THE GRADIENT BOUNDARY—THE LINE BETWEEN TEXAS AND OKLAHOMA ALONG THE RED RIVER

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FOREWORD

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Arthur A. Stiles, the author of the following article entitled "The Gradient Boundary," was born in Travis County, Texas, and is a Colonel of the Officers Honorary Retired List of the Army of the United States and a life member of the American Society of Civil Engineers. For many years he was engaged in topographical engineering in the United States Geological Survey and surveyed and mapped many hundreds of square miles in states west of the Mississippi River from the Canadian border to the Mexican border. He was appointed State Reclamation Engineer of the State of Texas in 1910 and served in that office until 1924 under appointment by five governors. He wrote the law creating the State Reclamation Department and the several laws pertaining to levees and drainage that were enacted by the State of Texas during that period, and he designed about five hundred miles of standard levees to reclaim about 200,000 acres of overflowed lands.

Colonel Stiles served as engineer for the State of Texas in the defense of the suit in the Supreme Court of the United States involving the boundary line along the Red River,¹ and he was appointed by the Court as one of the two commissioners to fix and mark the boundary between the two states. In that capacity he devised as the theory and plan for marking the line along the river what was later called "the gradient boundary," and that method was adopted by the Supreme Court of the United States as the law of the case. The history and development of the gradient boundary and the method of applying it on the ground are fully and carefully related and described by Colonel Stiles in the following article. The method of finding and marking the boundary is so clearly set out in nontechnical terms that it can be understood and followed by lawyers as well as engineers and surveyors.

The article is of real value to Texas lawyers because the gradient boundary which it describes and explains was adopted by the Supreme Court of Texas in Pyle v. Boyd,² and has been applied in later decisions as the law of Texas for marking the line between public and private

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¹Associate Justice, The Supreme Court of Texas.
³116 Tex. 82, 286 S.W. 456 (1926).
ownership along streams, the beds of which are owned by the state. However, the particular value of the article, aside from its thoroughness and clarity, is that it comes from the hand of the distinguished Texas engineer and surveyor by whom the gradient boundary was devised and so presented and demonstrated that it was approved and adopted by the Supreme Court of the United States and later by the Supreme Court of Texas.

THE GRADIENT BOUNDARY

The boundary line between the states of Texas and Oklahoma along the Red River is a portion of the boundary between the territory of the United States and the Spanish possessions established by the treaty of 1819. This portion of the line has been reaffirmed on several occasions, but never changed.

One hundred years after the treaty was agreed upon, oil was discovered on the Red River in Wichita County, Texas. Producing oil wells were completed northward across the valley and into the sand bed of the river. Land values moved skyward. The question arose with new and threatening importance: What is and where is the boundary line between Texas and Oklahoma along the Red River? Serious complications ensued and the governor of Texas dispatched the Rangers to the new oil field to preserve order.

On December 6, 1919, Oklahoma entered suit against Texas in the Supreme Court of the United States "to definitely locate and fix" the boundary between the states of Texas and Oklahoma along the Red River. The United States intervened. The important events which followed are related in the official record, to which reference is here made. This case is memorable for the large monetary values involved, for the wide field covered by the scientific investigations, for the eminent counsel employed, and for the noted scientists who testified at great length. The record in the case fills nine volumes containing a total of 5510 printed pages. Altogether, 418 witnesses testified regarding 539 miles of the Red River.

The following three expressions of the Court constitute the only original legal authority on the subject of the gradient boundary: (a) the opinion of the Court delivered by Mr. Justice Van Devanter on January 15, 1923, in which authorities are reviewed, conclusions announced, and the physical situation on the Red River described; (b) the decree of the

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*See Heard v. State, 146 Tex. 139, 204 S.W.2d 344 (1947); Maufras v. State, 142 Tex. 559, 180 S.W.2d 144 (1944); Heard v. Town of Refugio, 129 Tex. 349, 103 S.W.2d 728 (1937); Diversion Lake Club v. Heath, 126 Tex. 129, 86 S.W.2d 441 (1935).*
Court dated March 12, 1923, giving effect to the above opinion and designating Arthur D. Kidder and Arthur A. Stiles as commissioners to run, locate, and mark upon the ground portions of the boundary in accordance with this decree and the principles announced in the opinion; and (c) the (first) Report of the Boundary Commissioners, dated April 25, 1924, in which the gradient boundary is promulgated and described with field notes and maps. The gradient boundary has not been changed since it was confirmed by decree of the Court on June 9, 1924.

In this litigation, the interests of the United States and the State of Oklahoma were largely identical as against the State of Texas. For that reason the appointment of three boundary commissioners was not considered appropriate. As between the two commissioners who were designated, Mr. Justice Van Devanter presided as referee on the part of the Court. Commissioner Kidder was a cadastral engineer of officially recognized ability in the United States General Land Office at Washington, D.C. He had testified in this case in behalf of the United States and Oklahoma. Commissioner Stiles was the State Reclamation Engineer of Texas. He had testified briefly in behalf of the State of Texas.

By order of the Court, the commissioners first determined and marked the boundary through the Big Bend area in Wichita County, Texas, where all oil wells within three hundred feet of the boundary were located with respect to the boundary. This work is described in the (first) Report of the Boundary Commissioners, dated April 25, 1924, confirmed June 9, 1924. They next determined and marked the boundary through the Fort Auger area in Wichita County, Texas. This work is described in the Second Report of the Boundary Commissioners, dated January 5, 1925, confirmed March 9, 1925. The necessary surveying and mapping in the Big Bend and Fort Auger areas was done cooperatively by the surveyors of the United States General Land Office under the supervision of Mr. Kidder and by the topographers of the State Reclamation Department of Texas under the supervision of Mr. Stiles.

Under paragraph 12(c) of the decree, the commissioners located and marked the boundary as thus directed by the Court:

"Along all places where by avulsion since 1821 the river has come to occupy a new channel whereby fast upland theretofore on one side of the river has come to be on the other side,—the line in every such instance to be run, located and marked on and along what was the south bank before the change occurred."

Where an avulsion has occurred, the gradient boundary, upon leaving the river and passing around the old bend, ceases to be a gradient of the flowing water and becomes a boundary line on the upland. Upon re-
turning to the river, the boundary is the gradient as before. This work is described in the Third Report, dated November 16, 1925, confirmed January 4, 1926, and in the Fourth Report, dated January 31, 1927, confirmed April 25, 1927, of the Boundary Commissioners.

Paragraph 12(d) of the decree directed the commissioners to locate the boundary along "any other places which either state or the United States may designate," but no requests were received for supplemental surveys.

I. ORIGIN OF THE GRADIENT BOUNDARY

As boundary commissioners, Mr. Kidder and Mr. Stiles walked together many times over the Big Bend and Fort Auger areas examining the river with respect to the boundary. In the beginning, and for some time, they sought to locate the boundary in the manner generally in vogue in federal land surveying, apparently based upon various court decisions and surveying instructions derived from them. But the preliminary determinations of the boundary made in this way were not mutually satisfactory to the commissioners. The requirements of the Court were not at fault. They were far more comprehensive and precise than any result that could be obtained by these heterogeneous rules of surveying.

At other times, Mr. Stiles walked for miles along the river with the opinion in hand studying the river with sole regard to the requirements of the Court in this individual case. This work amounted to fitting the opinion to the river. It clearly indicated that a gradient of the flowing water in the river was the only possible datum for locating this boundary upon the ground in thorough compliance with the requirements of the Court. In this way, the gradient boundary was laboriously worked out on foot, bank by bank, on the Red River.

A section of several hundred feet of the boundary had been tentatively located in the usual manner. The line followed a series of banks of varying heights and positions, selected without reference to any underlying principle, but rather upon broad grounds of experience and training in land surveying not altogether applicable to the explicit requirements of the Court concerning this treaty boundary. A profile was made of the line. The lowest bank was 1.2 feet high; the highest, 6.9 feet high. Intervening heights in feet were respectively, 2.6, 2.9, 4.1, 1.4, 5.2, 2.4, and 3.6. Judged by the principle of a gradient of the flowing water in the river, the boundary was a model of inconsistency. As the river ran downhill, the boundary in places ran uphill. If it had not been controlled by a gradient of the flowing water in the river, the boundary might well have been an inconsistent and arbitrary line of this kind.
Upon request, Mr. Justice Van Devanter held a joint conference with the commissioners at his summer home in Canada, September 12 to 15, 1923. At the suggestion of the Justice, the commissioners first discussed jointly with him their individual views upon the work then in progress on the river. Concerning the boundary, it was explained that of any two banks both otherwise equally fulfilling the requirements of the Court, the lower bank must be accepted as correct because the Court had specified that the water must "reach and wash the bank without overflowing it." Obviously, if the water reaches and washes the higher bank, it has completely overflowed the lower bank and all other banks of that height in the vicinity, so that they no longer conform to the specifications of the Court. A gradient of the flowing water in the river proposed as a datum from which to locate the boundary was fully described and illustrated to the Justice, who seemed quick indeed to grasp the nature and practical purpose of such a reference plane. He commented briefly:

"Then if you had the one correct bank, you could locate the boundary thence; and the line would run on the bank consistently with the water in the river."

Subsequently, other joint conferences were held with Justice Van Devanter in Washington. The (first) Report of the Boundary Commissioners was written as of April 25, 1924. In conference with the commissioners, the Justice carefully read the original copy of the report promulgating the gradient boundary and locating it midway between the two levels of the water on the lowest qualified bank. The Justice asked a number of questions concerning the report, all of which were fully answered. The report was ordered to be printed, and it was in all respects confirmed by the Court on June 9, 1924.

Thus the gradient boundary was finally established and fixed at the mid-height point of the lowest "acceptable" or qualified bank in the vicinity. The significant portion of the report reads as follows:

"The foregoing specifications applied in the light of the opinion admit of and require the exercise of practical judgment in determining the line intended; but certain fundamentals such as the following, obviously must form the final basis for the exact location of the line.

"The boundary line is a gradient of the flowing water in the river. It is located midway between the lower level of the flowing water that just reaches the cut bank and the higher level of it that just does not overtop the cut bank. The physical top of the cut bank being very uneven in profile, cannot be a datum for locating the boundary line; but a gradient along the bank must be used for that purpose. The highest point on this gradient must not be higher than the lowest acceptable point on the bank in that vicinity. The boundary line has been determined accordingly."
II. Nature of the Gradient Boundary

When the surface of the flowing water in the river and the elevation of the boundary coincide, the boundary is on the ground at the feather-edge of the water, and stakes driven there will mark the perfect gradient and the perfect boundary—hence the name, "gradient boundary."

A realistic view of the gradient boundary can be had by walking along the bank of the river and closely observing the edge of the flowing water. Leaving the river front the water line enters the inlets; then emerging on the lower side, it veers off the high ground. Where the bank is too low, the water line swings toward higher ground and leaves the low bank in the overflow of the river. Where the bank is too high, the water line swings nearer the river and leaves the bank on the high ground. Where the ground is smooth, the water line is smooth. Where the river is flowing against a steep bank, the water line is difficult to follow. In short, the height and position of the gradient boundary are fixed by the bank of the river; the grade is fixed by the surface of the water in the river; and the course is fixed by the topography along the river.

The boundary is set at the mid-height point of the lowest qualified bank in the vicinity where the water, rising against the bank, will first overflow it. But until this bank is found, the height and position of the boundary are unknown. Therefore, finding and marking this bank conclusively locates the gradient boundary upon the ground for the first time. Thence the boundary runs on and along the bank as a gradient of the flowing water in the river. The gradient boundary does not run on the water. For one given height there is but one possible course for the boundary, since changing the height changes the course. When the height is known, the course is established in advance.

The Court has not placed the boundary at any of the various "stages" of the water in the river. The two levels of the water locating the boundary at the mid-height point of the one and only correct bank to be found in the vicinity are requirements of the Court specifying where on this bank the boundary is. The mid-height point of this bank is determined by the surveyor with his level. For this purpose it would be more convenient for him if the river were dry. To examine gage-height records and hydrographs of the river for the height of the boundary is a misconception and a waste of time. The height of the gradient boundary is determined by the bank of the river, not by the water in the river. This principle appears to be in full accord with the conclusion of the Court expressed in the opinion:
"We therefore are concerned with an instance in which the bank of a river, and not the river itself, has been made the boundary between two nations,—now between two states of the Union."

The level is the only surveying instrument with which the gradient boundary can be located upon the ground. The boundary line cannot be projected. It goes where the level leads; the surveyor follows. The level gives him little discretion and no choice in locating the boundary. To a marked degree, the correct location of the boundary is beyond surmise, doubt, approximation, or bias. Each stake set on the gradient boundary represents a separate operation in surveying. Every stake is independent of every other stake. Hence, there are no circuits to be closed, nothing to be balanced, and no random or trial lines to be run.

The consistency of the gradient boundary is illustrated by the following practical example. The boundary was being established on the left bank of the Colorado River in Hornsby's Bend about ten miles below Austin, Texas, upon the principles promulgated by the Supreme Court in Oklahoma v. Texas. The lowest qualified bank in the vicinity had been found to be 3.2 feet high. Forty-four independent points fairly distributed had been carefully located on the gradient boundary on about one mile of the river. At each point the exact elevation of the boundary on the surface of the ground had been precisely marked by the square top of a stake driven deep into the dry ground and accompanied by a numbered lath guard stake close by. Not all of the stakes were set on the same day, but once set, no stake was moved the slightest from its original position and elevation. As a rule the prevailing vertical distance from the surface of the flowing water up to where the boundary was to be on the adjacent bank was barely a foot. The river had been generally normal but at times the water had fluctuated somewhat and the vertical distances read on the gages had to be corrected correspondingly as the work progressed. Since the surveying began, the water in the river had not been up to the gradient boundary as located on the ground and a direct check on the work had been impossible for that reason. The last stake was set on the boundary about 4 p.m. on May 31, 1949. Nothing remained but to check the numbers on the lath guard stakes. This was to be done the next day.

On inspection the next morning, June 1, it was discovered that the ground, very dry the day before, was now very wet and muddy; yet it had not rained in the meantime. Promptly the forty-four stakes were closely examined one by one. The ground was wet at each stake but not appreciably above it. On the square top of each stake the water had left a film of river silt with a corresponding faint water mark on each lath guard stake adjacent. At each stake the two inde-
dependent marks left by the water were level. The physical evidence was unmistakable. The river had risen unseen in the night to the square top of each stake on the boundary, but no higher, and thence had receded into the bed of the river where the water was then placidly flowing. Thus the river had confirmed each of the forty-four stakes previously set on the gradient boundary.

The remarkable consistency of these forty-four stakes on the gradient boundary may be attributed to the clear and practical requirements of the Court. The boundary was restricted by the Court to the lowest qualified bank. Within this restriction there is little room for material changes in the boundary; outside of it, the river is out of bounds and has no significance in determining the gradient boundary. Considering the plain description of the bank intended as the boundary bank and the qualifications placed upon it by the Court, the fundamental correctness of the gradient boundary appears obvious when the requirements of the Court are fully understood and faithfully complied with. The gradient boundary has been variously called a "formula," a "theory," a "rule," and a "medial line." It is none of these things. Concisely, it is the gradient boundary, the term used here.

III. The Boundary Bank

The expression "cut bank" was used in the opinion and the decree of the Court and in the report of the boundary commissioners as a designation and not in any sense as a restrictive qualification of the bank intended as the boundary bank. Many witnesses testified about what they called the "cut bank." According to their testimony, the position of this bank ranged all the way from the "line of vegetation" at the edge of the river bed on the Texas side, southward for several miles into Texas with farms and homes intervening. The height of the "cut bank" varied from three or four feet above low water in the river to the tops of the Texas bluffs, twenty or thirty feet high. Witnesses were not asked to describe the "cut bank" or to state why they called it a "cut bank." The long record of testimony indicates that whenever a witness testified about any bank commonly known or well defined, the usual legal objection was instantly forthcoming. But if the witness referred to the "cut bank," no objection was heard from either side. This unidentified and obscure status of the "cut bank" persisted to the closing of the testimony.

The "cut bank" appears to have been a bank in name only, and by tacit agreement it was intentionally all but meaningless topographically. To suppose that the boundary bank is one and continuous
in character and that it is capable of being recognized and followed by means of the designation, "cut bank," is a fundamental misconception. There is no such bank. The boundary bank is an erosion bank here; an accretion bank there; and a transverse slope yonder. The boundary bank is determined by the relative height of the bank, not by its form, condition, or name.

Paragraph 7 of the decree reads as follows:

"At exceptional places where there is no well defined cut bank, but only a gradual incline from the sand bed of the river to the upland, the boundary is a line over such incline conforming to the mean level of the waters when at other places in that vicinity they reach and wash the cut bank without overflowing it."

At the time this paragraph was written, the Court was not cognizant of the gradient boundary. When located upon the ground, the gradient compels this course of the boundary line with respect to all of the banks and transverse slopes on the river. Therefore, paragraph 7 is in nowise discriminating as to the so-called "cut bank," and the paragraph obviously becomes superfluous. In the event of contradictions between previous expressions of the Court and the principles of the gradient boundary subsequently confirmed by the Court, it is believed that the principles of the gradient boundary must prevail.

Presuming that the unidentified "cut bank" is a bank that has been "cut" or eroded by the natural processes of the river, the well understood expression, "eroded bank," will be used hereinafter in lieu of the apparently very misleading designation, "cut bank." As indicating the reverse process of the river, the equally well understood expression, "accretion bank," will be used. The bank purporting to be the boundary bank will be referred to as such. There are two boundary banks, one on each side of the river. What may be said of one may be said with equal force of the other, hence for convenience here, these two opposite banks will be treated as one bank.

The Court left no doubt about the identity of the bank intended as the boundary bank, where the boundary is on the bank, and what constitutes the bed of the river. Significantly omitting the designation "cut bank" in this instance, the Court in the opinion described these features in this unmistakable language:

"Upon the authority of these cases, and upon principle as well, we hold that the bank intended by the treaty provision is the water-washed and relatively permanent elevation or acclivity at the outer line of the river bed which separates the bed from the adjacent upland, whether valley or hill, and serves to confine the waters within the bed and to preserve the course of the river, and that the boundary intended is on
and along the bank at the average or mean level attained by the waters in the periods when they reach and wash the bank without overflowing it. When we speak of the bed we include all of the area which is kept practically bare of vegetation by the wash of the waters of the river from year to year in their onward course, although parts of it are left dry for months at a time; and we exclude the lateral valleys which have the characteristics of relatively fast land and usually are covered by upland grasses and vegetation, although temporarily overflowed in exceptional instances when the river is at flood."

Being described by the Court as relatively permanent and at the outer line of the river bed, the boundary bank is necessarily the low, fluvial bank. There is little in the fluvial channel of the river that is stable. The boundary bank is ever subject to changes by erosion and accretion and the gradient boundary follows the change. Where the bank is, there is the boundary also.

The work of the river is pictured in the banks. The erosion bank is a direct result of destruction by the river, a topographic wreck in the making. It is that which is left of the terrain into which the river is eroding at the time and place. In erosion the waters undermine the existing bank near the bottom. The material caves from the top, falls into the river, and is carried away. The resulting bank is purely accidental, without design or continuity. The top of the erosion bank may be anywhere from the low water in the river to the summits of the adjacent bluffs. The profile of the bank is uneven, its top uncertain. Where the river is "cutting" or eroding into the lower ground, the erosion bank being formed is soon too low to be the boundary bank. Where the river is eroding into the higher ground, the resulting erosion bank is soon too high to be the boundary bank. It is comparatively seldom that the correct height of the gradient boundary can be determined from the erosion bank. The erosion bank is the bank that was, not the bank that is.

On the other hand, the accretion bank is built with material conveyed and deposited by the water in the river. The bank is smooth in profile and reflects the height of the water at the time the bank was formed. The accretion bank is fundamentally consistent because the material composing it cannot be deposited above the level of the water conveying it. The accretion bank has these features. Between the top of the bank and the rising ground beyond, there is a slight depression somewhat paralleling the river but not a part of the river and in no sense a "by pass" or "slough." Near the head of this depression is a minute "divide" frequently discoverable only with an engineers' level. This divide is the exact top of the bank. The rising water in the river,
upon reaching the top of the bank, barely overflows it. Thence the water flows down the depression and returns to the river in a different place. This topographic form marks the typical accretion bank and sets it apart from the erosion bank and the transverse slope against which the water rises to an uncertain height and thence recedes over the same ground. To a more or less approximate extent the bottom of the bank is indicated by the vertical consistency of the edge of the river bed and the bottom of the adjacent bank; by the washing of the river against the bank at prevailing low stages; by the edge of the bare sand, gravel, small stones worn smooth, rock, or mud composing the bed of the river contrasted with the more conglomerate material composing the bank; and by the aquatic vegetation on the river side of the bank which is soon dead out of the water compared with the upland vegetation on the land side of the bank which is soon dead in the water.

The accretion bank is generally the only bank from which the height of the gradient boundary can be determined. The correct height of the boundary cannot be determined from transverse slopes or at waterfalls or rapids in the river.

IV. Establishing and Locating the Gradient Boundary

Establishing this boundary is a far cry from land surveying. This is the work of the professional topographer and the experienced hydrographer, their duties being about equally divided. Finding the one correct bank in the vicinity that locates the gradient boundary upon the ground is no casual undertaking. If this bank is wrong, the whole boundary is wrong on both sides of the river. Once established, the gradient boundary permits no subsequent "corrections" or "adjustments" in the line. The boundary is either right or it is wrong in the first instance, depending upon the correctness of this one lowest bank which is the basis of the gradient boundary. Hence, finding this bank is the first objective. In order to find it with certainty and precision, it is necessary first to have a thorough understanding of the requirements of the Court concerning the banks and bed of the river and a clear comprehension of the principle and purpose of a gradient of the flowing water in the river.

While at work on the river the surveyor should have in hand for direct reference the opinion and decree of the Court and the report of the boundary commissioners to which reference is made and of which the following is but a summary.
The bank intended is water-washed and relatively permanent. It is at the outer line of the river bed, separates the bed from the adjacent upland, and serves to confine the waters within the bed and to preserve the course of the river. The boundary intended is on the bank at the average or mean level of the waters when they reach and wash the bank without overflowing it.

The bed is all of the area kept practically bare of vegetation by the wash of the waters of the river and is composed of light, loose sand. Excluded from the bed are the lateral valleys of relatively fast land which are usually covered with upland grasses and often studded with trees. The valley land is separated from the sand bed by a water-washed bank designated a "cut bank." On the valley side of the bank is vegetation and on the river side, bare sand. When the water is in substantial volume, it flows over the whole of the sand bed and washes both banks.

The boundary line is a gradient of the flowing water in the river. It is located midway between the lower level of the flowing water that just reaches the bank and the higher level of it that just does not overtop the bank. The highest point on this gradient must not be higher than the lowest acceptable point on the bank in that vicinity.

The lowest qualified boundary bank can be found only by close study in walking along the banks, not by inspection from a distance, from the air, from across the river, or from a few isolated places most easily reached in an automobile. No intelligent idea of the river can be had from survey diagrams, aerial photographs, or contour sketches made from them and examined in some office. Such procedure results in superficial knowledge, false impressions, wrong conclusions, and bad work. Finding this bank means hard work on foot on the river.

The boundary bank has many ramifications. It should be studied continuously by working downstream rather than upstream. The various features of the banks and the river are best observed seriatim and seen in elevation rather than in plan. If considered disconnectedly, parts of the river may be confusing. Occasionally, important changes in the bank cannot be seen more than about fifty feet away in the best of light, and may require the level to confirm what they appear to be.

In many places the surface of the river sand bed is far from smooth. It is broken by small islands with scant vegetation, by banks and bars of bare sand or other material left by the high water, and by sand dunes formed by the wind. These contrary heights should be excluded; otherwise, the sand bed is made too high. Similarly, sloughs, by-passes,
and secondary channels of the river should be excluded or the boundary bank is made too low.

The bank being looked for is at the outer line of the river bed. In almost every case it is an accretion bank, and, although both sides of the river should be examined, it is seldom an erosion or "cut bank." As a rule the bank will be found on the side of the river where accretion is generally in progress. Of any two banks otherwise equally fulfilling the requirements of the court, the lower bank must be accepted as correct. This series of positive eliminations lead but downward and ultimately to the lowest qualified bank in the vicinity, the bank being sought.

When the correct boundary bank has been found, the mid-height point on the bank is taken where the water would first overflow the bank. The exact position of this point is permanently marked as a bench mark, and the elevation, which henceforth is the elevation of the gradient boundary, is assumed as zero. From this bench mark a reference mark, set on higher and safer ground nearby, is located in bearing, distance, and elevation. In this way the boundary is originally established and marked upon the ground. Thence the boundary is located on and along this bank as a gradient of the flowing water in the river.4 This bench mark, elevation zero, will hereinafter be referred to as the "basic point."

The basic point may be found on one side of the river, whereas the gradient boundary is to be located on the other side. In that event the

4 The lowest qualified boundary banks on the following rivers in the several localities have been sought out and carefully measured with the level upon the principles of the gradient boundary as described herein. The vertical heights of these banks are given as illustrating the application of these principles.

- North Fork of Red River in Gray County, Texas. Height of bank 2.2 feet. Height of boundary 1.1 feet.
- Red River in Wichita County, Texas, 260 miles further down the river. Height of bank 3.0 feet. Height of boundary 1.5 feet.
- Red River in Cooke County, Texas. Height of bank 3.0 feet. Height of boundary 1.5 feet.
- Colorado River in Burnet County, Texas, 3 or 4 miles down the river from Marble Falls. Height of bank 3.0 feet. Height of boundary 1.5 feet.
- Colorado River at Austin, Texas. Height of bank 3.22 feet. Height of boundary 1.6 feet.
- Colorado River at Hornsby's Bend, Travis County, Texas, about 10 miles down the river from Austin. Height of bank 3.5 feet. Height of boundary 1.6 feet.
- Colorado River in Bastrop County, Texas, about 4 miles up the river from Bastrop. Height of bank 3.2 feet. Height of boundary 1.6 feet.
- Mission River in Refugio County, Texas. Height of bank 2.4 feet. Height of boundary 1.2 feet.

Finding the foregoing lowest qualified banks required examining on foot both sides of these rivers for distances ranging from five to ten miles.
bank, which is the zero on the bench mark, is projected with the level and marked on the post. The zero graduation on the gage scale is made to coincide with the zero mark on the post, and in that position, the scale is nailed to the post. The zero on the gage is the correct elevation of the gradient boundary at the basic point. The gage reading above zero is the prevailing vertical distance that the boundary is under water and perhaps inaccessible for the time being. The gage reading below zero is the prevailing vertical distance from the surface of the water up to the boundary on the bank.

The next gage is set where the location of the boundary is to begin, and additional gages are placed where needed. Suitable positions for the gages should be selected in advance. They should be a scant mile apart if they are to be reached on foot, or somewhat further apart if accessible by automobile. All gages should be favorably situated for close-up reading at the contemplated stages of the water.

The zero marks on the supplemental gage posts emanate from the zero at the basic point. Therefore the equivalent of this zero will be carried to the posts by the surface of the flowing water used as the auxiliary gradients described in (a), (b), and (c) below. For this purpose the river must be flowing steadily and the water must be smooth. (a) When the surface of the water is at zero at the basic point, marking the surface on the posts marks the zero on the posts. (b) When the surface of the water is above zero at the basic point, the surface is marked on all the posts. When the surface is the same distance below zero, it is marked again on all the posts. Halfway between the two marks on each post will be the zero mark on each post. (c) When the surface of the water is above zero at the basic point, the surface is marked on all the posts. When the surface is below zero, it is marked again on all the posts. The position of the zero between the two marks on each post is proportionally the same as the distances above and below zero read on the gage at the basic point.

For example, suppose that when the posts were marked the first time, the surface of the water was 0.8 foot above zero at the basic point. When they were marked the second time, the surface was 1.2 feet below zero. The total distance between the two readings on the gage at the basic point is 2.0 feet. The distance between the two marks on the adjacent post is 1.8 feet. From the proportion, $2.0:1.8::0.8:x$, $x$ is 0.72 foot, and from the proportion, $2.0:1.8::1.2:y$, $y$ is 1.08 feet. Therefore, the true position of the zero on the adjacent post is 0.72 foot below the upper mark and 1.08 feet above the lower mark. The zero marks on the other posts may be determined in the same way.

The auxiliary gradients should be confined between the bottom and top of the boundary bank. The nearer the water is to zero when the
posts are marked the more accurate the marks will be. From the zero mark on each post a permanent reference mark on the adjacent high ground should be located in bearing, distance and elevation. Gage scales are nailed to the posts as at the basic point, and the gages are ready for use in locating the gradient boundary upon the ground.

Experience on the river has shown that locating the gradient boundary from gages determined as described above is amply accurate for all practical purposes. However, on rare occasions when it is justified, a more elaborate procedure may be followed. This method is based upon the time required for the water to pass from the zero level at the basic point to the equivalent zero level at the corresponding point. The time is measured by comparing two continuous gage-height records or hydrographs starting at the same moment and covering the same extended period of time. One record is made by an automatic gage installed at the basic point. The other record is made by another automatic gage installed at the corresponding point. As the calculated time elapses, the zero level of the water can be anticipated and marked at the corresponding point. A detailed description of this method is hardly called for here.

The gradient boundary is located upon the ground exclusively with a level, not with a transit, compass, chain, or stadia. After it is located and marked, the line may be meandered in the usual way with the usual instruments. Locating the boundary may begin at the most convenient river gage, and from there it should be run preferably downstream. The boundary should be located on one side of the river at a time.

If the location of the boundary is to begin at the basic point, the first point on the boundary will be the mid-height point of the boundary bank previously found and marked by the bench mark and by the zero on the gage. If the boundary is begun at any other gage, the first point on the boundary will be on the adjacent bank normal to the gage and level with the zero on the gage. Intervening points on the boundary must be located from the surface of the water in the river as read upon the nearest gage. The zero on every gage is the elevation of the boundary at the gage.

When the boundary is being located, an assistant should be stationed to watch the nearest gage. If any appreciable change occurs in the surface of the water, the assistant should quickly report it to the levelman, who will immediately discard the vertical distance then being used and substitute the new vertical distance. In this way all vertical changes in the surface of the water are virtually eliminated as they occur, and the resulting boundary is a consistent and smooth line whereas the surface of the flowing water from which it was derived may have been at the time an irregular and wave-like line.
For every point on the boundary a separate reading or “back sight” must be taken on the surface of the water directly opposite or normal to the point being set on the boundary. Otherwise the line will be in part a gradient and in part a contour, and the boundary will be an indeterminate hodge-podge of both lines.

Where no solid support is available for the level rod when sighting upon the surface of the water, the rod should be held on the square top of a “hub” stake driven for the purpose in the edge of the water and exactly level with the surface of the water.

When the boundary is being located from the surface of the water, the nearer the surface is to zero on the gage the more nearly perfect will be the location of the boundary on the ground. If the gages show that the river is beginning to fluctuate, the boundary locating should be stopped and not resumed until the river is flowing steadily. It is useless to locate the boundary along a steep bank. When the bank changes by erosion and accretion, the boundary changes with it. In the meantime the bank is the most practical marker for the gradient boundary. If the surface of the water is more than four or five-tenths of a foot above zero, measuring the distance vertically downward to locate the boundary under the water may not be feasible and may be dangerous because the topography is then obscured by the water. But if the surface of the water is below zero, the prevailing distance read on the gage will be measured with the level vertically upward from the surface of the water and brought into contact with the adjacent bank or sloping ground by trial settings of the level rod. The resulting point of contact is a point on the gradient boundary, and a stake or post will be set there to mark the line. Other points on the boundary wherever needed will be located and marked in the same way. Thus the gradient boundary is located point by point and stake by stake throughout the course.

V. INTERMITTENT STREAMS

There are many water courses miles long with beds of sand from thirty feet to several hundred feet wide in which there may be no flowing water for days or months at a time. In topographic work such water courses are classified as “intermittent streams,” and they are so designated by symbol on the topographic maps.

A gradient of the natural surface of the ground is not equivalent to a gradient of the flowing water in the river. The surface of the flowing water in places may appear to be level, but the water forever runs downhill whereas the surface of the ground in places runs uphill. The two slopes are radically incompatible. For that reason a gradient of the flowing water is essential.
It is obvious that where there is no flowing water there is no gradient of the flowing water. Consequently, the final location of the gradient boundary in the intermittent streams must await the coming of the flowing water. Similarly, when the water covers the river bed, the lower banks, and the valleys, the final location of the gradient boundary must await the receding of the water. The temporary absence of the flowing water is not altogether a disadvantage, however. Preliminary work on the boundary is best done when the water course is dry. The whole water course is then visible and safely accessible on foot for close examination. The lowest qualified banks are easily found in advance. Those most favorable can be marked and numbered for future reference. Using the first flowing water as a datum plane, the lowest qualified bank can be selected and marked as the basic point.

When the flowing water is likely to continue indefinitely, the gradient boundary should be located as heretofore explained. But if the flowing water is expected to be of short duration, the boundary may be located in the following manner. If the water is conveniently at hand and flowing steadily, the surface should be accurately and speedily marked with bench marks and guard stakes corresponding to the points to be set on the boundary. Later, when the water is out of the way, the gradient boundary can be located with the level directly from the bench marks. The vertical distance from the bench marks to the boundary is obtained from the basic point.

If there is no water in the water course, certain water marks of recent origin may be used in lieu of the water. When the water stops rising, flows steadily onward for a time, and then recedes, it usually leaves behind it a well defined line or trace upon the ground. This line is a gradient of the flowing water. It consists mainly of small fluvial deposits of scum, silt, sand, drift, and litter which temporarily are easily recognized and followed. From these remaining water marks, the surface of the flowing water can be recovered and marked with bench marks and guard stakes. The gradient boundary is located with the level directly from these bench marks, using the appropriate vertical distance obtained from the basic point as in the first instance. When the water marks are clearly identified, the resulting position of the gradient boundary is sufficiently accurate for all ordinary purposes. River gages are not necessary in either case since the boundary is to be located directly from the bench marks and not from the fluctuating surface of the flowing water in the river.

Stages of the flowing water materially above the top or below the bottom of the boundary bank at the basic point are not suitable for locating the gradient boundary. Flood stages for that purpose were automatically eliminated by the Court in Oklahoma v. Texas.