difference criterion as long as uncertainties in the water-surface measurements are noted (for example,

Table 9. Computed adjustment values for each instrument setup of a four-instrument level circuit with a closure error of –0.005 foot.

[Closure error of circuit: –0.005 foot. The final elevation of the origin reference mark was 0.005 foot higher than the given elevation]

Sequential instrument setup	Amount to add to initial elevations (foot)
1	–0.0012
2	–0.0025
3	–0.0038
4	–0.0050

Table 10. Technique for rounding off numbers.

[Modified from Hansen (1991)]

Example	Original number	Rounded number	
1	0.32891	0.329	If the first of the discarded digits is greater than 5, add 1 to the digit representing the third significant figure
2	47,543	47,500	If the first of the discarded digits is less than 5, leave the digit representing the third significant figure unchanged
3	11.65	11.6	If the first of the discarded digits is 5, all the following digits are zero, and the digit representing the third significant figure is even, leave the digit unchanged.
4	22.75	22.8	If the first of the discarded digits is 5, all the following digits are zero, and the digit representing the third significant figure is odd, round the digit up to the next even number.
5	18.05	18.0	If the first of the discarded digits is 5, all the following digits are zero, and the digit representing the third significant figure is zero, leave the digit unchanged.
6	18.051	18.1	If the 5 is followed by any of the digits 1 through 9, add 1 to the digit representing the third significant figure

± 0.01). Final elevations for objective points are calculated by averaging the adjusted first and second elevations. The elevation for the origin reference mark is still the given value. To properly determine whether a gage needs to be reset, and if it is reset, to ensure that it is reset correctly, levels must be computed and checked in the field. The level note form provided in appendix C adheres to the gaging-station levels procedures and requirements presented here.

Methods for Taking Foresights on Gages and the Water Surface

Two FSs must be taken to all gages and the water surface from two different instrument heights when levels are run at a gaging station. Levels are run at gaging stations to make sure that all gages are properly set and accurately reporting water-surface elevation in the gage datum. Therefore, these FSs are the most important shots taken. When gages do not agree with the gage datum, the survey crew must accurately reset the affected gages. Many different types of gages are used at gaging stations, and various techniques are used to take a FS on each gage type and the water surface. Some of the more common techniques for taking a FS on gages and the water surface are presented below.

Vertical Staff Gage

Vertical staff gages are perhaps the type of gage most commonly found at gaging stations. Staff gages are placed in direct contact with the water. They can be placed inside stilling wells or attached to various objects on the banks of a stream. Stations on streams that have a large range in stage often have a series of staff plates that are installed in vertical intervals along a sloping bank. While it is feasible to directly read staff plates using an engineer's level, this technique is usually not practical. The most common method for taking a FS on a staff plate is to establish a reference point by partially driving a nail or screw into the staff plate backing next to the plate. The elevation of the reference point, in relation to the staff plate, should be read from the plate and noted. To take the FS, a rod should be held level on the reference point (fig. 17). For the staff plate to agree with the gage datum, the elevation of the reference point, read using the plate, should equal the elevation computed from the FS. Staff gages consisting of multiple plate sections should have a FS taken on all sections or a measuring tape can be used to measure from a location where the FSs have been taken on one plate section, such as a reference point, to each of the other plate sections. For obvious reasons, staff plates must be installed vertically. A carpenter's level should be used to verify that plates are vertical when levels are run.

Electric Tape Gage

Electric tape gages (ETG) are used in stilling wells to safely measure the water surface inside the well without entering the confined space. Electric tape gages are permanently mounted on a shelf inside the stilling well. These gages consist of a spooled graduated steel tape with an attached weight and an analog voltage readout (fig. 18). The gage is connected to a battery terminal, and a lead wire from another battery terminal is extended below the water surface in the well. To obtain a gage reading, the ETG weight is spooled down to the water, and when the bottom of the weight contacts the water surface, the circuit is closed and the voltage dial responds. The graduated tape is read at a reading index, called the ETG index, marked by a line and located just above the surface on which it is mounted.

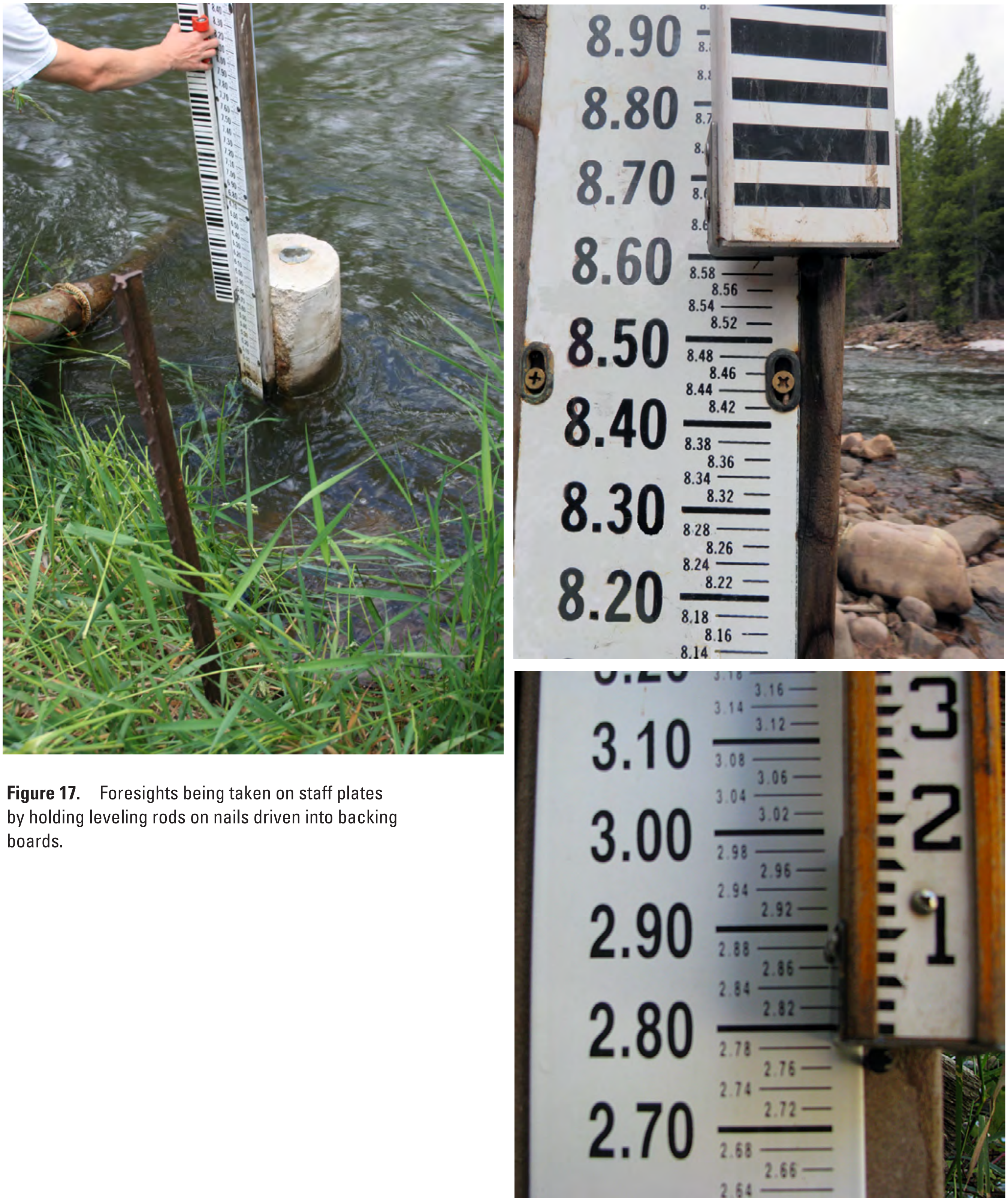


Figure 17. Foresights being taken on staff plates by holding leveling rods on nails driven into backing boards.

Electric tape gage index

Figure 18. Electric tape gage with a pocket rod held on a stack of coins at the elevation of the index.

When running levels at a station with an ETG, FSs should be taken on the ETG index, and when feasible, FSs should also be taken on the bottom of the weight. A slight gap exists between the ETG index and the object on which it is mounted. When taking a FS on the ETG index, be sure that the rod, which is likely a carpenter's ruler, a measuring tape, or a "pocket rod," is set at the level of the ETG index. A stack of coins on the shelf can usually be used as a stable place to hold the rod and obtain an accurate FS (fig. 18).

Foresights taken on the bottom of the ETG weight should be taken with the weight as close to the water surface as possible. However, unless the stilling well is equipped with a clean-out door, the FS on the bottom of the weight will likely be taken with the weight located just below the instrument shelf. The level should be set up so that the instrument height is at least one length of the weight lower than the ETG index. To take a FS, the ETG weight should be lowered until the bottom of the weight is at the cross hairs of the level. While the weight is at this location, the gage height should be read at the ETG index. If the ETG agrees with the gage datum, the instrument height will equal the reading at the ETG index. Electric tape gages are susceptible to any movement of the shelter they are installed in. They are also sensitive to any movement of the shelf that they are mounted on. Adding weight, such as a larger battery, to an instrument shelf may cause the shelf to flex downwards, which could change the elevation of the ETG index and cause incorrect gage height readings.

Wire-Weight Gage

Wire-weight gages are most often installed on bridge structures (fig. 19), but can also be installed on a cantilever on a stream bank (fig. 20). Suspended above the water surface, wire-weight gages are weighted cables that are spooled on a calibrated drum. To take a gage reading, the weighted cable is lowered until the bottom of the weight contacts the water surface. The gage-height value is read from the digital counter and the calibrated drum of the wire-weight gage. The contact with the water surface is determined visually, which introduces uncertainty associated with the sightline distance, lighting, and the surface characteristics of the water. When running levels to a wire-weight gage, a FS should be taken on both the check bar (fig. 19) and the bottom of the weight near the water surface. For cantilever installations (only), FSs on the check bar are not required as they are not associated with the elevation of the weight of the wire-weight gage; however, tracking elevations of the check bar of a cantilevered wire-weight gage may be useful in determining stability of the cantilever structure.

Foresights taken on the check bar of a traditional wire-weight gage are taken with the check bar in its outer position (away from the object it is mounted on) using a leveling rod. Foresights taken on the bottom of the weight for all wire-weight gages should be taken from an instrument set up on the low water bank, such that the FS is taken with the wire weight as close to the water surface as possible. The wire weight should be lowered until the bottom of the weight is at the cross hairs of the level. With the weight at this location, the gage height should be read from the digital counter and the calibrated drum. If the wire-weight gage agrees with the gage datum, the instrument height will equal the reading of the wire-weight gage.

A wire-weight gage has several potential sources of error to be considered when checking it (Kennedy, 1990). The drum is calibrated so that every rotation accounts for a distance traveled by the weight. For this reason, the cable should be evenly spooled on the drum. Wire weights tend to spin as they are lowered and raised. If the cable is not allowed time to unwind, it will be twisted and thus shorter. This can lead to incorrect gage heights. After the cable reaches its proper length, the wire weight should be spooled back up onto the drum. The weight should be placed on the check bar, and the associated check bar reading should be noted. The weight can then be lowered to the water surface to determine the gage height. These procedures should be followed when taking a FS on the bottom of the weight as well.

Variations in the drum and the cable diameter of a wire-weight gage can cause calibration errors (Kennedy, 1990). Gage height readings from a wire-weight gage represent a count of the number of revolutions made by the calibrated drum before the weight contacts the water surface. Any differences between the actual diameters of the drum and the cable, and the diameters programmed into the revolution counter will accumulate as the drum revolves. Fortunately, because of this accumulation, these calibration errors are linear and can be corrected for once recognized and documented.

At most gaging stations, wire-weight gages should be set to accurately read low water elevations. If a wire-weight gage is properly set to read low water elevations, a calibration error can be recognized if the check bar reading differs from the check bar elevation determined from levels. By preparing a graph of the wire-weight gage readings for the bottom of the weight and the check bar and the elevations from levels, corrections for gage height readings at different stages can be determined (fig. 21). The equation for this linear relation is shown in figure 21 and can be used to compute the correction to the gage reading by inputting the wire-weight reading. When such corrections are defined, a plot and an equation similar to these should be prepared and stored at the gaging station. The sources of error for wire-weight gages discussed here are usually negligible for wire-weight gages mounted less than 15 ft above the water, and increase with greater distances (Kennedy, 1990).

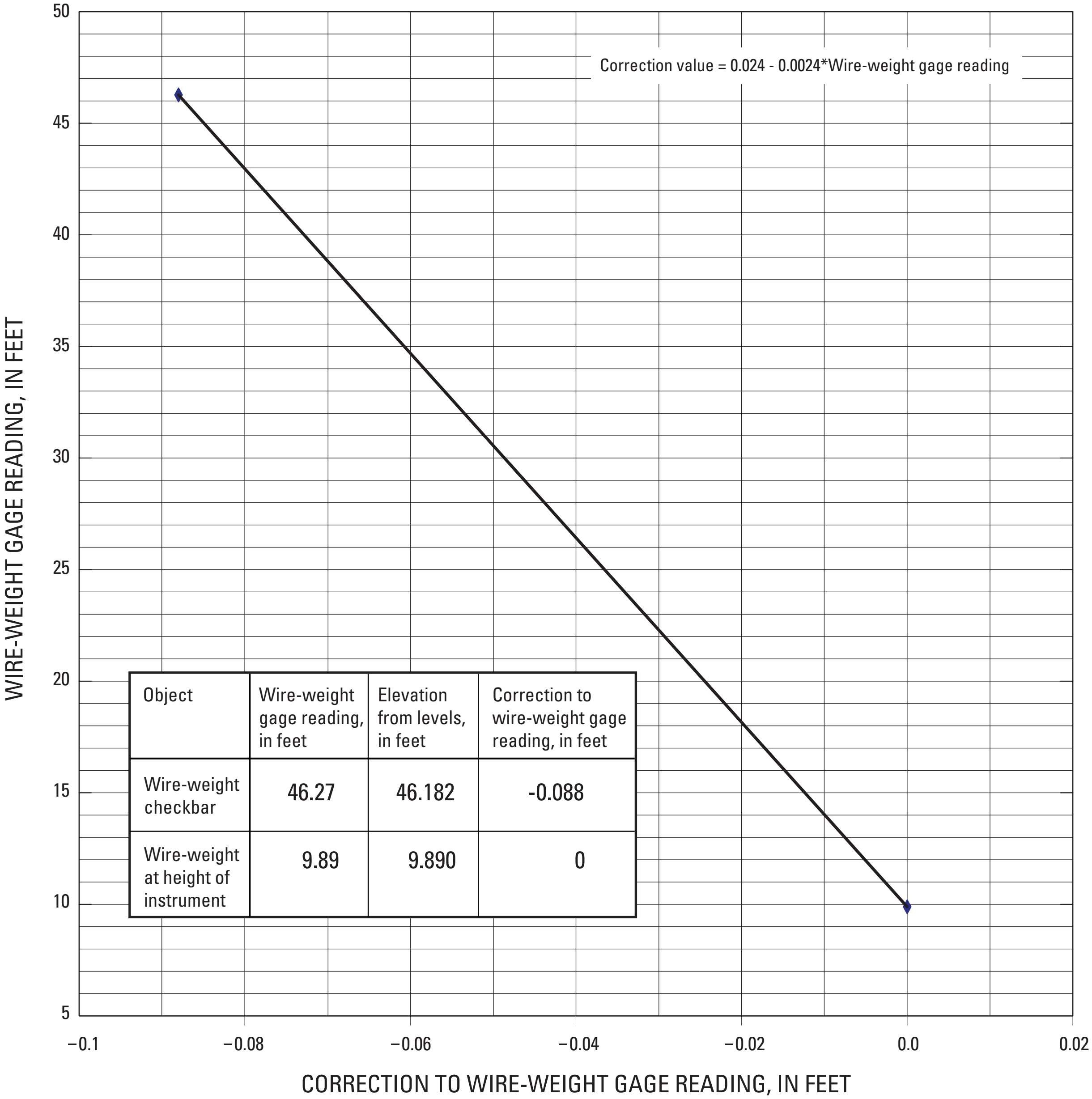
Figure 19. Wire-weight gages mounted on bridges.

Figure 20. Cantilevered wire-weight gage located to the left of a stilling well.

Crest-Stage Gage

Crest-stage gages (CSG) record the peak water-surface elevation, or gage height, as a high water mark consisting most often of a cork line on a stick inside a pipe. A vertically installed pipe, which is capped on the top and bottom, communicates with stream water by a set of holes drilled into a cap on the bottom of the pipe. As the water-surface elevation decreases, the maximum level of the water is recorded by a cork line on a stick contained within the pipe. To recover the recorded maximum instantaneous gage height, the stick is removed from the pipe and the distance from the bottom or the top of the stick to the cork line is measured. If the index of the CSG is located at the bottom, the stick is measured up from the bottom. If the index is at the top, the stick is measured from the top.

Foresights taken on the index of a CSG can usually be taken with a leveling rod. The location where the leveling rod is held depends on location of the index. Often, the bottom cap has a metal stud attached in the center where the stick rests (fig. 22 inset). The elevation of this stud is equal to the cap surface where the threads begin, and the FS is taken by holding the rod on the top of the bottom cap (fig. 22). A bolt installed through the pipe near the bottom provides a surface



Object	Wire-weight gage reading, in feet	Elevation from levels, in feet	Correction to wire-weight gage reading, in feet
Wire-weight checkbar	46.27	46.182	-0.088
Wire-weight at height of instrument	9.89	9.890	0

Figure 21. Stage-related wire-weight corrections determined from levels.

for the stick to rest on and is an excellent index to hold a rod on to take a FS (fig. 23). For both of these CSG configurations, the maximum stage is determined by measuring from the bottom of the stick to the cork line high water mark and then adding that value to the elevation of the CSG index. Some CSGs have the index on the top of the stick. Foresights are taken by holding the leveling rod on top of the stick at the index, and the maximum stage is determined by measuring from the top of the stick down to the cork line high water mark and then subtracting that value from the elevation of the CSG index.

Inclined Staff Gage

Inclined staff gages are permanent structures that are installed at about the same slope as the streambank (fig. 24). The scale along the incline is set to represent the water-surface elevation. The slope of these gages minimizes damage caused by debris and ice. The permanence of the inclined staff gages makes them very difficult to adjust if they disagree with the gage datum. Foresights are taken on several foot marks throughout the gage's range, from one or more instrument heights (Kennedy, 1990). If the inclined staff gage is a composite of multiple slopes, at least 2 FSs must be taken on each slope.

Figure 22. Crest-stage gage where the index is the bottom cap. Inset photograph of the bottom cap showing the internal stud.

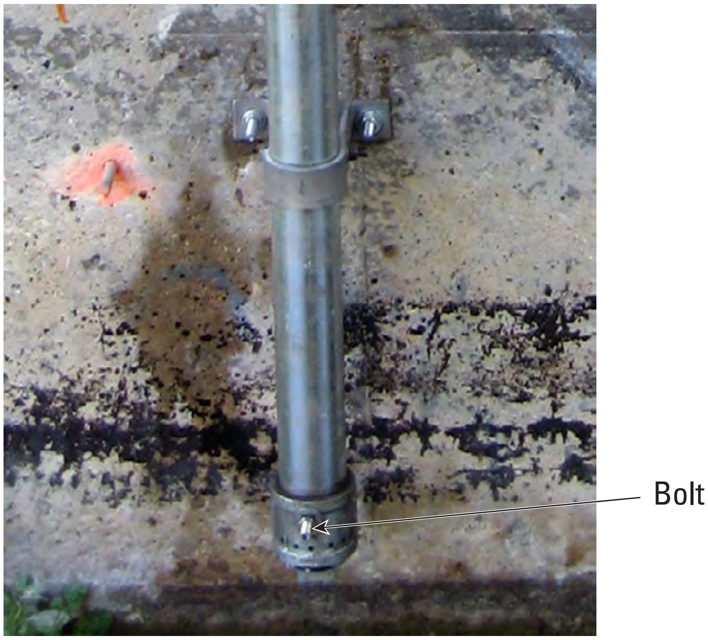


Figure 23. Crest-stage gage where the index is a bolt installed through the pipe.

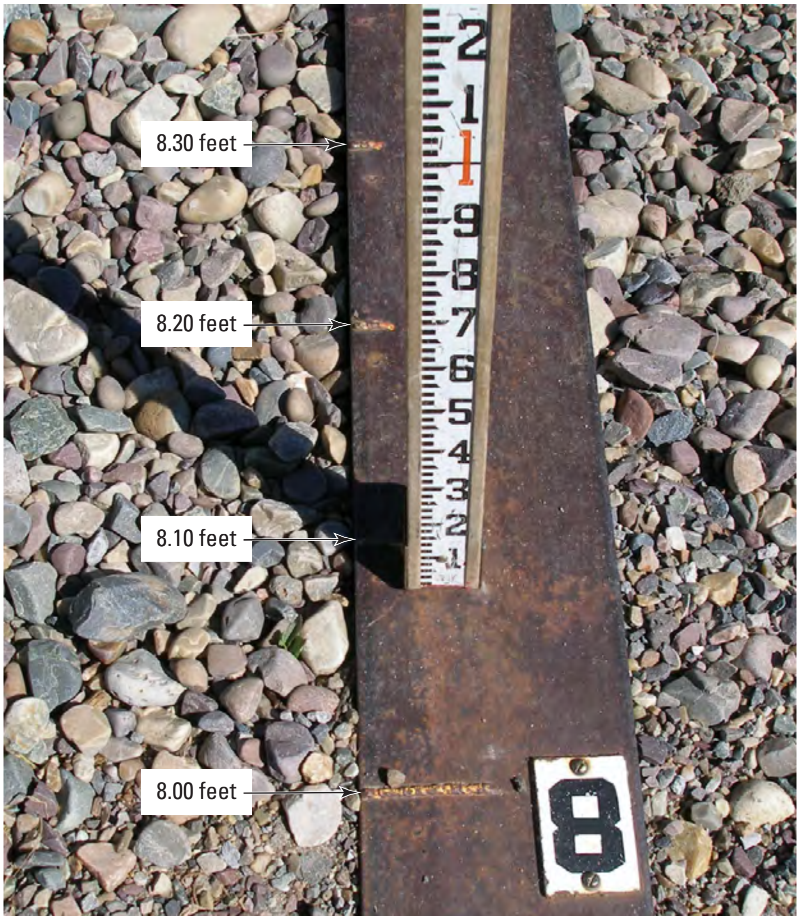


Figure 24. Inclined staff gage installed on a streambank.

Water Surface

Traditional gaging stations are established to measure the elevation of the water surface. When running levels at gaging stations, two FSs are required to be taken on the water surface. These FSs can be difficult to obtain because the water surface is not a firm object and therefore a rod cannot be held directly on it. Also, the water surface may not be vertically stable at the time and (or) location of the measurement. There are three techniques that can assist in taking precise and accurate FSs on the water surface. For streams that are shallow along the banks, a stable object such as a rock, a stake, or a screwdriver driven to the water surface, or even the wading boot of the rod man can be used as a stable location to hold a leveling rod. These objects will have to be positioned in a manner that allows a visual determination of the water surface and firm placement of the bottom of the leveling rod. A second technique that can be used if stream conditions (including depth and velocity) allow is to hold the rod on the streambed, take a FS of the elevation of the streambed, and manually read the depth of the water off of the rod. To determine the elevation of the water surface, compute the elevation of the streambed and add the water depth to it. Finally, if the conditions of the stream do not allow both of these techniques, a reference point (either a temporary or a permanent one) can be established as close as possible to the water surface. From this reference point, a measuring tape can be used to tape down to the water surface. An estimate of the uncertainty in the FS taken on the water surface should always be provided by the rod man and included in the remarks on the level notes.

Resetting Gages Based on the Results of Levels

The main purpose of running levels at gaging stations is to verify that gages, specifically the primary reference gage, are properly set to read the stage in the gage datum. The primary reference gage should be reset if the absolute value of the difference between the elevation reading of the reference gage and the gage datum is greater than or equal to 0.015 ft. Before the gage is reset, the level circuit containing the gage must be completed. A complete level circuit is one in which circuit closure error is less than or equal to the established limit, adjustments associated with closure error have been applied, differences between the adjusted first and second elevations of objective points have been computed, and it has been verified that these differences meet the established criteria. Final elevations for all gages are determined and the computations for the circuit are checked. If the reference gage needs to be reset, it should be reset on the basis of the final computed elevation.

The survey crew must verify and document that the gage was reset correctly. There are three verification methods: (1) an abbreviated level circuit consisting of a closed objective point (part of a completed and valid level circuit), the gage, and a turning point (2) a tape down from a reference point that was part of a completed and valid circuit; and (3) an independent check of the water-surface elevation and gage reading. Resetting auxiliary gages (those other than the primary reference gage) also is recommended when the difference between the elevation reading of the auxiliary gage and the gage datum is greater than or equal to $|0.015|$ ft.

Methods for Simplifying Complex Level Circuits

Complex level circuits for the purposes of this discussion are level circuits that require more than two instrument setups to obtain two independent FSs for all objective points. In a complex circuit, elevation must be carried from one instrument setup location to another by using intermediate turning points to establish more than two instrument heights. After obtaining all first FSs and before obtaining second FSs, an independent turning point that is not an objective point is required to establish the first instrument height from which second FSs will be taken. In contrast, simple level circuits have only two instrument setups, with the second instrument height being established from an independent turning point that is not an objective point to take second FSs.

The error tolerances set forth for circuit closure and for differences between adjusted first and second elevations are strict. The method described by Thomas and Jackson (1981) for distributing closure error by instrument setup assumes that error is evenly accumulated through the level circuit. While this assumption may not always be true, this method provides the best means available for distributing closure error because it is difficult, if not impossible, to determine the specific instrument setups where errors are incurred within a leveling circuit. Unfortunately, this method of error distribution, and its underlying assumption, can lead to incorrect adjustments to valid elevations.

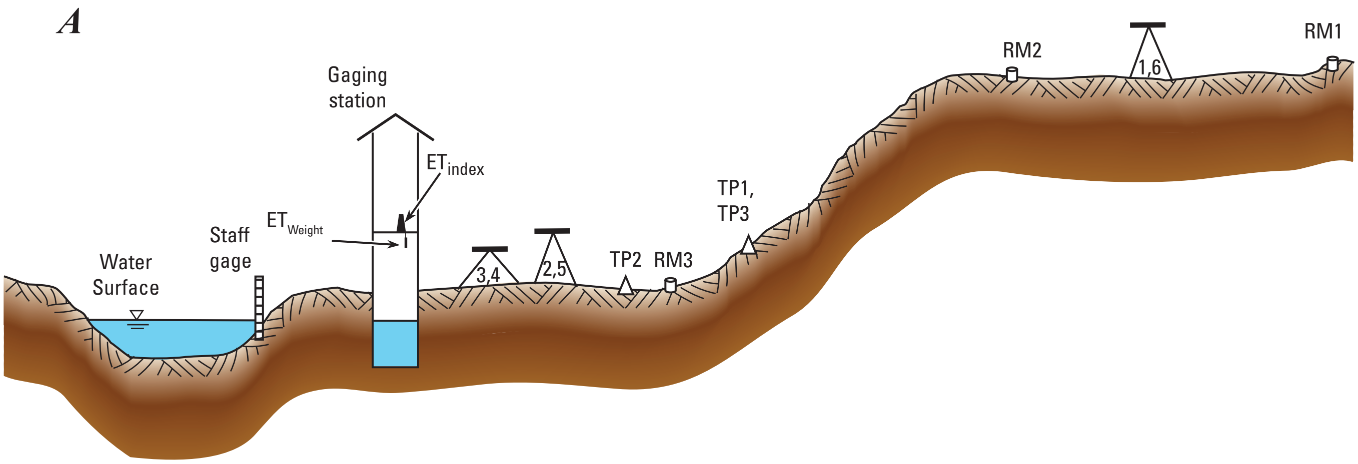
Level circuits with more than two instrument setups have more opportunity to incur error in both closure and final elevations. By limiting the number of instrument setups in a circuit, the potential for error can be minimized. In most cases, by implementing some of the techniques discussed below, a level circuit consisting of more than two instrument setups can be broken down into a series of independent level circuits, each having a minimum of two instrument setups.

Separating Complex Level Circuits into a Set of Sequentially Closed Simple Level Circuits

Most complex level circuits can be broken down into a series of simple level circuits that are closed in sequence. A simple level circuit requires a turning point that is not an objective point, and a complex level circuit needs to carry elevation using an objective point(s) or an intermediate turning point(s), and requires at least one turning point that is not an objective point.

Level notes and a leveling diagram for a complex level circuit are shown in figure 25. Shots from a single instrument setup cannot be taken on all of the objective points of this circuit: RM1, RM2, RM3, the ETG index, the bottom of the ETG weight, the outside staff gage, and the water surface. RM1 (the origin) and RM2 are located up a slope above the other objective points at the site. This level circuit uses an intermediate turning point (TP1) to carry elevation down to the remaining part of the circuit. From the second instrument setup, FSs are taken on the ETG index, the outside staff gage, the water surface and RM3. RM3 is then used as an intermediate turning point to establish the third instrument height, which is needed to take a FS on the bottom of the ETG weight. An independent turning point is established (TP2) and the circuit is shot in reverse order back to RM1.

The complex level circuit described above can be broken down into three simple level circuits that are sequentially closed. Level notes and a leveling diagram for the three simple level circuits are shown in figure 26. The first simple circuit consists of objective points RM1, RM2, and TRM1. RM1 is the origin and is used as the starting point to set the initial instrument height. A temporary reference mark, TRM1, is established in the first simple level circuit to carry elevation to the second circuit. Note that the location of TRM1 is the same as that of the first turning point in the complex leveling circuit diagram discussed above. An independent turning point (TP1) is established to ensure that two FSs are taken on each of the objective points for the first level circuit, which includes RM2 and TRM1. This first circuit is closed with the second FS taken on RM1. The second simple circuit consists of objective points TRM1, RM3, the ETG index, the outside staff gage, and the water surface. The initial height of the instrument for the second circuit is determined from TRM1 which had two FSs taken on it in the first circuit. The second instrument height is determined from an independent turning point (TP2). This circuit is closed with the second FS taken on TRM1. Finally, the shots to the bottom of the ETG weight are made from a final simple circuit in which the initial instrument height is determined from RM3, which had two FSs taken on it in the second circuit. The second instrument height for the third simple circuit is determined from an independent turning point (TP3), and the circuit is closed with the second FS taken on RM3



EXPLANATION

RM	Reference mark	ET_{index}	Electric tape index
TP	Turning point	ET_{weight}	Electric tape weight
		1,2	Represents the sequential instrument setup number

Figure 25. *A*. Leveling diagram showing objective points in a complex circuit and *B*. level notes for a complex leveling circuit.

OBJECT	BS	CORRECTED BS	HEIGHT OF INSTRU-MENT (HI)	FS	CORRECTED FS	ELEVATION	Remarks	CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
		BS+(CTE* BS*(T−T_0))			FS+(CTE* FS*(T−T_0))									
RM1	4.655		30.666			26.011	Brass cap upslope 50' E	0.0000					26.011	Given, Origin
RM2				5.431		25.235	Brass cap upslope 35' E		25.235		0.000	25.235	25.235	
TP1				15.196		15.470								
			Moved Instrument											
TP1	1.553		17.023					0.0000						
ETG_{Index}				1.813		15.210	Mounted on shelf		15.210		0.000	15.210	15.210	
OG				6.683		10.340	Staff; Nail @ 10.34		10.340		0.000	10.340	10.340	
WS	@13:20			7.473		9.550	ETG(ref)=9.55, OG=9.55		9.550					+/ − 0.01, DCP = 9.55
RM3				4.723		12.300	Brass cap 12' E		12.300		0.000	12.300	12.300	
			Moved Instrument											
RM3	1.844		14.144					0.0000						
ETG_{Weight}				0		14.144	Ref. gage; Direct Read		14.144					ETG reads 14.14
TP2				1.911		12.233								
			Moved Instrument											
TP2	1.913		14.146											
ETG_{Weight}				0		14.146	Ref. gage, Direct Read			14.146				ETG reads 14.15
RM3				1.846		12.300				12.300				
			Moved Instrument											
RM3	4.803		17.103					0.0000						
WS	@13:30			7.553		9.550	ETG (ref)=9.55, OG=9.55			9.550				+/ − 0.01, DCP = 9.55
OG				6.763		10.340	nail @ 10.34			10.340				
ETG_{Index}				1.893		15.210				15.210				
TP3				1.633		15.470								
			Moved Instrument											
TP3	14.029		29.499					0.0000						
RM2				4.264		25.235				25.235				
RM1				3.488		26.011								
	CLOSURE ERROR = 26.011 - 26.011 = 0.000													
	CElimit = |0.003*(√6setups)| = |0.007|													

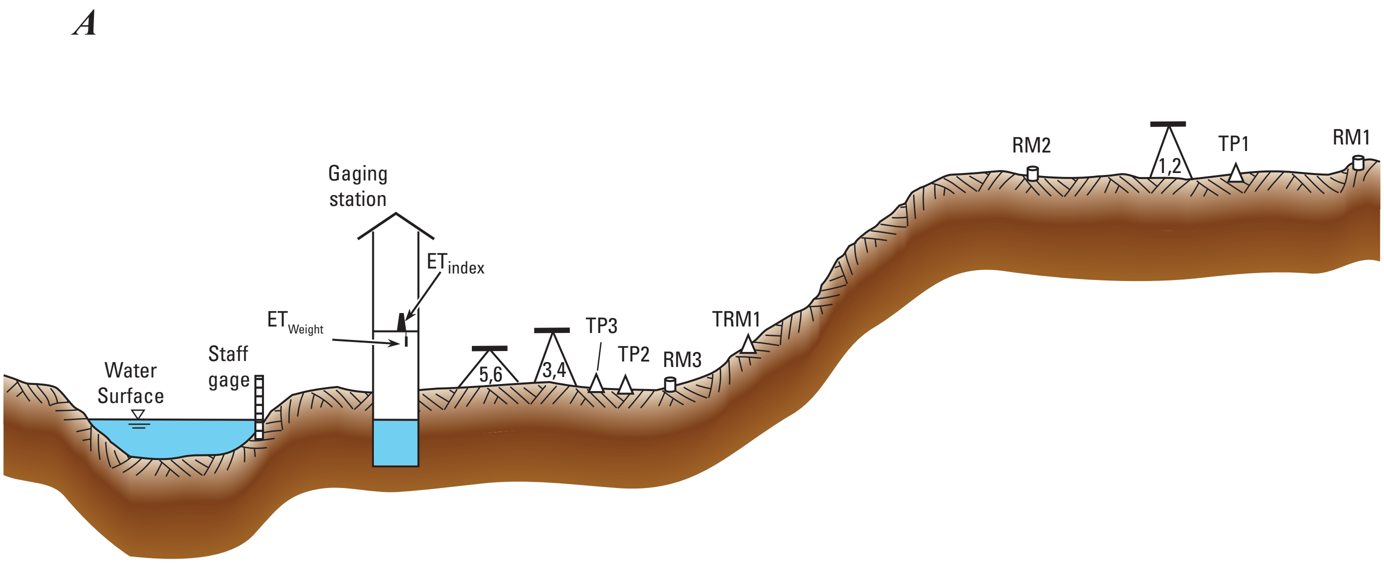
B

Figure 25. Continued.

Both the complex level circuit and the set of three simple circuits have a total of six instrument setups. A distinct difference is that in the complex circuit, elevation is carried through the six instrument setups consecutively, whereas in the simple circuits, elevation is carried through two setups at a time. The six setups in the complex circuit represent six opportunities where errors can occur. We assume that if present, these errors accumulate and will be represented in the closure error for the circuit. Where these types of errors occur within the circuit cannot be determined, and in a case such as this one, the closure error is distributed evenly to each of the six instrument setups. In the set of three simple level circuits, only two instrument setups were needed in each circuit to take FSs on the objective points and close the circuit. That created only two locations in each circuit where error could be introduced. All three simple circuits were closed sequentially, which ensured that elevations assigned to TRM1 and RM3, used to determine instrument heights for the second and third circuits, respectively, were valid before running those circuits. If an error is introduced into one of the simple circuits, that error can be recognized and rectified before shooting all objective points twice at the site. The above examples also demonstrate that sequentially closing the simple circuits eliminates the need to go back up the slope to the origin reference mark, RM1. The accuracy and efficiency in running levels at gaging stations can be improved by breaking down a complex level circuit into a series of simple level circuits. Strategic placement of permanent reference marks, such as in locations where elevation has to be carried up or down a slope, would reduce the need to establish temporary reference marks or intermediate turning points for every level run.

Using a Suspended Weighted Steel Tape to Carry Elevation to or from a Bridge Structure

Many gaging stations are separated by a range in elevation that is greater than the length of one extended leveling rod. This often happens when reference marks, reference points, and (or) the wire- weight gage are located on a bridge that is relatively high above the stream, and other reference marks, reference points, various gages, and the water surface are located well below the bridge deck. Kennedy (1990) describes how a weighted steel tape can be suspended from a bridge and be used as a long leveling rod to carry elevation from a lower streamside level circuit to a higher level circuit on the bridge deck (and vice versa). This method incorporates running a series of simple level circuits. The effects of thermal expansion and contraction, tension, and wind must be understood and the precision and accuracy requirements attainable before using a suspended steel tape for levels (see section on "Leveling Rods"). Two sets of level notes, one presenting the bridge-down method and the other the ground-up method, and a leveling diagram are provided as an example of how to use a suspended weighted steel tape to run a series of simple level circuits at a gaging station (fig. 27).



EXPLANATION

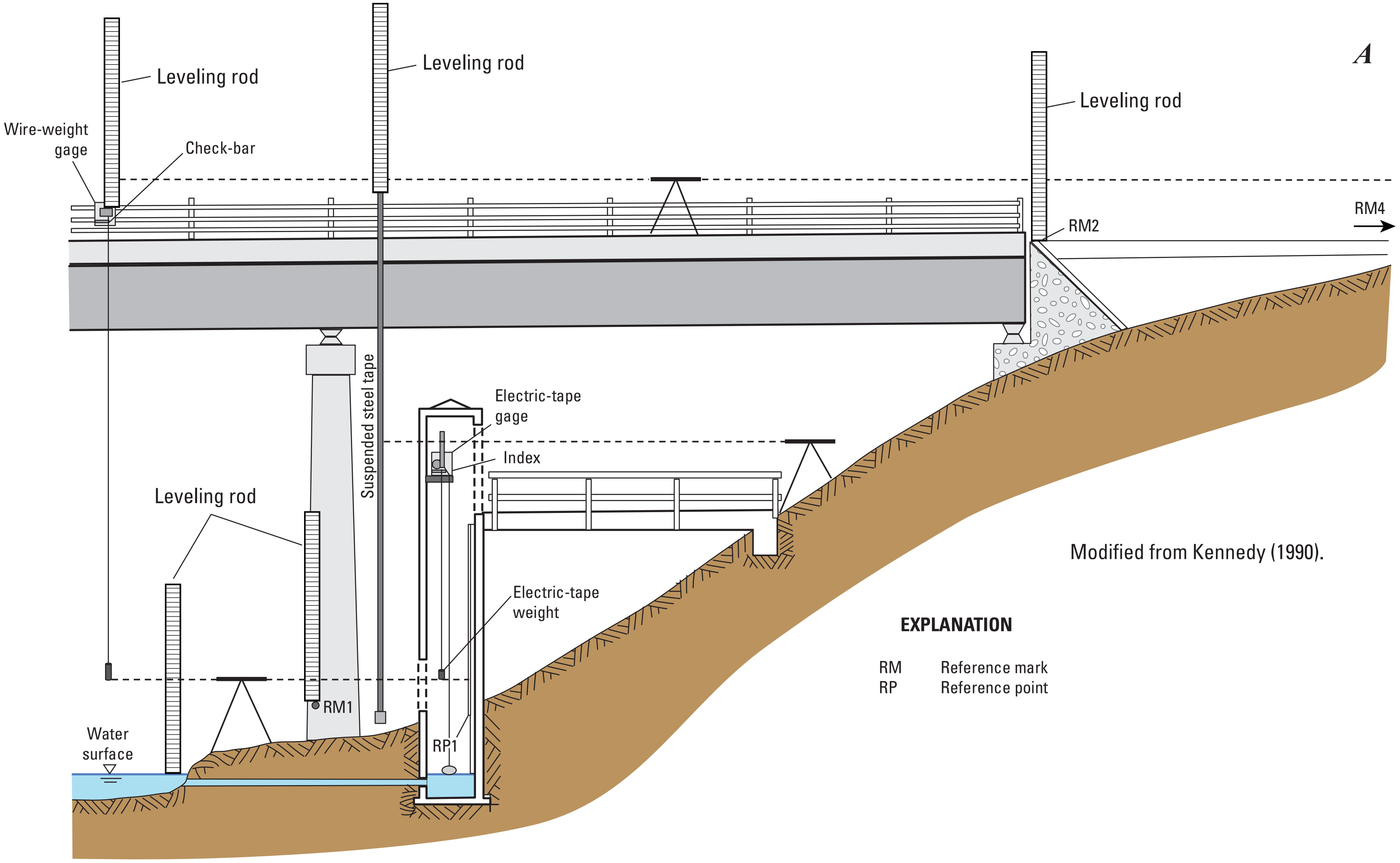
RM	Reference mark	ET$_{index}$	Electric tape index
TP	Turning point	ET$_{weight}$	Electric tape weight
TRM	Temporary reference mark	1,2	Represents the sequential instrument setup number

Figure 26. *A*. Leveling diagram and *B*. level notes showing 3 simple level circuits used to replace 1 complex level circuit.

OBJECT	BS	CORRECTED BS BS+(CTE* BS*(T−T_0))	HEIGHT OF INSTRU-MENT (HI)	FS	CORRECTED FS FS+(CTE* FS*(T−T_0))	ELEVATION	Remarks	CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
RM1	4.655		30.666			26.011	Brass cap upslope 50' E	0.0000					26.011	Given, Origin
RM2				5.431		25.235	Brass cap upslope 35' E		25.235		0.000	25.235	25.235	
TRM1				14.152		16.514			16.514		0.000	16.514		
TP1				5.664		25.002								
			Moved Instrument											
TP1	5.748		30.750					0.0000						
TRM1				14.236		16.514				16.514				
RM2				5.515		25.235				25.235				
RM1				4.739		26.011								
CE = 26.011 -26.011 = 0.000 CElimit =|0.003*(√2setups)|=|0.004|														
TRM1	1.586		18.100			16.514		0.0000						Given
RM3				5.800		12.300	Brass cap 12' E		12.300		0.000	12.890	12.890	
ETG$_{Index}$				2.890		15.210	Mounted on shelf		15.210		0.000	15.210	15.210	
OG				7.760		10.340	Staff, Nail @ 10.34		10.340		0.000	10.340	10.340	
WS	@13:25			8.550		9.550	ETG(ref) = 9.55, OG=9.55		9.550					+/ − 0.01, DCP = 9.55
TP2				1.576		16.524								
			Moved Instrument											
TP2	1.639		18.163					0.0000						
WS	@13:30			8.613		9.550	ETG(ref) = 9.55, OG=9.55			9.550				+/ − 0.01, DCP = 9.55
OG				7.823		10.340	Nail @ 10.34			10.340				
ETG$_{Index}$				2.953		15.210				15.210				
RM3				5.863		12.300				12.300				
TRM1				1.649		16.514								
CE=16.514 -16.514=0.000 CElimit=|0.003*(√2setups)|=|0.004|														
RM3	1.800		14.100			12.300		0.0000						Given
ETG$_{Weight}$				0		14.100	Ref gage, direct read		14.100					ETG reads 14.10
TP3				2.655		11.455								
			Moved Instrument											
TP3	2.710		14.155					0.0000						
ETG$_{Weight}$				0		14.155	Ref gage, direct read			14.155				ETG reads 14.16
RM3				1.855		12.300								
CE=12.300 -12.300=0.000 CElimit=|0.003*(√2setups)|=|0.004|														

B

Figure 26. Continued.



Modified from Kennedy (1990).

Figure 27. *A*. Leveling diagram and *B*., *C*. level notes illustrating the use of a suspended steel tape to carry elevations from a bridge down to a streamside gage location and from a streamside gage location up to a bridge.

OBJECT	BS	CORRECTED BS	HEIGHT OF INSTRU-MENT (HI)	FS	CORRECTED FS	ELEVATION	Remarks	CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
		BS+(CTE* BS*(T−T_0))			FS+(CTE* FS*(T−T_0))									
RM2	3.410		46.216			42.806	Brass cap right abutment	0.0000					42.806	Given, Origin
RM4				4.302		41.914	Brass cap on sidewalk 75'N		41.914		0.000	41.914	41.914	
WWCB				1.475		44.741			44.741		0.000	44.741	44.741	Check bar reads 44.74
Tape				42.843		3.373	Clamped @ 40', rod=2.843		3.373					Bottom of tape
TP1	2.682		46.003	2.895		43.321	Moved Inst	0.0000						
Tape				42.630		3.373	Clamped @ 40', rod=2.630			3.373				
WWCB				1.262		44.741				44.741				Check bar reads 44.74
RM4				4.089		41.914				41.914				
RM2				3.197		42.806								
CE = 42.806 − 42.806 = 0.000			CElimit = |0.003*(√2setups)|=|0.004|											
	0 ft mark on clamped tape is 3.373 ft gage datum													
Tape	22.409		25.782			3.373	Direct read	0.0000						Given
ETG_{Index}				0.873		24.909			24.909		0.000	24.909	24.909	
TP2	6.234		26.365	5.651		20.131	Moved Inst	0.0000						
ETG_{Index}				1.456		24.909				24.909				
Tape				22.992		3.373	Direct read							
CE = 3.373 − 3.373 = 0.000			CElimit = |0.003*(√2setups)|=|0.004|											
Tape	6.061		9.434			3.373	Direct read		3.373		0.000	3.373		Given
RM1				2.328		7.106	Bolt E side Rt Pier	0.0000						
ETG_{Weight}				0		9.434	@ HI		9.434					ETG reads 9.43
RP1				3.231		6.203	Nail @ 6.20 ft		6.203		0.000	6.203	6.203	
WS	@10:15			8.008		1.426	ETG(ref) = 1.43, WW=1.43		1.426					+/-0.01, DCP=1.43
WW_{bottom}				0		9.434	@ HI		9.434					WW reads 9.43
TP3	7.043		9.568	6.909		2.525	Moved Inst	0.0000						
WW_{bottom}				0		9.568	@ HI			9.568				WW reads 9.57
WS	@10:20			8.142		1.426	ETG(ref) = 1.43, WW=1.43			1.426				+/-0.01, DCP=1.43
RP1				3.365		6.203	nail @ 6.20 ft			6.203				
ETG_{Weight}				0		9.568	@ HI			9.568				ETG reads 9.57
RM1				2.462		7.106				7.106				
Tape				6.195		3.373	Direct read							
CE = 3.373 − 3.373 = 0.000			CElimit = |0.003*(√2setups)|=|0.004|											

B

Figure 27. Continued.

OBJECT	BS	CORRECTED BS BS+(CTE* BS*(T−T_0))	HEIGHT OF INSTRU-MENT (HI)	FS	CORRECTED FS FS+(CTE* FS*(T−T_0))	ELEVATION	Remarks	CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
RM1	2.328		9.434			7.106	Bolt E side Rt Pier	0.0000					7.106	Given, Origin
ETG$_{Weight}$				0		9.434	@HI		9.434					ETG reads 9.43
RP1				3.231		6.203	nail @ 6.20 ft		6.203		0.000	6.203	6.203	
Tape				6.061		3.373	Direct read		3.373		0.000	3.373		Bottom of clamped tape
WS	@ 10:15			8.008		1.426	ETG(ref)=1.43, WW=1.43		1.426					+/ −0.01, DCP=1.43
WW$_{bottom}$				0		9.434	@HI		9.434					WW reads 9.43
TP1	7.043		9.568	6.909		2.525	Moved Inst	0.0000						
WW$_{bottom}$				0		9.568	@HI			9.568				WW reads 9.57
WS	@ 10:20			8.142		1.426	ETG(ref)=1.43, WW=1.43			1.426				+/-0.01, DCP=1.43
Tape				6.195		3.373	Direct read			3.373				
RP1				3.365		6.203				6.203				
ETG$_{Weight}$				0		9.568	@HI			9.568				ETG reads 9.57
RM1				2.462		7.106								
CE = 7.106 − 7.106 = 0.000			CElimit = |0.003*(√2setups)|=|0.004|											
		Bottom of tape = 3.373												
Tape	22.409		25.782			3.373	Direct read	0.0000						Given
ETG$_{Index}$				0.873		24.909			24.909		0.000	24.909	24.909	
TP2	6.234		26.365	5.651		20.131	Moved Inst	0.0000						
ETG$_{Index}$				1.456		24.909				24.909				
Tape				22.992		3.373	Direct read							
CE = 3.373 − 3.373 = 0.000			CElimit = |0.003*(√2setups)|=|0.004|											
Tape	42.843		46.216			3.373	Clamped @ 40', rod=2.843	0.0000						Given
WWCB				1.475		44.741			44.741		0.000	44.741	44.741	Check bar reads 44.74
RM2				3.410		42.806	Brass cap right abutment		42.806		0.000	42.806	42.806	
RM4				4.302		41.914	Brass cap on sidewalk 75'N		41.914		0.000	41.914	41.914	
TP3	2.682		46.003	2.895		43.321	Moved Inst	0.0000						
RM4				4.089		41.914				41.914				
RM2				3.197		42.806				42.806				
WWCB				1.262		44.741				44.741				Check bar reads 44.74
Tape				42.630		3.373	Clamped @ 40', rod=2.630							
CE = 3.373 − 3.373 = 0.000			CElimit = |0.003*(√2setups)|=|0.004|											

C

Figure 27. Continued.

Bridge-Down Method

The diagram in figure 27 shows a weighted steel tape clamped at its 40.000-ft marking to the bridge deck rail. The first level circuit is on the bridge deck and the objective points are RM2, RM4, the wire-weight check bar, and the clamped steel tape (noted as “tape” in the level notes). RM2 is the origin and is used to establish the initial instrument height. Foresights are taken on the wire-weight check bar and the bridge deck rail where the tape is clamped. The FS to the top of the deck rail at the tape is 2.843 ft, noted in the remarks column in the level notes. The tape is being used as a long leveling rod; therefore, the FS to the rod at the tape, 2.843 ft, is added to the suspended length of the tape, 40.000 ft, to get the representative FS, 42.843 ft. An independent turning point, TP1, is established and a second instrument height is determined from which second FSs are taken on the tape, wire-weight check bar, and RM4. The circuit associated with the bridge deck is completed by taking a second FS on the origin, RM2. The first and second elevations of the 0.000-ft mark on the suspended tape are determined by subtracting the representative FSs for the tape from the instrument height. Both representative FSs for the tape are used to determine that the elevation at the 0.000-ft mark on the suspended tape is 3.373 ft. The closure error for this circuit is 0.000 ft, elevations do not need to be adjusted, and the differences between first and second elevations for all of the objective points are 0.000 ft.

A second level circuit is about half the distance from the bridge deck to the low-water bank, and the objective points are the tape and the ETG index. The instrument height is established with a BS taken on the tape, which is a direct read of 22.409 ft. This BS is added to the determined elevation for the 0.000-ft mark of the tape, 3.373 ft, to determine an instrument height of 25.782 ft. A FS is taken on the ETG index and an independent turning point, TP2, is established to determine the second instrument height. A second FS is taken on the ETG index and this circuit is completed by taking a second FS on the suspended tape, which again is a direct read of the tape. This circuit has a closure error of 0.000 ft, elevations do not need to be adjusted, and the difference between first and second elevations for the ET index is 0.000 ft.

The final level circuit is on the low-water bank and the objective points are the tape, RM1, the bottom of the electric tape weight (ETG weight), RP1, the water surface, and the bottom of the wire weight (noted as “WW bottom” in the level notes). Again, the instrument height is established with a BS taken on the tape, which is a direct read of 6.061 ft. This BS is added to the determined elevation for the 0.000-ft mark of the tape, 3.373 ft, to determine an instrument height of 9.434 ft. From this instrument height, first FSs are taken on RM1, the ETG weight through the cleanout door, RP1, the water surface, and the bottom of the wire weight near the water surface. An independent turning point is established, TP3, to determine the second instrument height from which second FSs are taken. This final circuit is completed by taking a second FS on the suspended tape. This circuit has a closure error of 0.000 ft, elevations do not need to be adjusted, and differences between first and second elevations for each of the objective points are 0.000 ft. By using a weighted suspended steel tape clamped to the bridge deck rail to carry elevation from the bridge down to the low-water bank, levels can be run at a gaging station with an elevation difference of over 35 vertical ft using three sequentially closed level circuits that have a total of six instrument setups and three turning points.

Ground-Up Method

The ground-up method reverses the procedure for the bridge-down method and begins from the low-water bank. A weighted steel tape is clamped at its 40.000-ft marking to the bridge deck rail. The first level circuit is on the low-water bank and the objective points are RM1, the bottom of the electric tape weight (ETG weight), RP1, the steel tape, the water surface, and the bottom of the wire weight. The initial instrument height is established with a BS taken on RM1. Foresights are taken on the ETG weight through the cleanout door, RP1, the steel tape, the water surface, and the bottom of the wire weight near the water surface. An independent turning point is established, TP1, to determine the second instrument height from which second FSs are taken on the objective points. The circuit is completed by taking a final FS on the origin, RM1. The elevation of the 0.000-ft mark on the suspended tape is determined by subtracting the FSs for the tape from the associated instrument heights. Both FSs taken on the tape determined that the elevation of the 0.000-ft mark on the suspended tape is 3.373 ft. The closure error of this circuit is 0.000 ft, elevations do not need to be adjusted, and the differences between first and second elevations for all of the objective points are 0.000 ft.

A second level circuit is about half the distance from the low-water bank to the bridge deck, and the objective points are the tape and the ETG index. The instrument height is established with a BS taken on the tape, which is a direct read of 22.409 ft. This BS is added to the determined elevation for the 0.000-ft mark of the tape, 3.373 ft, to determine an instrument height of 25.782 ft. A FS is taken on the ETG index and an independent turning point, TP2, is established to determine the second instrument height. A second FS is taken on the ETG index and this circuit is completed by taking a second FS on the suspended tape, which again is a direct read of the tape. This circuit has a closure error of 0.000 ft, elevations do not need to be adjusted, and the difference between first and second elevations for the ETG index is 0.000 ft.

The final level circuit is on the bridge deck and the objective points are the steel tape, wire-weight check bar, RM2, and RM4. The instrument height is established with a BS of 2.843 ft, taken on the top of the deck rail at the tape, and noted in the remarks column in the level notes. The tape is being used as a long leveling rod; therefore, the BS to the rod at the tape is added to the suspended length of the tape, 40.000 ft, to get the representative BS, 42.843 ft. The determined elevation for the 0.000-ft mark of the tape, 3.373 ft, is added to the BS to determine an instrument height of 46.216 ft. From this instrument height, first FSs are taken on the wire-weight check bar, RM2, and RM4. An independent turning point, TP3, is established and a second instrument height is determined from which second FSs are taken on RM4, RM2, and the wire-weight check bar. The circuit associated with the bridge deck is completed by taking a second FS on the deck rail at the tape. The closure error for this circuit is 0.000 ft, elevations do not need to be adjusted, and the differences between first and second elevations for all of the objective points are 0.000 ft. By using a weighted suspended steel tape clamped to the bridge deck rail to carry elevation from the low-water bank to the bridge deck, levels can be run at a gaging station with an elevation difference of over 35 vertical ft using three sequentially closed level circuits that have a total of six instrument setups and three turning points.

Office Procedures

The task of running levels at gaging stations includes some important office-related activities. A final check of the computations made during the level run that were first checked in the field should be made and documented. Following a level run, any adjustments made to the elevation of the reference gage need to be applied to the time series record of gage height and any other affected measurements of the reference gage. The field notes, which include digital files, original hand written documents, and photographs taken during field work, should be stored according to office specifications. The historical level summary and station description should be updated to reflect the elevations found during the level run. Finally, if needed, the site sketch should be updated along with any descriptions of reference marks that may have changed or been added since the last level run.

Applying Datum Corrections to Gage Height Time Series

The primary reference gage at a continuously recording gaging station is used to set the gage height on the data logger and to determine the representative gage heights for discharge measurements. If the level run finds that the absolute value of the difference between the elevation reading of the reference gage and the gage datum is greater than or equal to 0.015 ft, the recorded stage record must be corrected. Corrections of this type are referred to as datum corrections. Similarly, observed gage height measurements made during the time period affected by the datum correction should be adjusted accordingly. The datum correction applied to the time series of recorded stage values should be applied in a manner that is consistent with what caused, or was assumed to cause, the reference gage elevation to be different from the gage datum. For example, if the reference gage is damaged during a flood, the datum correction should be applied at the time the damage occurs and held constant until the time levels are run and the reference gage is adjusted. If the reference gage is assumed to have been heaved by frozen ground during the winter, the datum correction should be held constant back to the winter period. If the gage remains ice-free during the winter and it is believed the reference gage was heaved slowly during the winter, the datum correction may then be prorated back through the winter period.

Developing a Site-Specific Historical Level Summary

A historical level summary that contains the final elevations of all objective points from every level run should be maintained for all gaging stations. The level summary also should contain descriptions of all reference marks, reference points, and gages. Other objects of interest that were shot during a level run, such as the gage height of zero flow or the orifice line terminus, can also be included in the level summary. The primary reference gage should be explicitly noted. The level summary provides a way to track elevations and thus, vertical stability of all objective points over the life of the station. The stage that each of the various gages at the station was found to be reading at the beginning of a level run should be noted as well as the stage each gage was reading at the end of a level run. The origin reference mark for each of the level runs should be noted. The historical level summary should be updated immediately every time levels are run at the gaging station. A digital summary file provides the best means for storage and retrieval and can easily be updated. A form template for the historical level summary for printing or download is provided in appendix D.

Developing a Site Sketch Map

A sketch map of the site will help anyone who runs levels at the station. This is especially true for someone who is unfamiliar with a particular station. This map should show the locations of the reference marks, reference points, and all gages with respect to the gaging station structure and other prominent objects. The location of the low-water control along with the direction of flow should be included. Recommended instrument setup locations that provide ideal shot distances are useful as well. Site sketch maps are best maintained and stored in digital format.

Auxiliary Data to be Obtained During Level Runs

Running levels at gaging stations provides an opportunity to acquire other useful elevation-related information. Fresh high-water marks, if present, should be surveyed and compared later to recorded gage heights. A cross section of the hydraulic control(s) (including section, channel, and bank-full elevations), surveyed in the gage datum, is easy to obtain and can aid in developing the stage-discharge rating for the site. The gage height of zero flow associated with the hydraulic control that defines the low-water stage-discharge relation can be easily measured when the instrument is set up to measure the water-surface elevation during levels. Documenting the elevation, or gage height, at which flow overtops either bank can assist the USGS and other agencies during flood conditions. Determining the minimum elevation of a bridge or road deck in the gage reach can be very useful during flood events. Measurements of the elevations of various gage components, such as the orifice line terminus or stilling well intakes, can assist in determining the gage height at which the gage is out of communication with the stream. A measurement of the elevation of the instrument shelf provides an estimate of the likely maximum gage height the data logger can record. In short, the efficiency with which engineer's levels can obtain accurate vertical measurements presents opportunities to acquire auxiliary data when running levels at gaging stations.

Summary

Levels are run at gaging stations to ensure gages are accurately set to the established gage datum. Differential leveling techniques are used to determine elevations for reference marks, reference points, all gages, and the water surface to a precision of 0.001 foot (ft). Desired accuracy for a set of station levels is less than 0.010 ft. Precision describes the closeness of one measurement to another while accuracy describes how close a given measurement is to the true value. The techniques presented in this manual provide guidance on instruments and methods that ensure gaging-station levels are run to both a high precision and accuracy.

Levels are run at gaging stations whenever unresolved gage reading differences are identified, damage is suspected to have occurred to the station, or according to a frequency recommended for a given station. Engineer's levels, optical levels and electronic digital levels, are commonly used for running levels at gaging-stations. Collimation tests should be run at least once during any week that levels are run. Collimation error for an instrument cannot exceed the absolute value of 0.003 ft/100 ft. Instruments exceeding this collimation tolerance should be adjusted, and another collimation test must be run before it is used for gaging-station levels. If an instrument fails a collimation test, all levels run since the prior passing collimation test cannot be used and must be re-run.

An acceptable set of gaging-station levels consists of a minimum of two foresights, each from a different instrument height, to at least two independent reference marks, all reference points, all gages, and the water surface. The initial instrument height is determined from a third independent reference mark, known as the origin, or base reference mark. The absolute value of the closure error of a leveling circuit must be less than or equal to $0.003\sqrt{n}$ ft, where n is the total number of instrument setups. The entire level circuit must be re-run if closure error exceeds this threshold; closure error may not exceed |0.015| ft, regardless of the number of instrument setups. Closure error for a leveling circuit is distributed by instrument setups in a manner that assumes error accumulates linearly and elevations for objective points are adjusted accordingly. Absolute differences between the adjusted first and second elevations for the objective points in the circuit must be less than or equal to 0.005 ft. Objective points with absolute differences between adjusted first and second elevations exceeding 0.005 ft require two more foresights from different instrument heights. Final elevations of objective points are determined by averaging the valid adjusted first and second elevations. Reference gages should be reset if the absolute value of the difference between the elevation reading of the reference gage and the gage datum is greater than or equal to 0.015 ft. A summary of selected requirements and tolerances for gaging-station levels is provided in appendix E.

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Glossary

Backsight (BS). The reading on a leveling rod held on a point of known elevation that is used to establish a height of an instrument.

Benchmark . A permanent marker with known survey control of vertical and (or) horizontal coordinates in an established geodetic system, such as the North American Vertical Datum of 1988.

Closure error. The difference between the elevation of the starting point, or origin, of a closed level circuit and the elevation of that same point from the final instrument setup; computed as the given elevation minus the final elevation.

Collimation. Agreement of a surveying instrument's line of sight with its horizontal axis.

Collimation error. The deviation or inclination of a level's line of sight from horizontal, often given in a vertical deviation per horizontal distance such as feet per 100 feet; positive when the line of sight points downward from the instrument.

Curvature and refraction effect. The increase in a leveling rod's reading caused by the combination of the Earth's curvature and atmospheric refraction effects.

Datum. A level surface that represents zero elevation.

Differential leveling. The determination of the difference in elevation of two points using a surveying instrument and a leveling rod.

Elevation. The vertical distance from a point to the datum.

Engineer's level. A surveying instrument consisting of a minimum of a telescopic sight and a sensitive leveling device to make the line of sight horizontal.

> **Optical level.** An engineer's level that is used to manually read a leveling rod.
>
> **Electronic digital level.** An engineer's level with an automated system that reads a leveling rod.

Foresight (FS). The reading on a leveling rod held on a point whose elevation is to be determined.

Gage datum. The zero elevation reference surface at a gaging station to which all gages are set.

Gage height. The elevation of the water surface at a gaging station, used interchangeably with stage.

Gage height of zero flow. The gage height at which streamflow ceases. Associated with the elevation of the lowest point on the low-water hydraulic control of a gaging station.

Gaging-station levels. Differential levels run (that is, carried out) at a gaging station to define and maintain a constant gage datum for all gages.

Height of instrument (HI). The elevation of the horizontal line of sight of a surveying instrument.

Horizontal. A direction that is perpendicular to the force of gravity.

Parallax. The relative movement of the image of a leveling rod with respect to the cross hairs of a surveying instrument as the observer's eye moves, caused by improper focusing of the objective lens of the instrument.

Reference mark (RM). A permanent marker, installed in the ground or on a structure, whose elevation above a set datum is known. Used to check and make sure that all gages and reference points are properly set to gage datum.

Reference point (RP). Objects, often bolts or screws that are assigned an elevation in the gage datum. Used to obtain gage heights when necessary by measuring their distance to the water surface.

Stage. The elevation of the water surface at a gaging station, used interchangeably with gage height.

Temporary reference mark (TRM). A temporary point of reference that was treated as an objective point in a previously closed level circuit that is used to carry elevations to other instrument setups.

Turning point (TP). A temporary point of reference in an open level circuit that is used to carry elevations to other instrument setups in the level circuit.

Vertical. The direction of the force of gravity.

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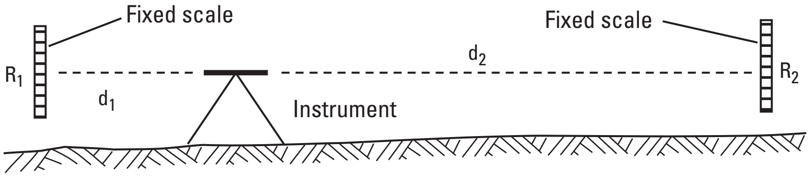
Appendix A. Fixed-Scale Test Form

FIXED SCALE COLLIMATION TEST OF ENGINEER'S LEVEL

Tested by: ________________________________ Date: ____________________________________

Make/Model: Circle system type(s): optical digital



$$\text{Collimation} = c = 100 * \left[\frac{(R_1 - R_2)}{(d_2 - d_1)}\right]$$

d_2 should be less than 110 ft.

OPTICAL SYSTEM

$$c = 100 * \left[\frac{(\qquad - \qquad)}{(\qquad - \qquad)}\right]$$

	R	d
1		
2		

c = _______________ft/100ft as found

DIGITAL SYSTEM

$$c = 100 * \left[\frac{(\qquad - \qquad)}{(\qquad - \qquad)}\right]$$

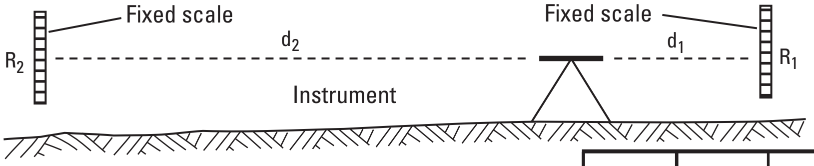
	R	d
1		
2		

c = _______________ft/100ft as found

ADJUSTMENT (level remains set up at ORIGINAL LOCATION)

To adjust level, set R_2 to read R_1 R_1 = ______________ System adjusted: optical digital

To test collimation after adjustment, set up near other scale and repeat measurements.



$$c = 100 * \left[\frac{(\qquad - \qquad)}{(\qquad - \qquad)}\right]$$

	R	d
1		
2		

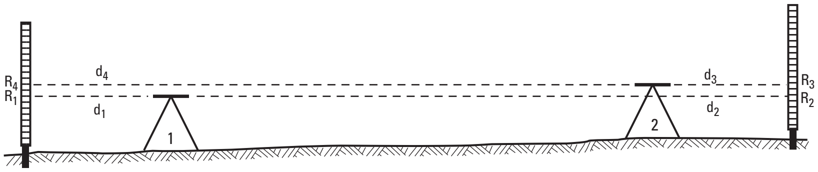
NOTES or COMMENTS:

Appendix B. Peg Test Form

PEG TEST OF ENGINEER'S LEVEL

Tested by: ______________________________ Date: ____________________________________

Make/Model: Circle system type(s): optical digital



$$\text{Collimation} = c = 100 * \left[\frac{(\ R_1 + R_3\ ) - (\ R_2 + R_4\ )}{(\ d_2 + d_4\ ) - (\ d_1 + d_3\ )}\right]$$

Average of d_2 and d_4 should be less than 110 ft.

OPTICAL SYSTEM

$$c = 100 * \left[\frac{(\qquad + \qquad) - (\qquad + \qquad)}{(\qquad + \qquad) - (\qquad + \qquad)}\right]$$

c = _______________ft/100ft as found

	R	d
1		
2		
3		
4		

DIGITAL SYSTEM

$$c = 100 * \left[\frac{(\qquad + \qquad) - (\qquad + \qquad)}{(\qquad + \qquad) - (\qquad + \qquad)}\right]$$

c = _______________ft/100ft as found

	R	d
1		
2		
3		
4		

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

Adjust cross hair to $R_4 \pm \left[\frac{(cd_4)}{100}\right] = \_\_\_\_\_ \pm \left[\frac{(\qquad)}{100}\right]$

Repeat collimation test after adjustment.

COLLIMATION TEST AFTER ADJUSTMENT

$$c = 100 * \left[\frac{(\qquad + \qquad) - (\qquad + \qquad)}{(\qquad + \qquad) - (\qquad + \qquad)}\right]$$

c = _______________ft/100ft as found

NOTES or COMMENTS:

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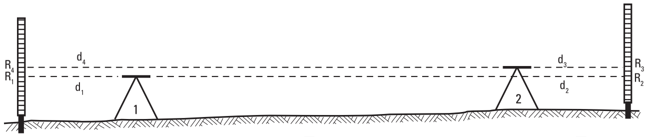
Appendix C. Level Notes Form

(Full-size form [8" x 10"] is available for download at http://pubs.usgs.gov/tm/tm3A19)

PEG TEST OF ENGINEER'S LEVEL

Make/Model: Circle system type(s): optical digital



$$\text{Collimation} = c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right]$$

Average of d_2 and d_4 should be less than 110 ft.

OPTICAL SYSTEM		R	d
$c = 100 * \left[\frac{(\quad + \quad) - (\quad + \quad)}{(\quad + \quad) - (\quad + \quad)} \right]$	1		
	2		
	3		
c = ______________ft/100ft as found	4		

DIGITAL SYSTEM		R	d
$c = 100 * \left[\frac{(\quad + \quad) - (\quad + \quad)}{(\quad + \quad) - (\quad + \quad)} \right]$	1		
	2		
	3		
c = ______________ft/100ft as found	4		

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

Adjust cross hair to $R_4 \pm \left[\frac{(cd_4)}{100}\right] = \_\_\_\_ \pm \left[\frac{(\qquad)}{100}\right]$ Repeat collimation test after adjustment.

COLLIMATION TEST AFTER ADJUSTMENT		R	d
$c = 100 * \left[\frac{(\quad + \quad) - (\quad + \quad)}{(\quad + \quad) - (\quad + \quad)} \right]$	1		
	2		
	3		
c = ______________ft/100ft as found	4		

CLOSURE-ERROR COMPUTATIONS

Circuit No.	No. of Inst. Setups (n)	Allowable closure 0.003 √ n	Closure Error (CE)	CE/(n) (take to 0.0001)

NOTES or SKETCHES:

U.S. DEPARTMENT OF THE INTERIOR

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Gaging Station Level Notes

Station Number:

Station Name

Date Party (inst.) (rod)

SUMMARY OF OBJECTIVE POINTS

Object	Adjusted 1^{st} Elevation (AE1)	Adjusted 2^{nd} Elevation (AE2)	Difference (AE1 −AE2)	Final Elevation ((AE1+ AE2)/2)

INSTRUMENT

Make/Model: ____________________

Serial Number: ____________________

Collimation (optical): __________________

Collimation test date: __________________

Collimation (digital): __________________

Collimation test date: __________________

ROD

Scale material: _______ CTE _________ 1/F° or 1/C°

CTE conversions: (1/°F * 1.8 = 1/°C) and ((1/°C)/1.8 = 1/°F)

Temperature (T): Rod:_____ °F or °C; Air:_____ °F or °C

Standard temp (T_o): 68°F or 20°C or other: _______

Given/Origin elevation: ____________

Max elevation of objective point: _____________

Min elevation of objective point: _____________

Max elevation difference (L): _____________

C_t= CTE * L (T−T_o) C_t= ____________

Other devices used as rod (list):

Rod taped (circle): yes no

Rod level used (circle): yes no

GAGE READINGS

Time	WS			Ref.

GAGE RESET

	Ref.			
Found				
Left				

WEATHER: ______________________________

NOTES: ______________________________

Computed by: Checked by: Date:

OBJECT	BS	CORRECTED BS	HEIGHT OF INSTRU-MENT (HI)	FS	CORRECTED FS	ELEVATION	Remarks
		$BS+(CTE*BS*(T-T_0))$			$FS+(CTE*FS*(T-T_0))$		

CLOSURE-ERROR ADJUSTMENT TO HI	ADJUSTED 1st ELEVATION	ADJUSTED 2nd ELEVATION	DIFFERENCE (AE1 −AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks

Appendix D. Historical Level Summary Form

(Digital Excel format is available for download at http://pubs.usgs.gov/tm/tm3A19)

HISTORICAL LEVEL SUMMARY

STATION NUMBER ____________ STATION NAME ____________________

										Primary Reference Gage																
		Reference Marks and Reference Points								Staff gage		Wire-weight gage				Auxillary gage		Crest Stage gage		Recorder						
DATE	PARTY	(Given)							Water surface by levels	Water surface found	Water surface left	Btm of weight nr water surface	Check bar	Electric tape index	Adjust. made	Water surface found	Water surface left	Index found	Index left	Found	Left	Check bar(Aux wire-weight)	Orifice line terminus	Gage height of of zero flow	Datum correction	Remarks

Descriptions of objective points:

RM1 —
RM2 —
RM3 —
RP1 —
RP2 —
RP3 —

CSG Index —
ORIFICE —
REF GAGE —
GZF —

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Appendix E. Summary of Selected Requirements and Tolerances for Gaging Station Levels

[n is the number of instrument setups in level circuit. ft, foot; <, less than; | |, absolute value]

	Requirements and tolerances
Precision of gaging station levels	0.001 ft
Accuracy of gaging station levels	<0.01 ft
Maximum number of days since the last collimation test	7
Maximum collimation error of level instrument	|0.003| ft/100 ft
Maximum allowable difference between rod scale and tape check	|0.002| ft
Minimum number of reference marks in a level run	3
Maximum temperature correction, Ct, computed using maximum vertical distance from origin (equation 3) that does not require correcting all shots for thermal expansion or contraction	|0.003| ft
Maximum allowable closure error	$\lvert 0.003\sqrt{n} \rvert$ and not to exceed |0.015| ft
Minimum number of foresights to	
at least two reference marks	2
all reference points	2
all gages	2
the water surface	2
the origin reference mark	1
Minimum number of non-objective point turning points	1
Maximum allowable difference between the adjusted first and the adjusted second elevations of objective points	|0.005| ft
Maximum allowable difference between the elevation reading of the reference gage and the gage datum	<|0.015| ft

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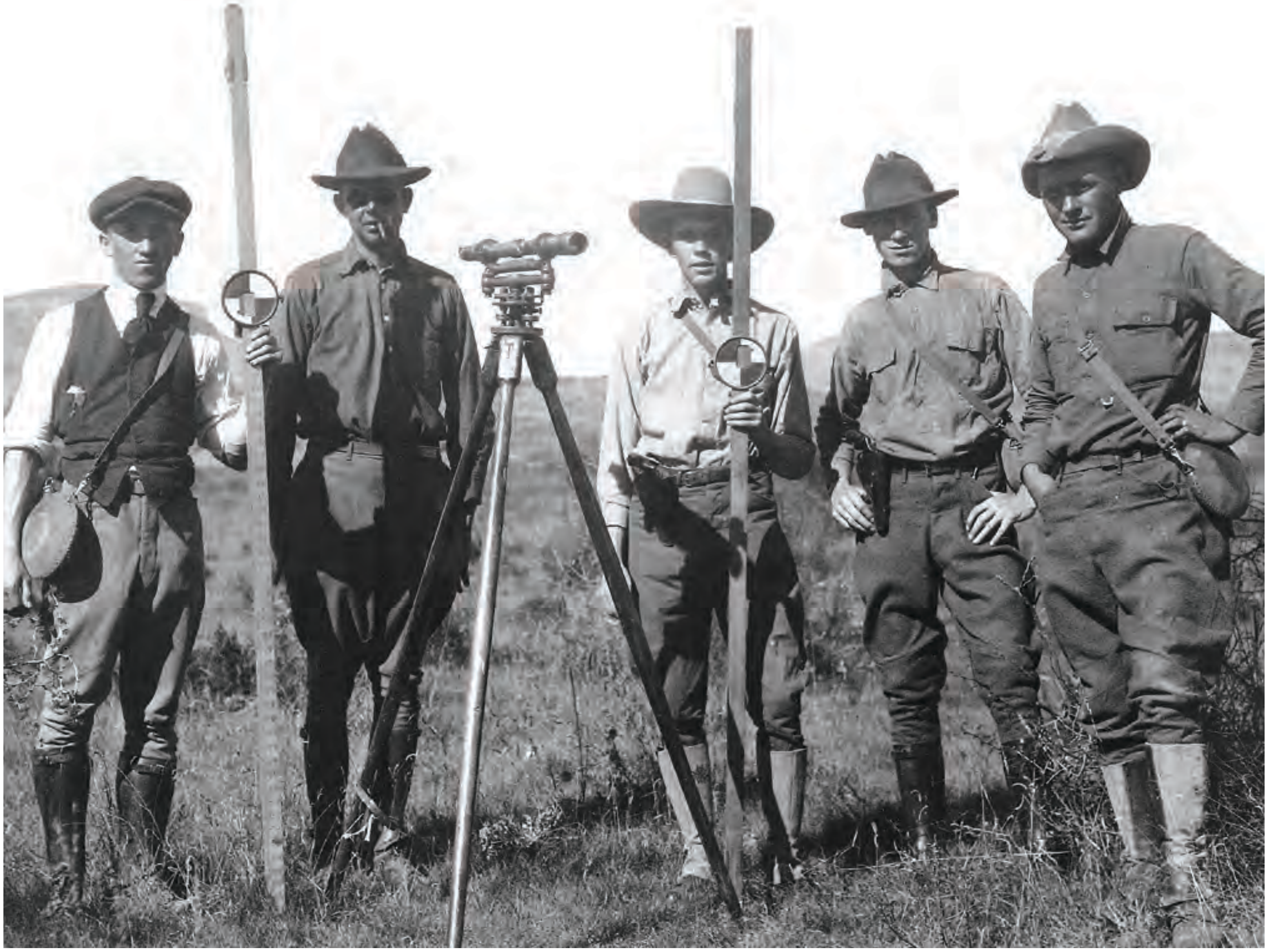

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