MEASUREMENT OF FLOWS FOR TWO IRRIGATION DISTRICTS IN THE LOWER COLORADO RIVER BASIN, TEXAS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96–4225

Prepared in cooperation with the
BUREAU OF RECLAMATION,
LOWER COLORADO RIVER AUTHORITY, *and*
TEXAS WATER DEVELOPMENT BOARD

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Austin, Texas
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U.S. DEPARTMENT OF THE INTERIOR

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Abbreviations:

acre-ft, acre-foot
ft^3/s, cubic foot per second
ft, foot
ft/s, foot per second
in., inch
Mgal/d, million gallons per day

Measurement of Flows for Two Irrigation Districts in the Lower Colorado River Basin, Texas

By L.S. Coplin, Fred Liscum, Jeffery W. East, *and* Lee B. Goldstein

Abstract

The Lower Colorado River Authority sells and distributes water for irrigation of rice farms in two irrigation districts, the Lakeside district and the Gulf Coast district, in the lower Colorado River Basin of Texas. In 1993, the Lower Colorado River Authority implemented a water-measurement program to account for the water delivered to rice farms and to promote water conservation. During the rice-irrigation season (summer and fall) of 1995, the U.S. Geological Survey measured flows at 30 sites in the Lakeside district and 24 sites in the Gulf Coast district coincident with Lower Colorado River Authority measuring sites. In each district, the Survey made essentially simultaneous flow measurements with different types of meters twice a day—once in the morning and once in the afternoon—at each site on selected days for comparison with Lower Colorado River Authority measurements. One-hundred pairs of corresponding (same site, same date) Lower Colorado River Authority and U.S. Geological Survey measurements from the Lakeside district and 104 measurement pairs from the Gulf Coast district are compared statistically and graphically. For comparison, the measurement pairs are grouped by irrigation district and further subdivided by the time difference between corresponding measurements—less than or equal to 1 hour or more than 1 hour. Wilcoxon signed-rank tests (to indicate whether two groups of paired observations are statistically different) on Lakeside district measurement pairs with 1 hour or less between measurements indicate that the Lower Colorado River Authority and U.S. Geological Survey measurements are not statistically different. The median absolute percent difference between the flow measurements is 5.9 percent; and 33 percent of the flow measurements differ by more than 10 percent. Similar statistical tests on Gulf Coast district measurement pairs with 1 hour or less between measurements indicate that the Lower Colorado River Authority and U.S. Geological Survey measurements are not statistically different. The median absolute percent difference between the flow measurements is 2.6 percent; and 30 percent of the flow measurements differ by more than 10 percent. The differences noted above between Lower Colorado River Authority and U.S. Geological Survey measurements with 1 hour or less between measurements and the differences between essentially simultaneous U.S. Geological Survey measurements are of similar orders of magnitude and, in some cases, very close.

INTRODUCTION

Background

Rice has been the most important agricultural product in Colorado, Wharton, and Matagorda Counties of south Texas since the late 1890s. Beginning in the 1920s, irrigation water from the Colorado River has been essential to rice producers in these counties. The Lower Colorado River Authority (LCRA) sells and distributes water to the rice producers in two LCRA-managed irrigation districts, the Lakeside district near Eagle Lake and the Gulf Coast district near Bay City. The water originates from the upstream Highland Lakes (fig. 1).

In 1993, the LCRA implemented a water-measurement program to quantify the water allocated from the Colorado River to the rice farms and to promote water conservation. The water-measurement program resulted from a 3-year study by the U.S. Department of the Interior, Bureau of Reclamation (BUREC) and the LCRA. The study evaluated the technical and economic feasibility of measuring water

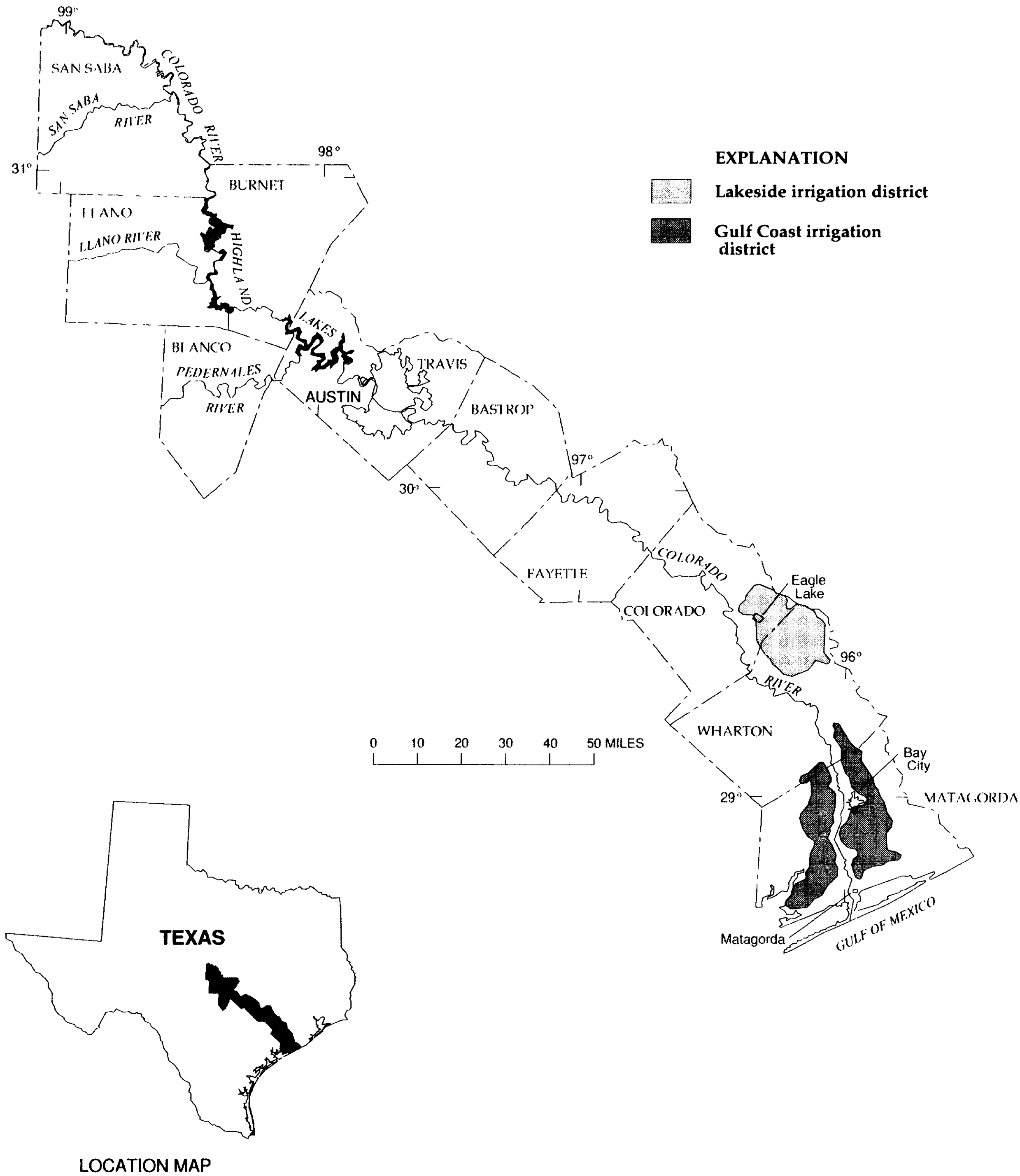

Figure 1. Lower Colorado River Authority irrigation districts.

delivered to individual rice farms. Field and laboratory studies were done to rate the accuracy of delivery structures. Based on the findings, a recommendation was made to implement a program to measure flow through existing farm-delivery structures and "develop a volumetric water rate that promotes the water conservation goals of the water management plan" (Bureau of Reclamation and Lower Colorado River Authority, 1992, p. 5). The LCRA, with assistance from the BUREC, developed methods and techniques to measure the volumetric flow delivered for field irrigation to each individual producer.

Rice producers have questioned the accuracy of the reported volumes of irrigation water delivered, and thus whether the LCRA is providing the water for which the rice producers are being charged. An unbiased assessment of the methods and techniques of flow measurement used by the LCRA was needed to bolster confidence in the water-measurement program and to help in the development of water-conservation practices.

This study was designed to provide information that can be used to assess the accuracy of the water-measurement program. Measurement accuracy should foster the use of only the amount of water needed for irrigation of crops, thus resulting in water conservation. The study was done by the U.S. Geological Survey (USGS) in cooperation with the Bureau of Reclamation, Lower Colorado River Authority, and Texas Water Development Board during the rice-irrigation season (summer and fall) of 1995. The work is a part of the Edwards Aquifer General Investigation administered and directed by BUREC.

Purpose and Scope

The purpose of this report is to document and compare LCRA and USGS measurements of irrigation flow at selected sites in the water-distribution systems of the Lakeside and Gulf Coast irrigation districts.

One-hundred LCRA-USGS flow-measurement pairs from 30 sites in the Lakeside district and 104 LCRA-USGS flow-measurement pairs from 24 sites in the Gulf Coast district are compiled and the differences in measurements characterized statistically and shown graphically.

Previous Related Work

USGS personnel accompanied LCRA personnel to both irrigation districts in October 1994. USGS personnel observed and documented measurement techniques and associated activities.

Before the 1995 irrigation season, 14 Global Flow Probe meters owned and used by the LCRA to measure flow in the two irrigation districts were tested at the USGS Hydrologic Instrumentation Facility in Stennis Space Center, Miss., for accuracy in the range of velocities encountered in water-delivery structures of the districts. The meters were tested at five velocities ranging from 0.243 to 0.451 ft/s (K.G. Thibodeaux, U.S. Geological Survey, written commun., 1995). In 70 to 100 percent of the tests at each velocity, the LCRA meters indicated velocities that were lower than the actual velocities. In the majority of the tests in which the meter-indicated velocities were lower than the actual velocities, the meter-indicated velocities were not within 25 percent of the actual velocities.

Description of Study Area

Physical Setting

The lower basin of the Colorado River begins northwest of Austin and ends at the Gulf of Mexico near Matagorda (fig. 1). The reservoirs on the Colorado River operated by LCRA, known collectively as the Highland Lakes, provide more than 2.3 million acre-ft of storage capacity (Bureau of Reclamation and Lower Colorado River Authority, 1992, p. 5). This storage capacity is used primarily for water supplies and to provide water for hydropower production.

The LCRA-Gulf Coast Division allows up to 7 days for water released for irrigation from the Highland Lakes to flow downstream to diversion pumps. An additional 2 days is needed for releases to reach the farm delivery structures (Bureau of Reclamation and Lower Colorado River Authority, 1992, p. 5).

Irrigation Districts

A private water-distribution company, the Lakeside Irrigation Company, was purchased by the LCRA in 1983 and became the LCRA-Lakeside Division. The Lakeside Division oversees the Lakeside irrigation district, in which as much as 28,500 acres in Colorado and northern Wharton Counties are irrigated annually. At maximum flow, the Lakeside Division diverts 456 Mgal/d of water from the river. Each of the six operating sections in the Lakeside district is managed by one LCRA irrigation coordinator (Mike Shoppa, Lower Colorado River Authority, written commun., 1994).

The Gulf Coast irrigation district, originally owned and operated by the Gulf Coast Water Company, was established in 1927 along the lower Colorado River in southern Wharton and Matagorda Counties. The company, purchased in 1960 by the LCRA, became the LCRA-Gulf Coast Division. The Gulf Coast Division directs the irrigation of up to 40,000 acres in the Gulf Coast district annually. The Gulf Coast irrigation district is divided into six operating sections, three on the east side of the Colorado River and three on the west side, each section managed by one LCRA irrigation coordinator (Henry Bradford, Lower Colorado River Authority, oral commun., 1994). Selected characteristics for the two districts are presented in table 1.

Two types of water-delivery structures—pipes and "water boxes"—transfer water from canals to individual farms. Water boxes are rectangular channels (most are concrete) with tongue-and-groove planks of wood to control flow (fig. 2). The water boxes have been "rated" so that flows can be determined from differences in water levels at the inflow and outflow ends of the structures. In the Lakeside district, an estimated 30 percent of the delivery structures are pipes and 70 percent are water boxes. In the Gulf Coast district, more than 80 percent of the delivery structures are pipes, and the remainder are water boxes.

Rice is grown on a rotation basis in both irrigation districts (table 1). The land is worked during fall and spring to prepare a seedbed and shape levees (fig. 3). Planting begins in mid-March. In the Lakeside district, rice is drilled in and fertilized. After the rice seedlings are established, fields are irrigated to facilitate the movement of fertilizer into the soil. In contrast, flooded fields are seeded by airplane in the Gulf Coast district. Following planting, fields in both districts are allowed to dry, then reflooded to maintain 3 to 5 in. of water to control weeds. The stage of growth dictates the level of water held. Water is drained for harvest of the first crop during July and August. Following harvest and establishment of new shoots from the root system, the fields usually are fertilized by airplane and reflooded to grow the second crop. Water again is maintained on the fields until drainage for harvest of the second crop in October. Levees are cut for drainage at the end of the growing season.

Rainfall can reduce the amount of irrigation water required to produce the crop if the rainfall comes at a time when it can be used (Griffin and others, 1984, p. 62). However, rainfall can adversely affect water conservation and (or) damage fields. Heavy rains on the flooded fields can break the levees or erode soil. Heavy rains during harvesting of the first crop in 1995 damaged many fields. Because fields must be level to hold a few inches of water, second cropping was minimal.

Acknowledgments

The USGS acknowledges the substantial contribution to the study by the rice producers in the Lakeside and Gulf Coast irrigation districts. The authors thank Ronald Gertson and members of the Lakeside Advisory Committee, and Haskell Simon and members of the Gulf Coast Advisory Committee, for their cooperation and assistance during the planning of this study. The authors also thank Mike Shoppa, Larry Harbers, and Randy Epps of the LCRA-Lakeside Division; Henry Bradford and Thomas Pivonka of the LCRA-Gulf Coast Division; and Kenneth Reid, USGS, Houston, Tex., for their assistance during collection of the data.

METHODS OF DATA COLLECTION AND INTERPRETATION

Lower Colorado River Authority Measurement of Flows

The flow of water through the water-delivery system "is controlled and operated by the judgment of . . ." the LCRA irrigation coordinators (Bureau of Reclamation and Lower Colorado River Authority, 1992, p. 5). The irrigation coordinators generally receive water orders from customers by telephone during early morning hours. "Normal operating procedures require that [the irrigation coordinators] make all changes in the morning" (Lower Colorado River Authority, 1994, p. 2). Irrigation coordinators change flow rates by varying the height of bulkheads in watercourses and opening and closing delivery structures. Also, irrigation coordinators are responsible for measuring the flow of water delivered to each field in their respective operating section. No quality-assurance/quality-control procedure is in effect for verification of field measurements.

During the study, irrigation coordinators generally measured flow once each day. Flow velocity through pipes was measured using the Global Flow Probe, a horizontal-axis meter. This meter provides an instantaneous velocity readout and displays a mean

Figure 2. A concrete water box with removable tongue-and-groove wood planks to control flow, Lakeside district.

Figure 3. A well-maintained levee system, Gulf Coast district.

Table 1. Selected characteristics for the Lakeside and Gulf Coast irrigation districts

[Source of information Lower Colorado River Authority, 1992; 1994. LCRA, Lower Colorado River Authority]

Fact	Lakeside	Gulf Coast
Origination		
Company	Lakeside Irrigation Company	Gulf Coast Water Company
Date	1911	1927
Date purchased by LCRA	1983	1960
Number employed by LCRA (1995)	23	25
Serviceable area		
square miles	217	360
acres	152,000	252,166
Rotation period for rice planted	3 to 4 years	2 to 3 years
Method of seeding fields	Drilling	Flying
Date LCRA begins pumping	April 1	March 15
Number of acres LCRA can irrigate annually	28,500	40,000
Number of miles of mainline canals and laterals	275	360
Location of pumping plants		
Plant #1	River Plant (primary lift)	East-Bay City (primary lift)
Plant #2	Prairie Plant (secondary lift)	East-Lane City (primary lift)
Plant #3	Lake Plant (secondary lift)	West (primary lift)
Pumping capacity, in gallons per minute		
Plant #1	24,000–79,000	80,000
Plant #2	25,000–56,000	260,000
Plant #3	27,000–60,000	240,000
Total lift from pumping plants, in feet		
Plant #1	28	22.5
Plant #2	32	30
Plant #3	32	22
Relifts	Two tertiary lifts which relift the water 10 additional feet	None

velocity for a cross section. The irrigation coordinators record the mean velocity. Flow through pipes was determined from velocities using a computer program. The computer program, developed and supported by BUREC, is known as "LCRAWMAN" (King and Kabir, 1991). Specifically, LCRAWMAN computes volumes of water furnished to individual delivery structures during specified periods; it also computes monetary charges applicable to volumes of water furnished.

Flow through water boxes was computed, also using LCRAWMAN, on the basis of the difference in water levels between the inflow and outflow ends of a box. The method requires the areal dimensions of the flow face of the box and assumes a water-tight seal around the flow-controlling planks. Leakage associated with the planks will affect the accuracy of the results of the flow computation. Errors in field measurement or computer entry of the areal dimensions can result in repeated computational errors of flow.

U.S. Geological Survey Measurement of Flows

Thirty sites in the Lakeside district (12 pipes and 18 water boxes) and 24 sites in the Gulf Coast district (all pipes) were selected for USGS flow measurements (figs. 4, 5). The sites, located at delivery points into irrigated fields, were coincident with LCRA measuring sites so that pairs of corresponding (same site, same date) LCRA and USGS measurements could be compared. Reference points were established at each site to determine water levels relative to an arbitrary datum. Relative stages were determined before and after flow measurements to determine if the flow was steady during the measurements. (Steady flow prevailed during all USGS measurements.)

Three types of flowmeters were used: The Price pygmy (for water depths less than 2.5 ft) or Price type AA (for water depths greater than 2.5 ft), the Marsh McBirney Flo-Mate 2000, and the Global Flow Probe as used by LCRA irrigation coordinators (fig. 6). The Price meters are vertical-axis mechanical flow-driven meters. Price meters have been the meters most commonly used by the USGS for many years. The Marsh McBirney meter uses an electromagnetic sensor rather than rotating cups to measure flow velocity. The Price and Marsh McBirney meters provided the measurements for comparison with the LCRA measurements. The Global Flow Probe measurements were made to determine whether the Global Flow Probe provides measurements that are not substantially different from measurements made with the types of meters used by the USGS.

The three-point method (Rantz and others, 1982, p. 135) was used for measuring velocities at pipes. Observations were made at 0.2, 0.6, and 0.8 of the depth below the water surface at the mid (lateral) section of the pipe. The mean of the 0.2- and 0.8-depth observations was determined; the mean of that value and the 0.6-depth observation was used as the mean velocity for the measurement.

The midsection method was used to measure velocities in water boxes. At least 10 observations of depth and velocity were measured in each box. The depth of flow was determined using a top-setting wading rod, and velocities were measured as appropriate on the basis of flow depth—at 0.2 and 0.8 of the depth below the water surface (two-point method) or at 0.6 of the depth below the water surface (0.6-depth method) (Rantz and others, 1982, p. 134).

Although the USGS takes great care to ensure that all of its flow measurements are as accurate as practical, inevitably some error is associated with each measurement. The error originates from one or more of three sources—the person making the measurement, through improper technique or data transcription; the meter; and the field conditions.

The USGS measured flow twice a day—once in the morning and once in the afternoon—at each site on selected days with the Price and Marsh McBirney meters, and usually the Global Flow Probe. Essentially simultaneous measurements with the different meters for each date and time at each site were made so that a morning and an afternoon USGS measurement would be available for comparison to each LCRA daily measurement; and to provide information on the variability in daily flows.

The LCRA provided their daily flow measurements for the same sites and dates as the USGS measurements, including copies of all field sheets used by the irrigation coordinators to record measurement data. No meter identification or meter calibration information was included.

Comparing Differences Between Flow Measurements

As expected, essentially simultaneous USGS measurements with the three meters differ. The differences between simultaneous USGS Price and USGS Marsh McBirney measurements are described by median absolute percent differences and the percent of the paired measurements that differ by more than 10 percent.

Differences between the USGS Price and USGS Marsh McBirney measurements could relate to the fact that the Price meter is mechanical and the Marsh McBirney is electromagnetic; or they could be unrelated to meter type, the same as if measurements from two Price meters were being compared (J.M. Fulford, U.S. Geological Survey, oral commun., 1996). Trying to account for the differences and thus determine which of the meters yields measurements closer to the actual discharge is not possible because the actual discharge is unknown. Researchers at the USGS Hydrologic Instrumentation Facility have tested the Price and Marsh

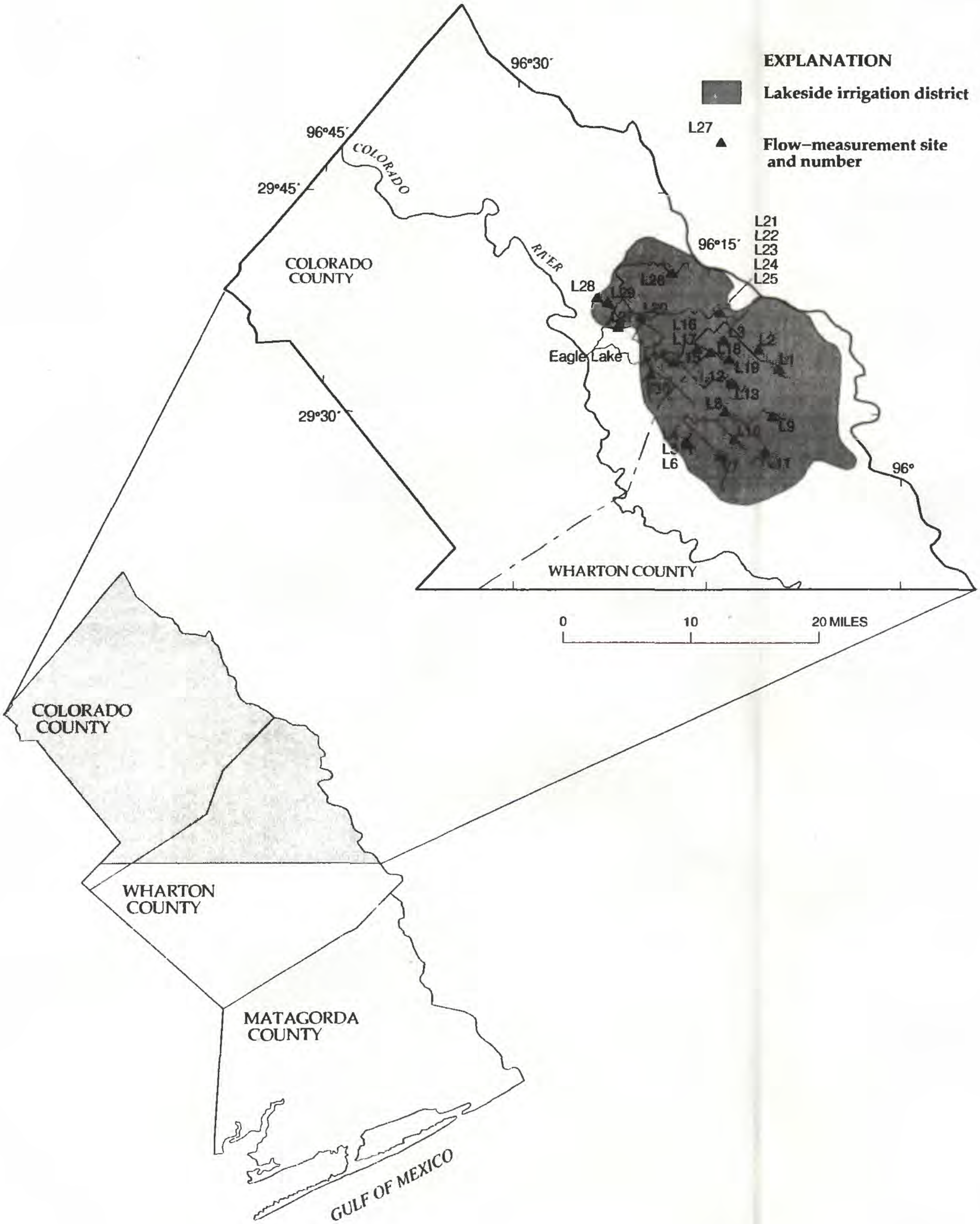

Figure 4. Flow-measurement sites in the Lakeside irrigation district.

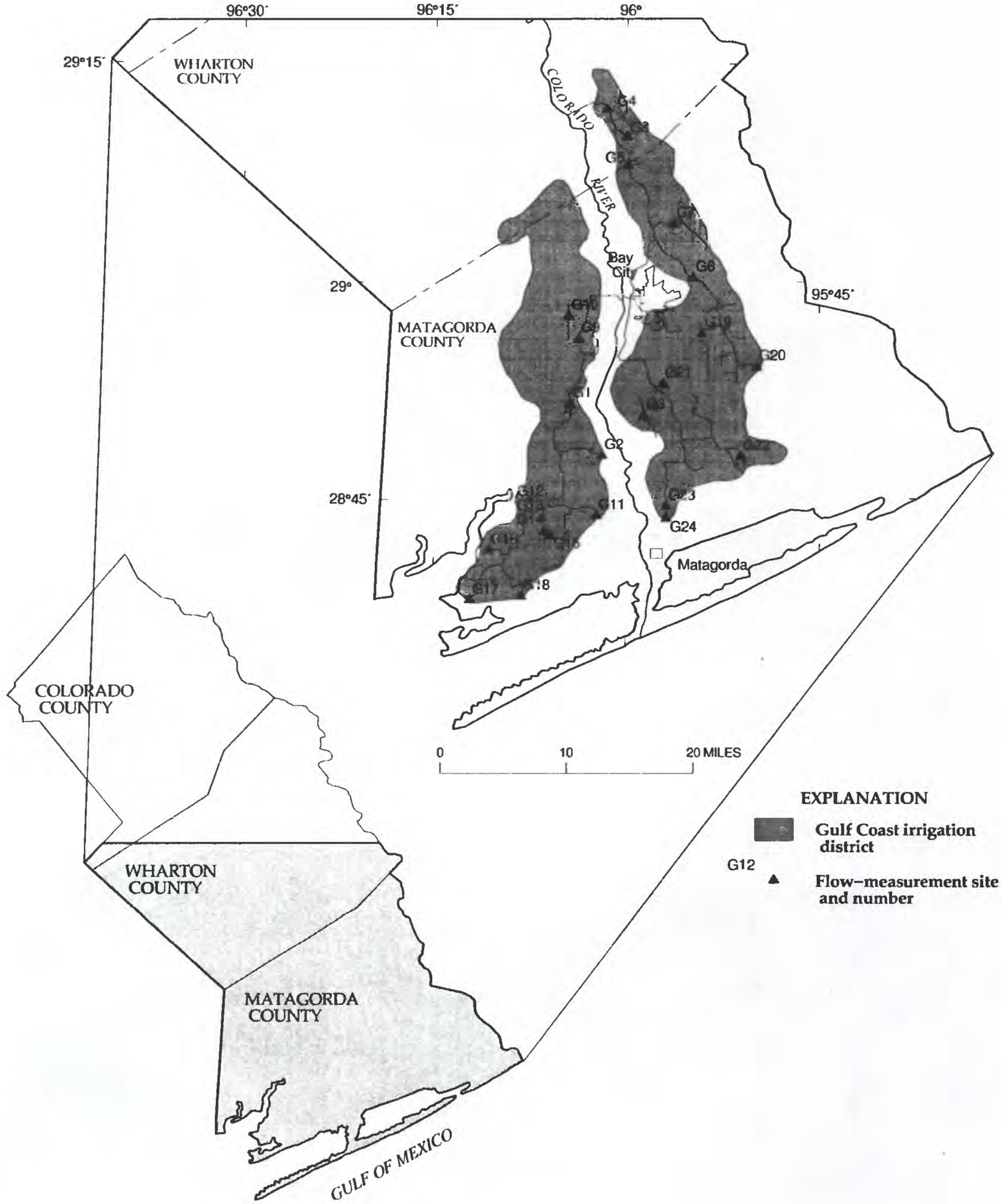

Figure 5. Flow-measurement sites in the Gulf Coast irrigation district.

(a)

(b)

(c)

Figure 6. Flow being measured with (a) a Price pygmy meter, Gulf Coast district; (b) a Marsh McBirney Flo-Mate 2000 meter, Lakeside district; and (c) a Global Flow Probe meter, Lakeside district.

McBirney meters extensively and concluded that there is no "best" current meter for field measurements (K.G. Thibodeaux, U.S. Geological Survey, written commun., 1996). Accordingly, the decision was made to use the mean of the Price and Marsh McBirney measurements for comparison with the LCRA measurements; and also for comparison with USGS Global Flow Probe measurements.

Daily fluctuations in water levels in the irrigation canals are observed. The morning and afternoon measurements made by the USGS at each of its selected sites on selected dates provides information on the variability in daily flows. For the two irrigation districts, the absolute percent differences between the USGS-measured morning and afternoon flows were computed and frequency histograms of the absolute percent differences constructed.

For comparison, the LCRA and USGS flow measurements were grouped by the LCRA district in which they were made. For comparisons within each of the two districts, measurements were grouped according to the time difference between corresponding (same site, same date) measurements—time difference less than or equal to 1 hour or time difference more than 1 hour. In the Lakeside district, the groups based on time difference were further subdivided on the basis of structure type—pipe measurements or water-box measurements—for selected comparisons.

Statistical and graphical means are used to compare LCRA and USGS flow measurements. The principal method for statistical comparison is the Wilcoxon matched-pairs signed-rank test (Helsel and Hirsch, 1992, p. 142). The signed-rank test (a 2-sided hypothesis test in this study) provides an objective way to determine whether two groups in which there is a logical pairing of observations within each group are statistically different. The test result is based on whether the differences between paired observations are symmetrically distributed about zero; the magnitudes of the differences do not influence the test. The test works as follows: A hypothesis is made that the two groups are not statistically different; then the statistical test is run. The result of interest from the test is the "p-value." We decide whether the LCRA and USGS measurements are statistically different on the basis of the p-value. If the p-value from the test is greater than a predetermined value (α-value), we accept the hypothesis that the measurements are not different because the evidence is not strong enough for us to conclude otherwise. If the p-value from the test is less than the α-value, we reject the hypothesis that the measurements are not different because the evidence is strong enough for us to do so. Commonly used α-values are .01, .05, .1, and .2; we chose an α-value of .05, which requires that we are 95-percent certain before we conclude that the measurements are different. Thus, if we conclude that the LCRA and USGS measurements are statistically different on the basis of a p-value less than .05, we are at least 95-percent certain that they are different.

The p-value indicates the strength of the evidence against the hypothesis that the measurements are not statistically different—the smaller the p-value, the stronger the evidence. Accordingly, p-values are documented in the report to allow the reader to judge the strength of the evidence against the hypothesis that the measurements are not statistically different.

The differences between paired LCRA and USGS measurements are further described by median absolute percent differences and the percent of the paired measurements that differ by more than 10 percent. Scatterplots and frequency histograms are used to show the relations between LCRA and USGS measurements. The scatterplots comprise LCRA-USGS measurement pairs plotted as points based on the respective magnitudes of flow. The histograms show the distribution of percent differences between paired measurements by percentile.

Water-Balance Measurements

A water-budget method for determining water volumes delivered to irrigated fields was applied. The method involved measurement of total inflows and outflows to and from a selected reach in each irrigation district for a period of time. Water-level recorders were placed at the entrance and exit of each selected reach and at each delivery structure in the reach to quantify the volume of water entering and leaving the reach during a period.

Water levels at the entrance and exit of a reach and all outflow structures were recorded at 1-hour intervals using wet pressure transducers and data loggers. Stage-discharge relations were developed for each structure to compute flows from corresponding recorded water levels. These data would be used to compute flow volumes into and out of each reach. The subsequent data then would be analyzed to compare the volume of water available at the reach entrance to the volume applied to the irrigated fields.

The method requires an accurate determination of flow entering and leaving each reach. Thus, accurate measurements of water levels are necessary. After processing the recorded water-level data and comparing these data to observed water levels, it was determined that the pressure readings sensed by the transducers and recorded by the data loggers tended to "drift" from actual values. Because of inadequate water-level data, accurate water budgets for the reaches could not be developed for the study period.

COMPARISONS BETWEEN U.S. GEOLOGICAL SURVEY FLOW MEASUREMENTS

Of the 100 Price-Marsh McBirney measurement pairs in the Lakeside district, 69 percent of the Marsh McBirney measurements are larger than the Price measurements; the median absolute difference is 3.0 percent, and 24 percent of the paired measurements differ by more than 10 percent.

If the Lakeside measurement pairs are grouped by structure type, comparison of Marsh McBirney pipe measurements with Price pipe measurements shows that, of the 50 pipe-measurement pairs, 88 percent of the Marsh McBirney measurements are larger than the Price measurements; the median absolute difference is 2.3 percent, and 18 percent of the measurement pairs differ by more than 10 percent; the maximum absolute difference is 27 percent.

Comparison of Marsh McBirney water-box measurements with Price water-box measurements in the Lakeside district shows that, of the 50 water-box-measurement pairs, 50 percent of the Marsh McBirney measurements are larger than the Price measurements; the median absolute difference is 4.3 percent, and 30 percent of the measurement pairs differ by more than 10 percent; the maximum absolute difference is 110 percent (which is anomalously large and undoubtedly due to error in one or both measurements).

In the Gulf Coast district, where all measurements are pipe measurements, Price-Marsh McBirney measurement differences are consistent with those of Lakeside district pipe measurements. Of the 104 pipe-measurement pairs, 88 percent of the Marsh McBirney measurements are larger than the Price measurements; the median absolute difference is 1.8 percent, and 5.8 percent of the paired measurements differ by more than 10 percent; the maximum absolute difference is 27 percent.

Although in both districts most of the Marsh McBirney pipe measurements are larger than the Price pipe measurements, the differences generally are small. The Marsh McBirney water-box measurements in the Lakeside district are not mostly larger or smaller than the Price water-box measurements; however, the differences generally are larger than those of the pipe-measurement pairs.

No substantial differences between the USGS measurements made with the Global Flow Probe and those made with the Price and Marsh McBirney meters occurred. Sixty-two of the 100 same-date, same-time measurements in the Lakeside district include Global Flow Probe measurements. Forty-seven percent of the USGS Global Flow Probe measurements are larger than the mean of the corresponding Price and Marsh McBirney measurements. The median absolute difference between the USGS Global Flow Probe measurements and the mean of the corresponding Price and Marsh McBirney measurements is 6.0 percent; 34 percent of the pairs differ by more than 10 percent.

All but 1 of the 104 same-date, same-time measurements in the Gulf Coast district included Global Flow Probe measurements. Fifty-three percent of the USGS Global Flow Probe measurements are larger than the mean of the corresponding Price and Marsh McBirney measurements. The median absolute difference between the USGS Global Flow Probe measurements and the mean of the Price and Marsh McBirney measurements is 4.2 percent; 17 percent of the pairs differ by more than 10 percent.

The comparisons between USGS flow measurements by irrigation district are summarized below:

	Lakeside district	Gulf Coast district
Differences between USGS Price and USGS Marsh McBirney		
Median absolute percent difference	3.0	1.8
Percent of differences greater than 10 percent	24	5.8
Differences between USGS Global Flow Probe and USGS Price-USGS Marsh McBirney mean		
Median absolute percent difference	6.0	4.2
Percent of differences greater than 10 percent	34	17

For the Lakeside district, the median absolute difference between the morning and afternoon flows[1] is 7.0 percent. The histogram of absolute percent differences (fig. 7) indicates that 62 percent of the morning and afternoon flows (31 of 50 paired measurements) differ by 10 percent or less; and 38 percent differ by more than 10 percent. The maximum absolute difference is 99 percent.

For the Gulf Coast district, the median absolute difference between the morning and afternoon flows is 8.6 percent. The histogram of absolute percent differences (fig. 8) indicates that 54 percent of the morning and afternoon flows (28 of 52 paired measurements) differ by 10 percent or less; and 46 percent differ by more than 10 percent. The maximum absolute difference is 153 percent.

COMPARISON OF LOWER COLORADO RIVER AUTHORITY AND U.S. GEOLOGICAL SURVEY FLOW MEASUREMENTS

Fifty daily LCRA flow measurements and the corresponding morning and afternoon USGS measurements are shown for the Lakeside district in table 2 (at end of report). The measurements are evenly split between pipe and water-box structures. Fifty-two daily LCRA flow measurements and the corresponding morning and afternoon USGS measurements are shown for the Gulf Coast district in table 3 (at end of report). The measurements are all pipe measurements.

Lakeside District

All Measurement Pairs

If all 100 LCRA-USGS measurement pairs in the Lakeside district are grouped without regard to time difference or structure type, the conclusion from the signed-rank test is that the LCRA and USGS measurements are not statistically different. This conclusion is based on the fact that the p-value = .0602 (table 4). The p-value is close to the critical value of .05, which indicates fairly strong evidence that the measurements are different; but not strong enough to declare them different on the basis of our decision criterion. The median absolute difference between paired measurements is 8.1 percent. The scatterplot of all measurement pairs (fig. 9) shows more points above the line of equal value than below it for flows greater than about 4 ft^3/s, indicating that more of the LCRA measurements are larger than the corresponding USGS measurements among the higher flows. Among the 100 measurement pairs, the LCRA measurement is larger than the USGS measurement in 63 percent of the pairs (table 4). Forty-four percent of the paired measurements differ by more than 10 percent: In 27 of the 100 measurement pairs, the LCRA measurement is more than 10 percent greater than the USGS measurement; and in 17 of the 100 pairs, the USGS measurement is more than 10 percent greater than the LCRA measurement (fig. 10).

If the 100 measurement pairs are grouped by structure type, the signed-rank test on the 50 pairs of pipe measurements does not yield evidence strong enough to conclude that the measurements are different (p-value = .4174) (table 4). The signed-rank test on the 50 pairs of water-box measurements yields considerably stronger evidence that the measurements are different but not strong enough to declare them different on the basis of our decision criterion (p-value = .0681) (table 4). The median absolute difference between paired pipe measurements is 7.4 percent; and the median absolute difference between paired water-box measurements is 9.0 percent.

Measurement Pairs with 1 Hour or Less Between Measurements

If the subset of 24 measurement pairs with 1 hour or less between measurements are grouped without regard to structure type, the signed-rank test yields little evidence that the measurements are different (p-value = .7971) (table 4). The median absolute difference between paired measurements is 5.9 percent. The scatterplot of measurement pairs with measurements less than or equal to 1 hour apart appears generally symmetrical about the line of equal value throughout the range of flows (fig. 11), although the LCRA measurement is larger than the USGS measurement in 63 percent of the 24 measurement pairs (table 4). Thirty-three percent of the paired measurements differ by more than 10 percent: In 3 of the 24 measurement pairs, the LCRA measurement is more than 10 percent greater than the USGS measurement; and in 5 of the 24 pairs, the USGS measurement is more than 10 percent greater than the LCRA measurement (fig. 12).

If the 24 measurement pairs are grouped by structure type, signed-rank tests on the 13 pairs of pipe measurements and 11 pairs of water-box measurements also

[1]Flow is mean of Price and Marsh McBirney measurements.

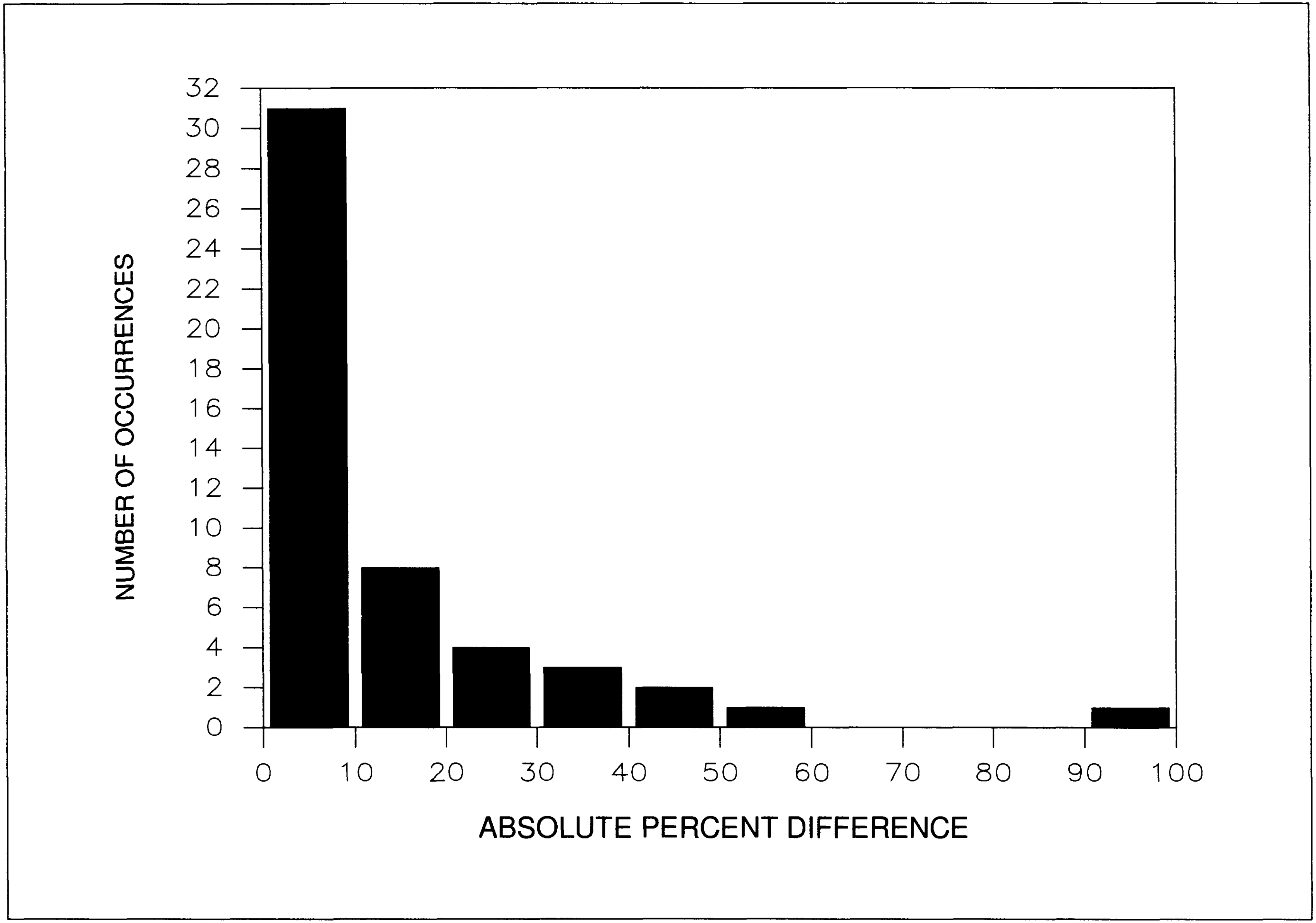

Figure 7. Histogram of absolute percent differences between U.S. Geological Survey-measured morning and afternoon flows, Lakeside district.

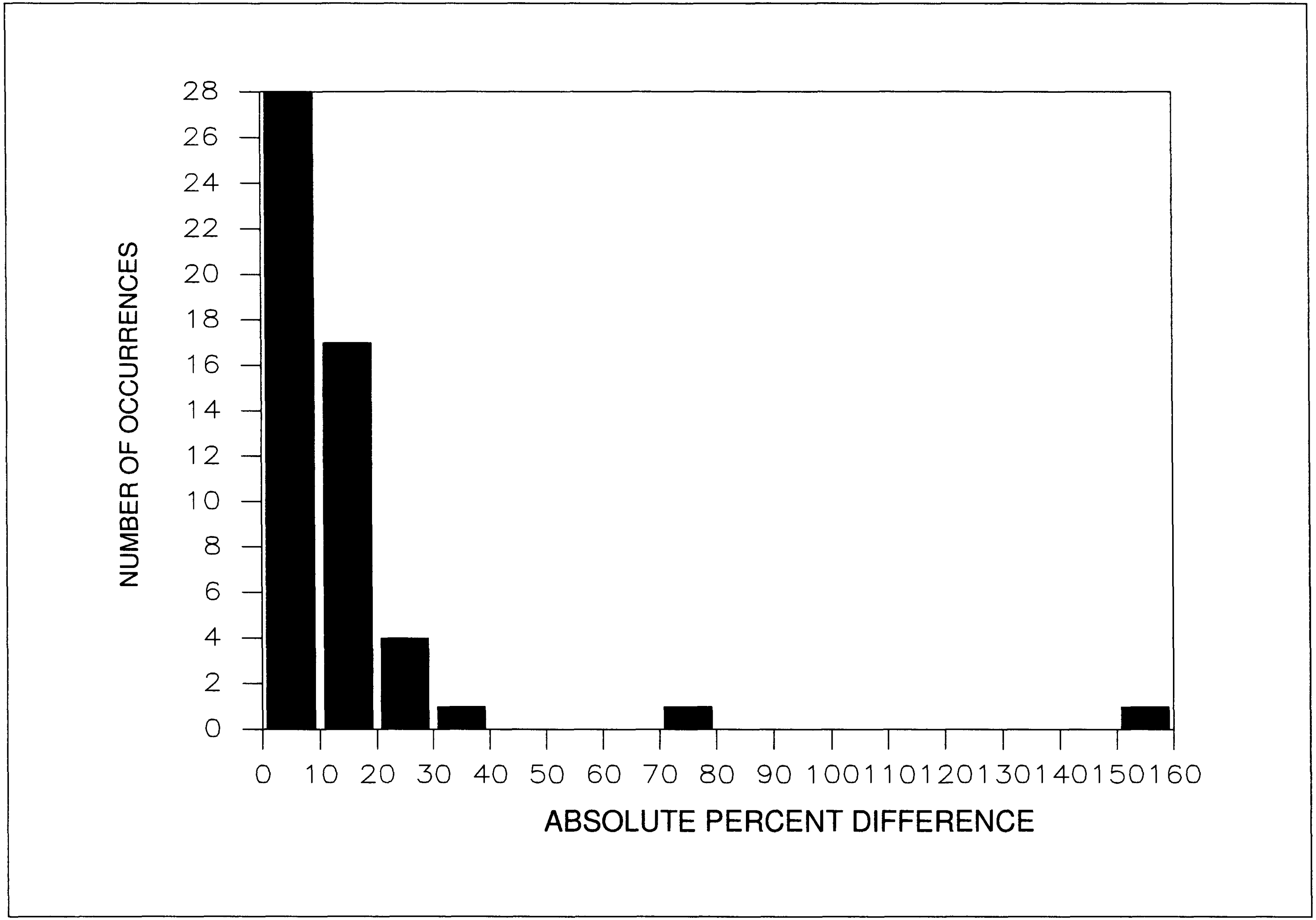

Figure 8. Histogram of absolute percent differences between U.S. Geological Survey-measured morning and afternoon flows, Gulf Coast district.

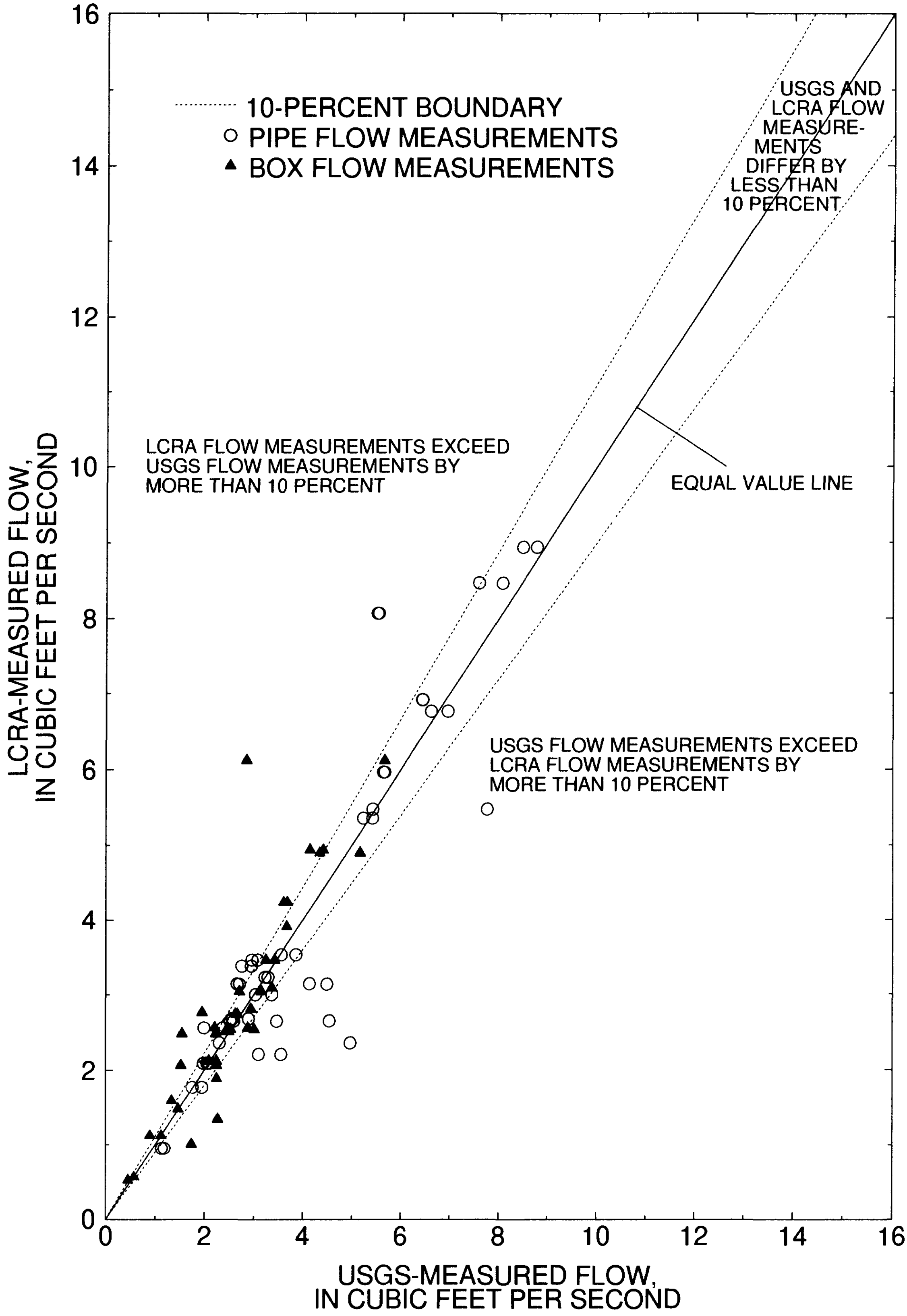

Figure 9. Relation between all Lower Colorado River Authority and U.S. Geological Survey flow measurements, Lakeside district.

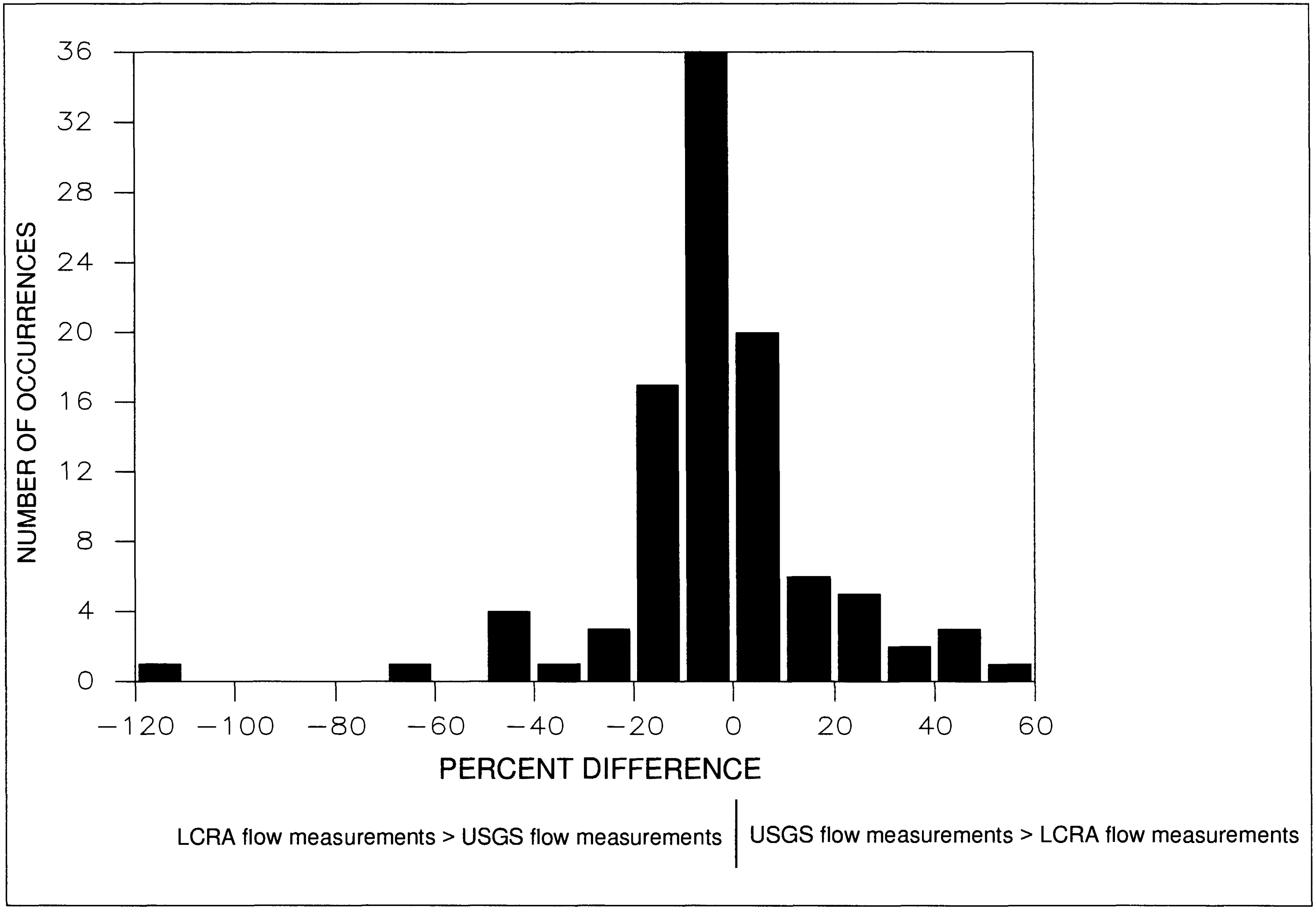

Figure 10. Histogram of percent differences between all Lower Colorado River Authority and U.S. Geological Survey flow measurements, Lakeside district.

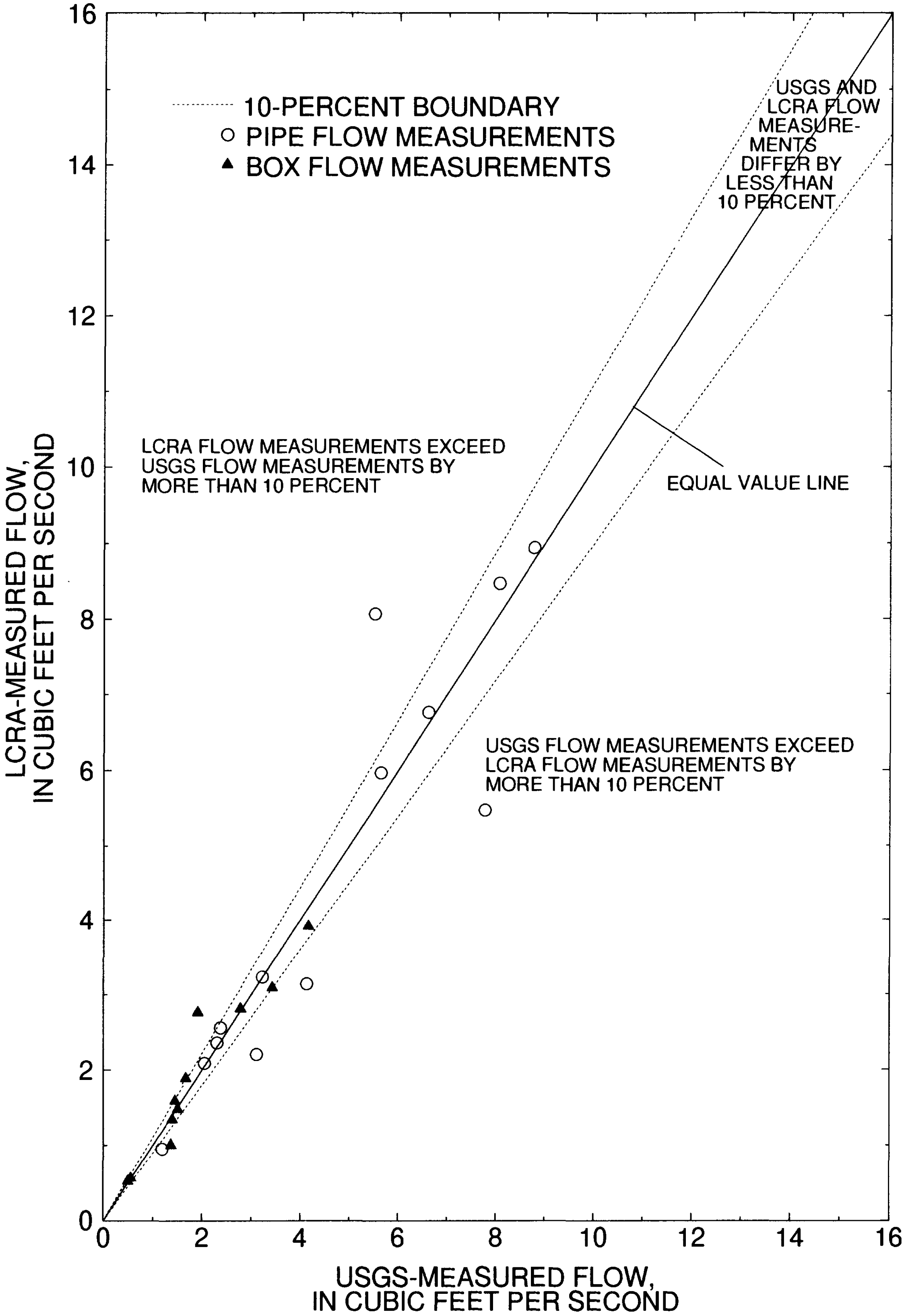

Figure 11. Relation between Lower Colorado River Authority and U.S. Geological Survey flow measurements made 1 hour or less apart, Lakeside district.

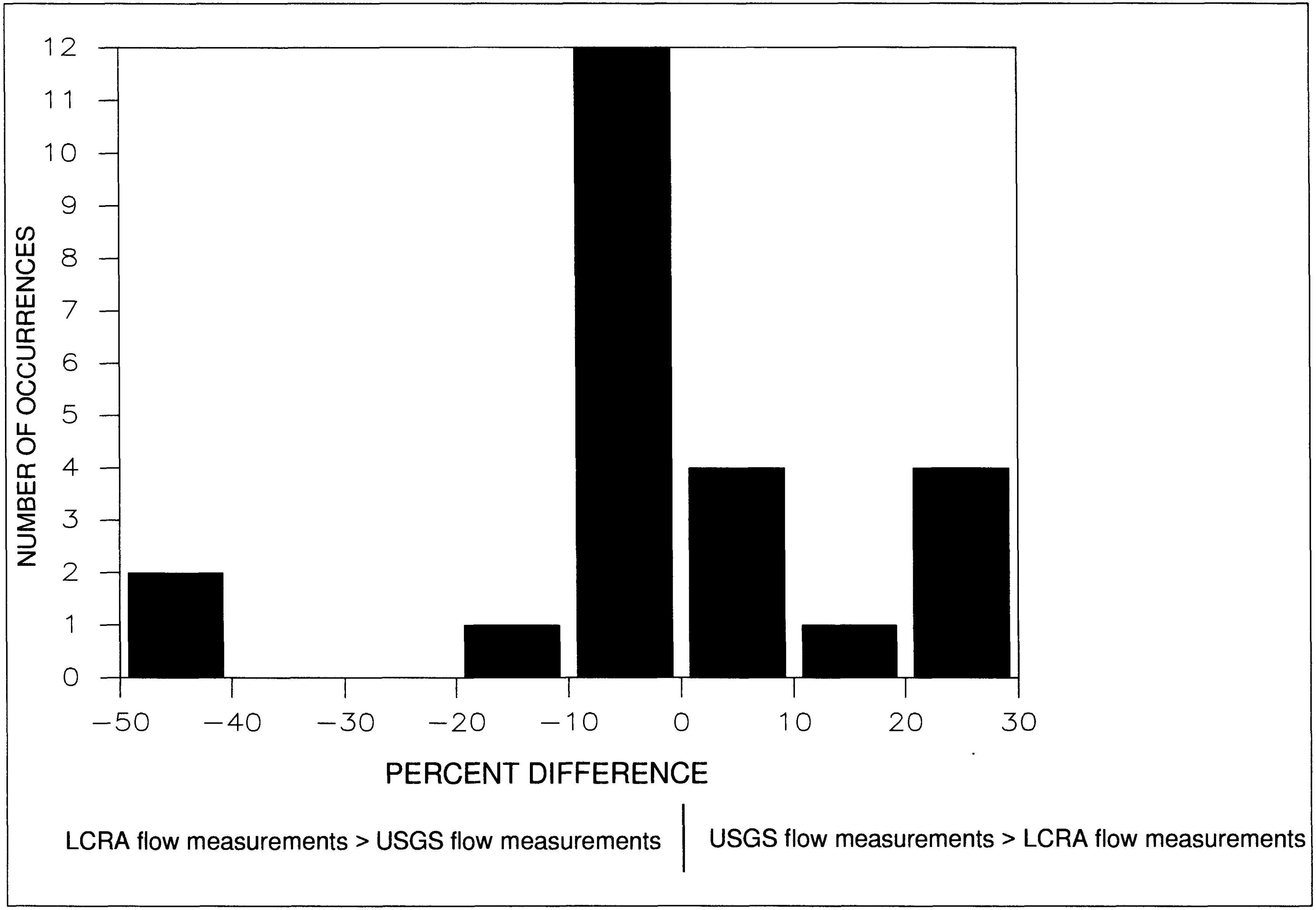

Figure 12. Histogram of percent differences between Lower Colorado River Authority and U.S. Geological Survey flow measurements made 1 hour or less apart, Lakeside district.

Table 4. Summary of statistical comparisons between Lower Colorado River Authority and U.S. Geological Survey flow measurements for the Lakeside irrigation district

[LCRA, Lower Colorado River Authority; USGS, U.S. Geological Survey; --, not computed]

	All measurements	Pipe measurements	Water-box measurements
All measurement pairs:			
Number of LCRA-USGS measurement pairs	100	50	50
p-value	.0602	.4174	.0681
Are paired measurements statistically different?	No	No	No
Median absolute percent difference between paired measurements	8.1	7.4	9.0
Percent of LCRA-USGS measurement pairs in which LCRA measurement is larger than USGS measurement	63	60	66
Percent of LCRA-USGS measurement pairs in which measurements differ by more than 10 percent	44	--	--
Measurement pairs with 1 hour or less between measurements:			
Number of LCRA-USGS measurement pairs	24	13	11
p-value	.7971	.7268	.9291
Are paired measurements statistically different?	No	No	No
Median absolute percent difference between paired measurements	5.9	5.9	6.0
Percent of LCRA-USGS measurement pairs in which LCRA measurement is larger than USGS measurement	63	--	--
Percent of LCRA-USGS measurement pairs in which measurements differ by more than 10 percent	33	--	--
Measurement pairs with more than 1 hour between measurements:			
Number of LCRA-USGS measurement pairs	76	37	39
p-value	.0446	.4110	.0475
Are paired measurements statistically different?	Yes	No	Yes
Median absolute percent difference between paired measurements	8.5	7.5	11.1
Percent of LCRA-USGS measurement pairs in which LCRA measurement is larger than USGS measurement	63	--	--
Percent of LCRA-USGS measurement pairs in which measurements differ by more than 10 percent	47	--	--

yield little evidence that the measurements in those subsets are different (p-value = .7268 and .9291, respectively) (table 4). The median absolute difference between paired pipe measurements is 5.9 percent; and the median absolute difference between paired water-box measurements is 6.0 percent.

Measurement Pairs with More Than 1 Hour Between Measurements

If the subset of 76 measurement pairs with more than 1 hour between measurements are grouped without regard to structure type, the evidence from the signed-rank test is strong enough to conclude that the measurements are statistically different (p-value = .0446) (table 4). The median absolute difference between paired measurements is 8.5 percent. The scatterplot of measurement pairs with measurements more than 1 hour apart (fig. 13) is similar to the scatterplot of all measurement pairs (fig. 9); which is not surprising, as about three-fourths of all measurement pairs are separated by more than 1 hour. The scatterplot of figure 13, like that of figure 9, shows that more of the LCRA measurements are larger than the corresponding USGS measurement for flows greater than about 4 ft^3/s. Among the 76 measurement pairs in this subset, the LCRA measurement is larger than the USGS measurement in 63 percent of the pairs (table 4). Forty-seven percent of the paired measurements differ by more than 10 percent: In 24 of the 76 measurement pairs, the LCRA measurement is more than 10 percent greater than the USGS measurement; and in 12 of the 76 pairs, the USGS measurement is more than 10 percent greater than the LCRA measurement (fig. 14).

If the 76 measurement pairs are grouped by structure type, the conclusions regarding statistical difference are mixed: The signed-rank test on the 37 pairs of pipe measurements does not yield evidence strong enough to conclude that the measurements are different (p-value = .4110) (table 4); whereas the signed-rank test on the 39 pairs of water-box measurements yields strong enough evidence to conclude that the measurements are different (p-value = .0475) (table 4). The median absolute difference between paired pipe measurements is 7.5 percent; and the median absolute difference between paired water-box measurements is 11.1 percent.

Gulf Coast District

All Measurement Pairs

If all 104 LCRA-USGS measurement pairs in the Gulf Coast district are grouped without regard to time difference, the conclusion from the signed-rank test is that the measurements are statistically different (p-value = .0300) (table 5). The median absolute difference between paired measurements is 7.5 percent. The scatterplot of all measurement pairs (fig. 15) shows more points are above the line of equal value than below it, indicating that more of the LCRA measurements are larger than the corresponding USGS measurements. Among the 104 measurement pairs, the LCRA measurement is larger than the USGS measurement in 63 percent of the pairs (table 5). Forty percent of the paired measurements differ by more than 10 percent: In 28 of the 104 measurement pairs, the LCRA measurement is more than 10 percent greater than the USGS measurement; and in 14 of the 104 pairs, the USGS measurement is more than 10 percent greater than the LCRA measurement (fig. 16).

Measurement Pairs with 1 Hour or Less Between Measurements

If the subset of 30 measurement pairs with 1 hour or less between measurements are grouped, the signed-rank test does not yield evidence strong enough to conclude that the measurements are different (p-value = .5716) (table 5). The median absolute difference between paired measurements is 2.6 percent. The scatterplot of measurement pairs with measurements less than or equal to 1 hour apart appears generally symmetrical about the line of equal value throughout the range of flows (fig. 17). The LCRA measurement is larger than the USGS measurement in 50 percent of the 30 measurement pairs (table 5). Thirty percent of the paired measurements differ by more than 10 percent: In 6 of the 30 measurement pairs, the LCRA measurement is more than 10 percent greater than the USGS measurement; and in 3 of the 30 pairs, the USGS measurement is more than 10 percent greater than the LCRA measurement (fig. 18).

Measurement Pairs with More Than 1 Hour Between Measurements

If the subset of 74 measurement pairs with more than 1 hour between measurements are grouped, the signed-rank test indicates that the measurements are

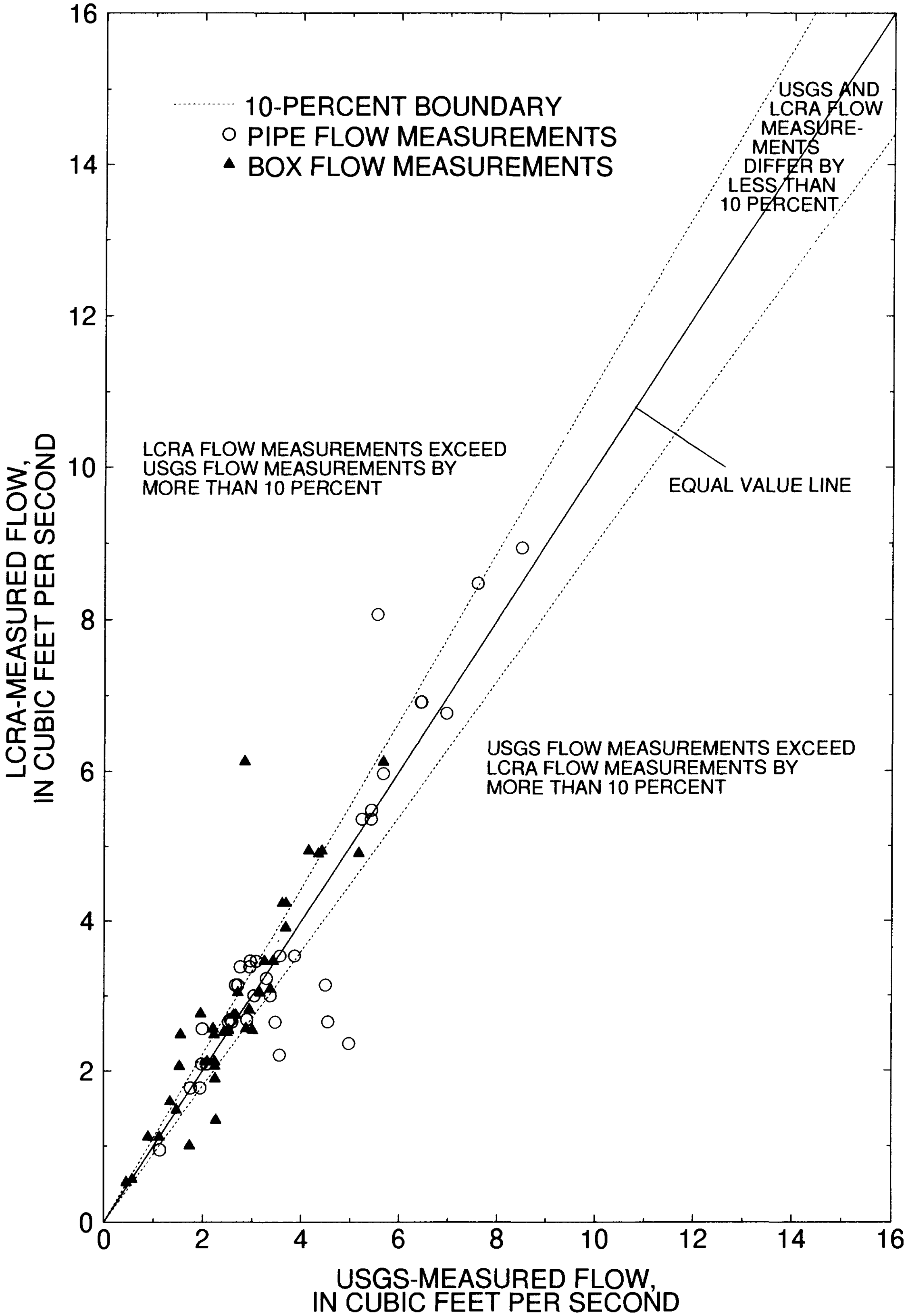

Figure 13. Relation between Lower Colorado River Authority and U.S. Geological Survey flow measurements made more than 1 hour apart, Lakeside district.

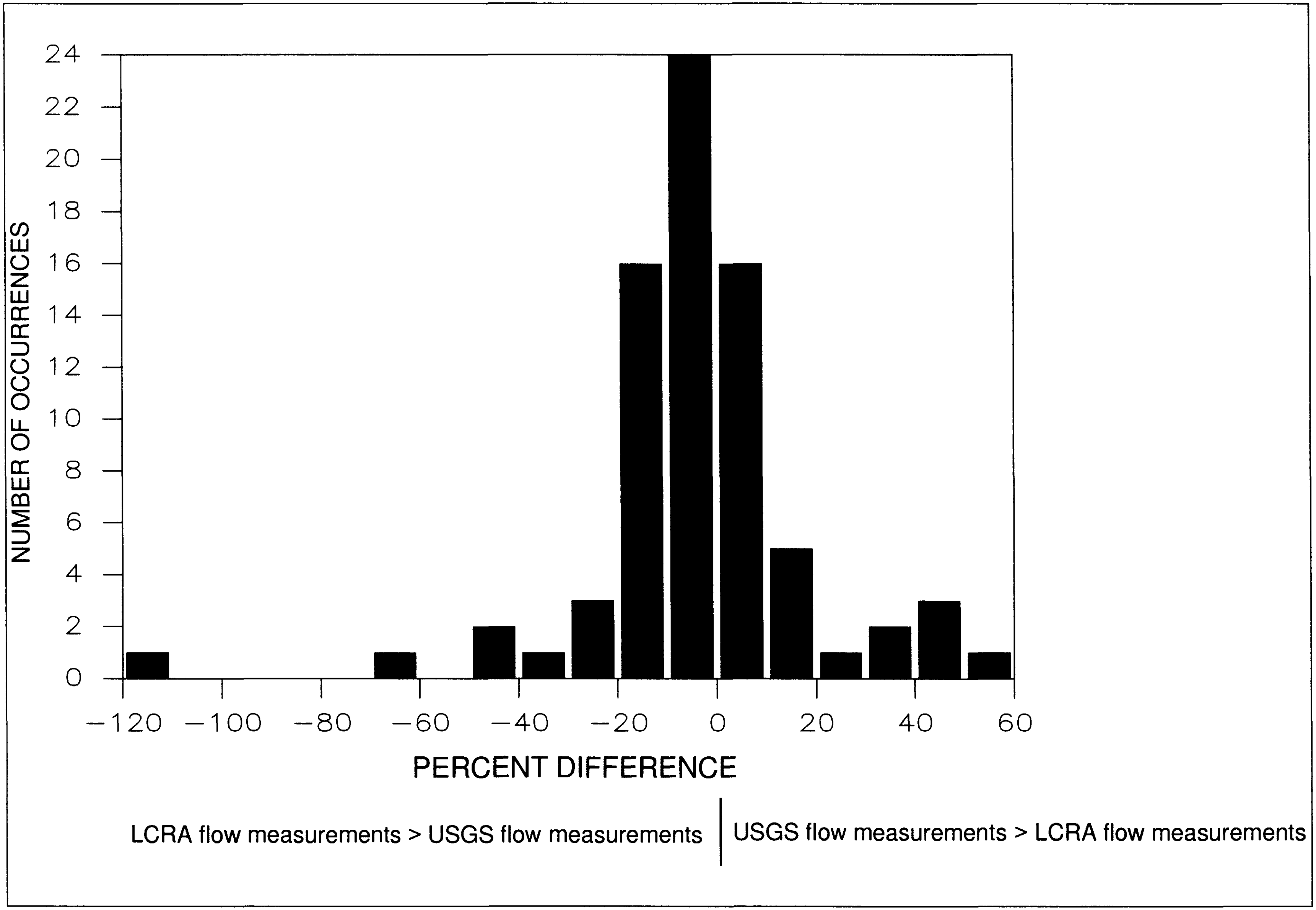

Figure 14. Histogram of percent differences between Lower Colorado River Authority and U.S. Geological Survey flow measurements made more than 1 hour apart, Lakeside district.

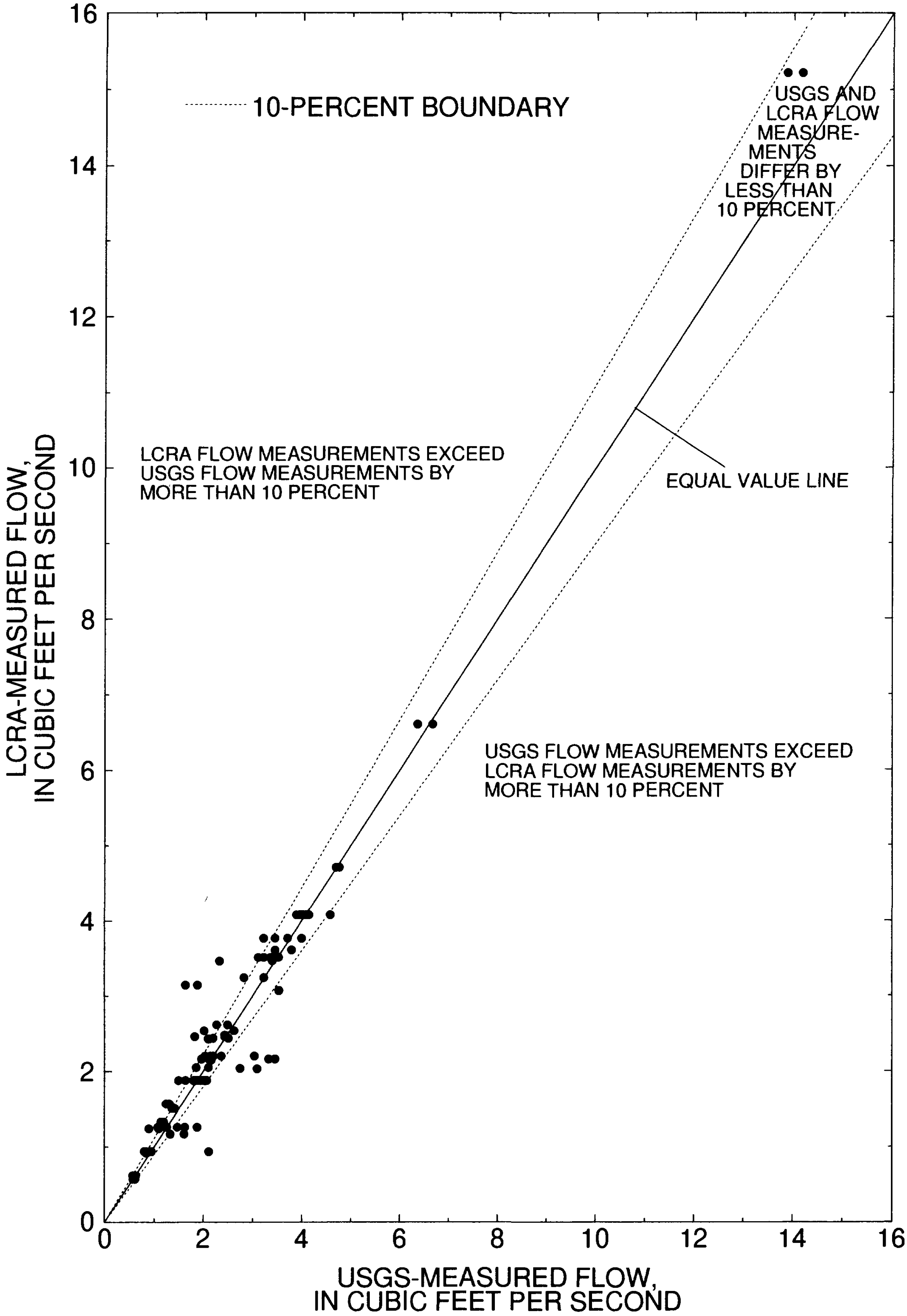

Figure 15. Relation between all Lower Colorado River Authority and U.S. Geological Survey flow measurements, Gulf Coast district.

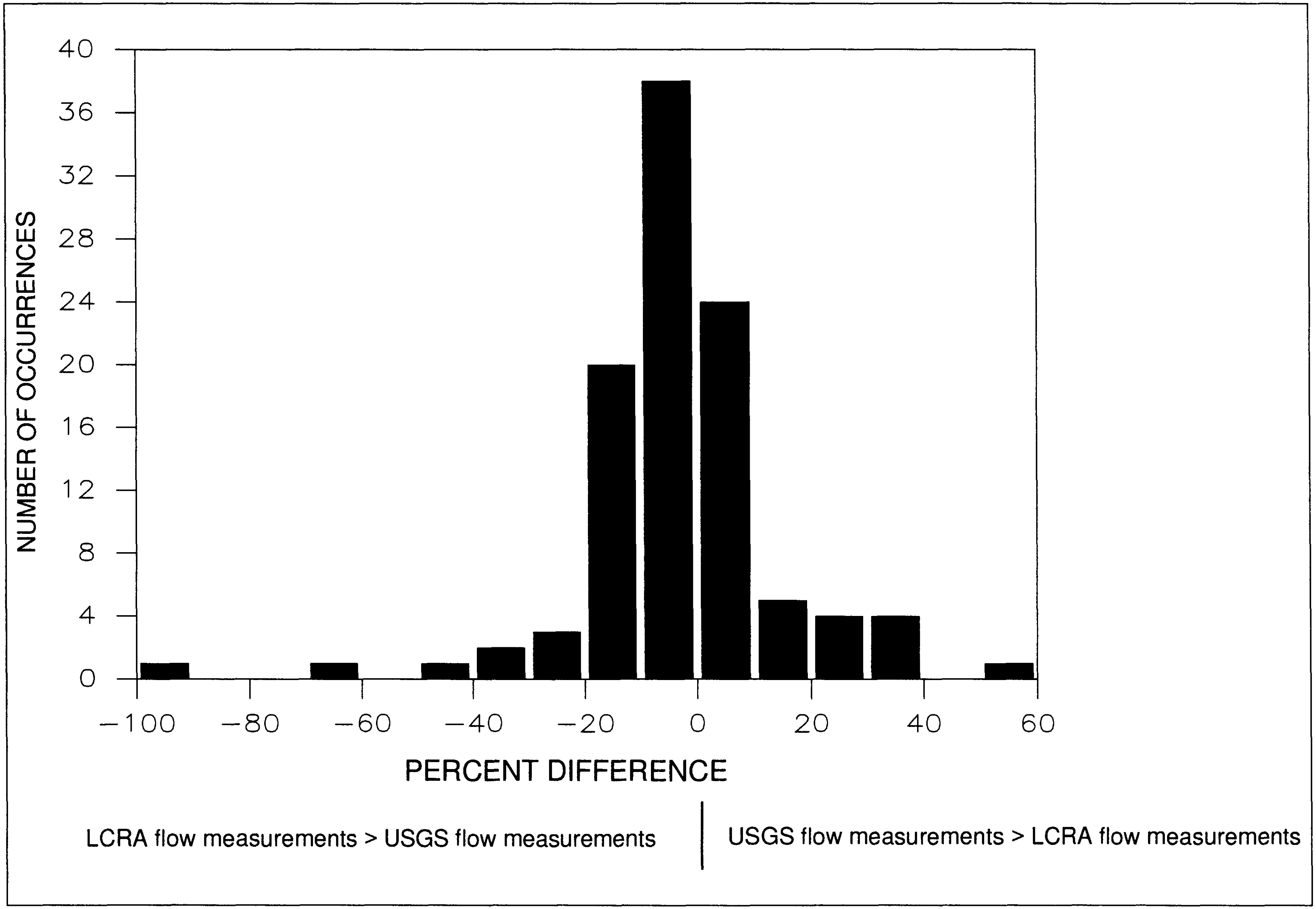

Figure 16. Histogram of percent differences between all Lower Colorado River Authority and U.S. Geological Survey flow measurements, Gulf Coast district.

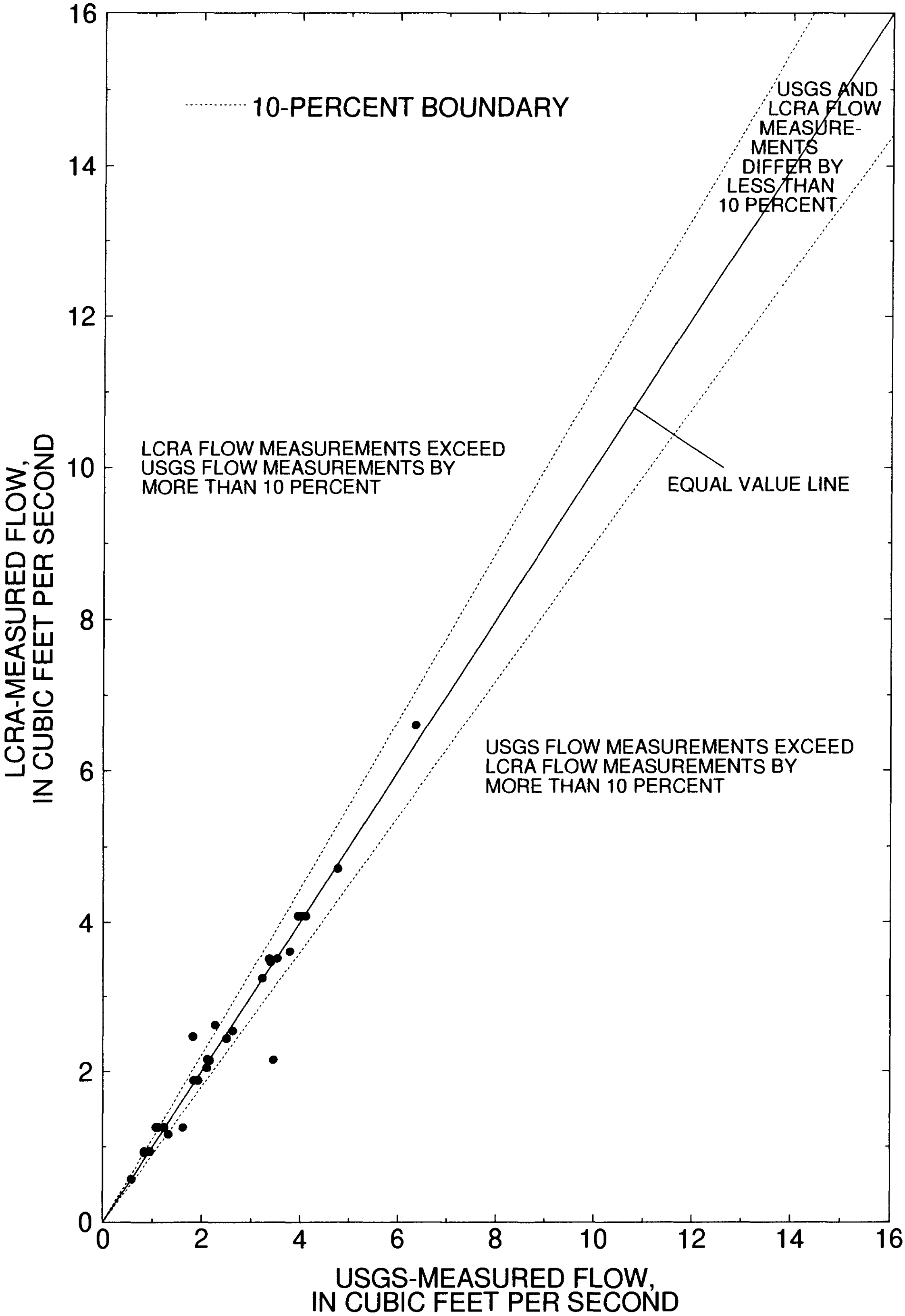

Figure 17. Relation between Lower Colorado River Authority and U.S. Geological Survey flow measurements made 1 hour or less apart, Gulf Coast district.

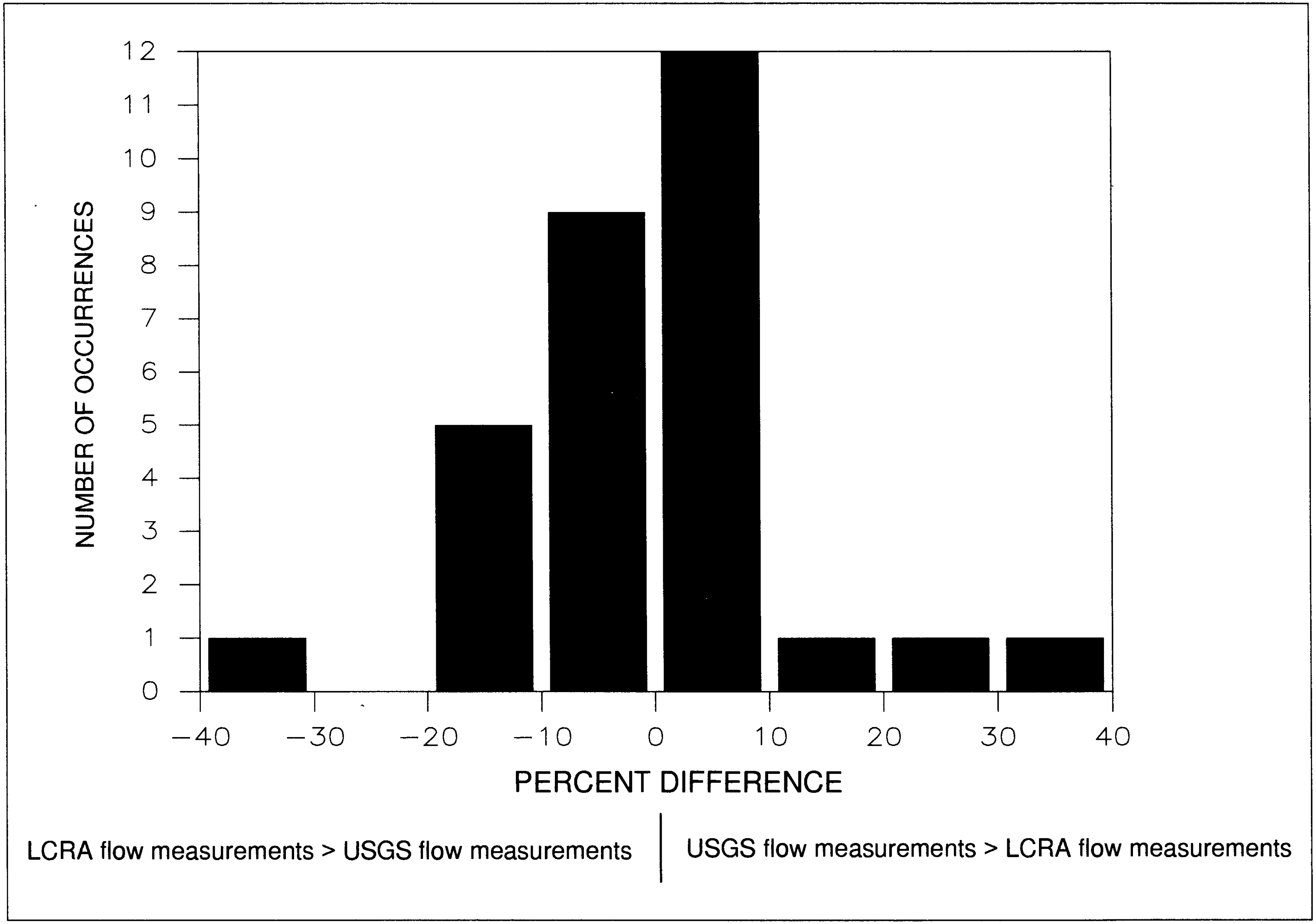

Figure 18. Histogram of percent differences between Lower Colorado River Authority and U.S. Geological Survey flow measurements made 1 hour or less apart, Gulf Coast district.

Table 5. Summary of statistical comparisons between Lower Colorado River Authority and U.S. Geological Survey flow measurements for the Gulf Coast irrigation district

[All pipe measurements. LCRA, Lower Colorado River Authority; USGS, U.S. Geological Survey]

	Pipe measurements
All measurement pairs:	
Number of LCRA-USGS measurement pairs	104
p-value	.0300
Are paired measurements statistically different?	Yes
Median absolute percent difference between paired measurements	7.5
Percent of LCRA-USGS measurement pairs in which LCRA measurement is larger than USGS measurement	63
Percent of LCRA-USGS measurement pairs in which measurements differ by more than 10 percent	40
Measurement pairs with 1 hour or less between measurements:	
Number of LCRA-USGS measurement pairs	30
p-value	.5716
Are paired measurements statistically different?	No
Median absolute percent difference between paired measurements	2.6
Percent of LCRA-USGS measurement pairs in which LCRA measurement is larger than USGS measurement	50
Percent of LCRA-USGS measurement pairs in which measurements differ by more than 10 percent	30
Measurement pairs with more than 1 hour between measurements:	
Number of LCRA-USGS measurement pairs	74
p-value	.0391
Are paired measurements statistically different?	Yes
Median absolute percent difference between paired measurements	9.1
Percent of LCRA-USGS measurement pairs in which LCRA measurement is larger than USGS measurement	68
Percent of LCRA-USGS measurement pairs in which measurements differ by more than 10 percent	45

statistically different (p-value = .0391) (table 5). The median absolute difference between paired measurements is 9.1 percent. The scatterplot of measurement pairs with measurements more than 1 hour apart (fig. 19) shows more points are above the line of equal value than below it, indicating that more of the LCRA measurements are larger than the corresponding USGS measurements. Among the 74 measurement pairs in this subset, the LCRA measurement is larger than the USGS measurement in 68 percent of the pairs (table 5). Forty-five percent of the paired measurements differ by more than 10 percent: In 22 of the 74 measurement pairs, the LCRA measurement is more than 10 percent greater than the USGS measurement; and in 11 of the 74 pairs, the USGS measurement is more than 10 percent greater than the LCRA measurement (fig. 20).

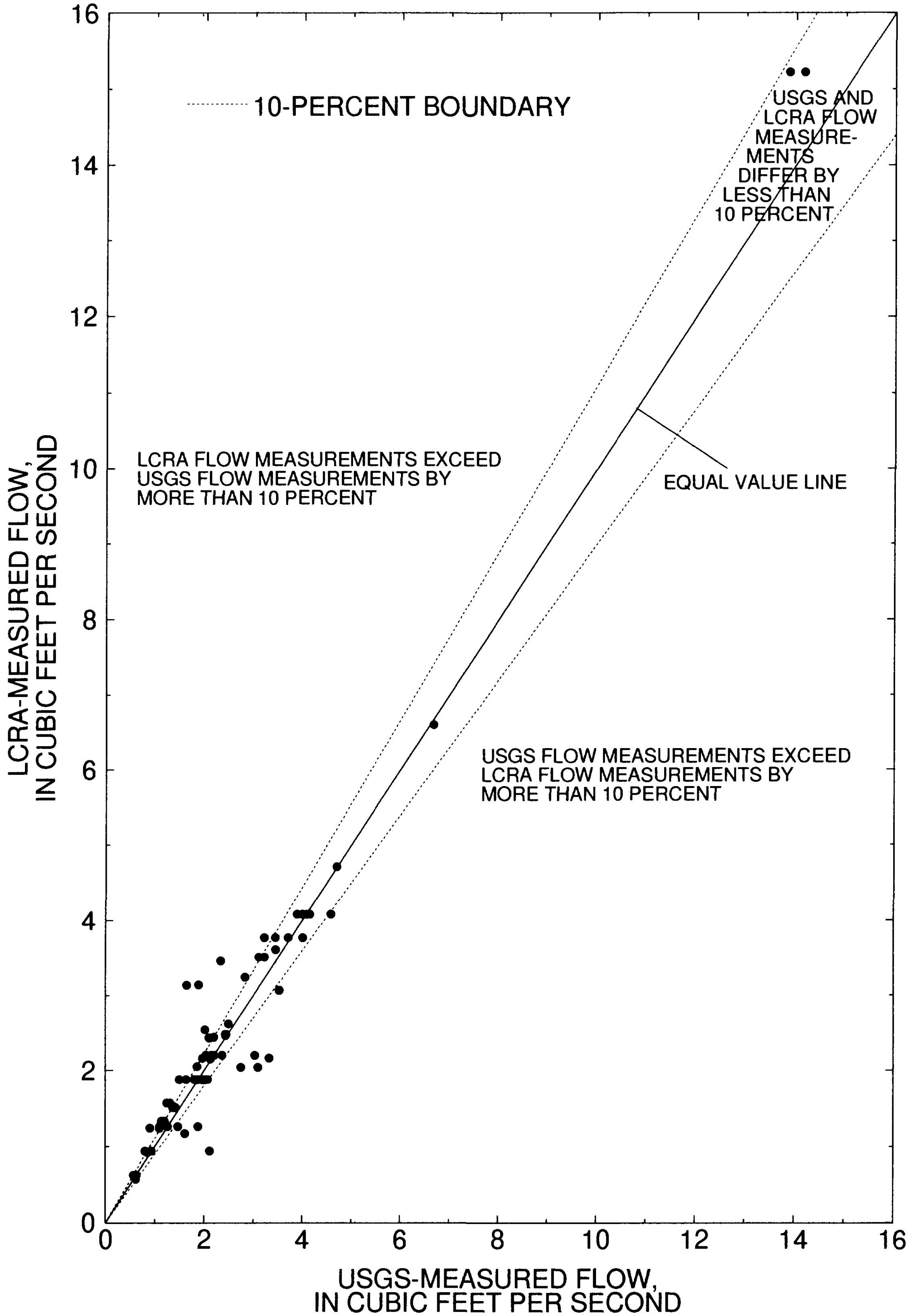

Figure 19. Relation between Lower Colorado River Authority and U.S. Geological Survey flow measurements made more than 1 hour apart, Gulf Coast district.

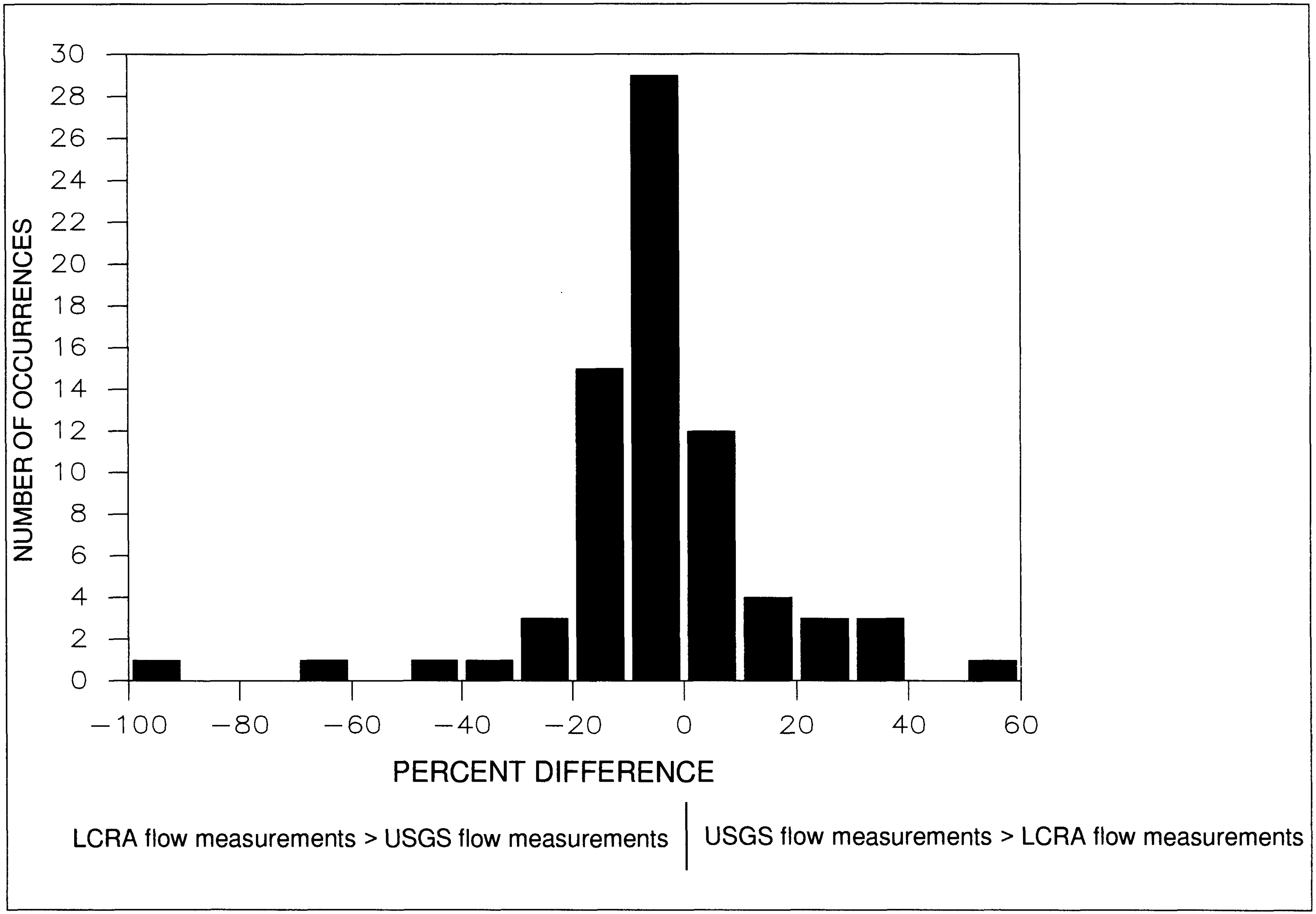

Figure 20. Histogram of percent differences between Lower Colorado River Authority and U.S. Geological Survey flow measurements made more than 1 hour apart, Gulf Coast district.

SUMMARY

The LCRA sells and distributes water for irrigation of rice farms in two LCRA-managed irrigation districts in the lower Colorado River Basin, the Lakeside district and the Gulf Coast district. In 1993, the LCRA implemented a water-measurement program to account for the water delivered to rice farms and to promote water conservation. During the rice-irrigation season (summer and fall) of 1995, the USGS collected flow-measurement data and compared LCRA and USGS flow measurements.

Two types of water-delivery structures—pipes and water boxes—transfer water from canals to individual farms. In the Lakeside district, an estimated 30 percent of the delivery structures are pipes and 70 percent are water boxes. In the Gulf Coast district, more than 80 percent of the delivery structures are pipes, and the remainder are water boxes. During the study, LCRA irrigation coordinators generally measured flow at water-delivery structures once each day. Flow through pipes was computed from velocities measured in pipes with Global Flow Probe meters; flow through water boxes was computed from water-level differences between inflow and outflow ends of the boxes.

The USGS measured flows at 30 sites in the Lakeside district (12 pipes and 18 water boxes) and 24 sites in the Gulf Coast district (all pipes). The sites, located at delivery points into irrigated fields, were coincident with LCRA measuring sites so that pairs of corresponding (same site, same date) LCRA and USGS measurements could be compared. The USGS used three types of flowmeters: the mechanical Price meter, the electromagnetic Marsh McBirney Flo-Mate 2000, the two meters commonly used by the USGS; and the Global Flow Probe as used by the LCRA. The Price and Marsh McBirney meters provided the measurements for comparison with the LCRA measurements. The Global Flow Probe measurements were made to determine whether the Global Flow Probe is capable of providing measurements that are not substantially different from measurements made with the types of meters used by the USGS.

In each district, the USGS made essentially simultaneous flow measurements twice a day—once in the morning and once in the afternoon—at each site on selected days with the Price and Marsh McBirney meters, and usually the Global Flow Probe. As expected, essentially simultaneous USGS measurements with the three meters differ. For the Lakeside district, the median absolute difference between the Price and the Marsh McBirney measurements is 3.0 percent; 24 percent of the paired measurements differ by more than 10 percent. For the Gulf Coast district, the median absolute difference between the Price and the Marsh McBirney measurements is 1.8 percent; 5.8 percent of the paired measurements differ by more than 10 percent.

The mean of the Price and Marsh McBirney measurements is used for comparison with the LCRA measurements; and also for comparison with USGS Global Flow Probe measurements: For the Lakeside district, the median absolute difference between the USGS Global Flow Probe measurements and the mean of the corresponding Price and Marsh McBirney measurements is 6.0 percent; 34 percent of the pairs differ by more than 10 percent. For the Gulf Coast district, the median absolute difference between the USGS Global Flow Probe measurements and the mean of the corresponding Price and Marsh McBirney measurements is 4.2 percent; 17 percent of the pairs differ by more than 10 percent.

In both irrigation districts, variability in daily flows occurs, based on differences between morning and afternoon USGS flow measurements. For the Lakeside district, the median absolute difference between the morning and afternoon flows is 7.0 percent; 38 percent of the morning and afternoon flows differ by more than 10 percent. For the Gulf Coast district, the median absolute difference between the morning and afternoon flows is 8.6 percent; 46 percent of the morning and afternoon flows differ by more than 10 percent.

For comparison, the LCRA and USGS flow measurements are grouped by the LCRA district in which they were made and subdivided by the time difference between corresponding (same site, same date) measurements—less than or equal to 1 hour or more than 1 hour. Measurements in the Lakeside district are further subdivided by structure type. Statistical tests were done to determine whether the LCRA and USGS flow measurements are statistically different. The comparisons are summarized in tables 4 and 5.

Wilcoxon signed-rank tests on all Lakeside district measurement pairs indicate that the LCRA and USGS measurements are not statistically different. The median absolute percent difference between the flow measurements is 8.1 percent; and 44 percent of the flow measurements differ by more than 10 percent. Similar statistical tests on all Gulf Coast district measurement pairs indicate that the LCRA and USGS measurements are statistically different. The median absolute percent difference between the flow measurements is 7.5 percent; and 40 percent of the flow measurements differ by more than 10 percent.

For LCRA and USGS measurement pairs with 1 hour or less between measurements in the Lakeside district, the median absolute difference between measurements is 5.9 percent; 33 percent of the flow measurements differ by more than 10 percent. For similar measurement pairs in the Gulf Coast district, the median absolute difference between measurements is 2.6 percent; 30 percent of the flow measurements differ by more than 10 percent. In both districts, the differences between LCRA and USGS measurements with 1 hour or less between measurements and the differences between essentially simultaneous USGS measurements noted above are of similar orders of magnitude and, in some cases, very close.

SELECTED REFERENCES

Bodhaine, G.L., 1967. Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A3, 60 p.

Bureau of Reclamation and Lower Colorado River Authority, 1992, Water management study of the Lower Colorado River Basin, Texas: Special Report (draft), 21 p.

Dodge, R.A., 1990, Lower Colorado River Authority water box calibrations: Bureau of Reclamation R–90–19, 15 p.

Fulford, J.M., Thibodeaux, K.G., and Kaehrle, W.R., 1994, Comparison of current meters used for stream gaging, *in* Fundamentals and advancements in hydraulic measurements and experimentation, Symposium Proceedings: American Society of Civil Engineers, p. 376–385.

Griffin, R.C., Perry, G.M., and McCauley, G.N., 1984, Water use and management in the Texas Rice Belt Region: College Station, Tex., Texas A&M University Report MP–1559, 87 p.

Helsel, D.R., and Hirsch, R.M., 1992, Studies in environmental science 49—statistical methods in water resources: Amsterdam, Elsevier, 522 p.

Kabir, Jobaid, 1991, Economic feasibility of irrigation water measurement: Austin, Tex., Lower Colorado River Authority Technical Memorandum No. 2.

King, David, and Kabir, Jobaid, 1991, Enhanced canal system scheduling using a PC, *in* Irrigation and Drainage 1991 National Conference, Proceedings: American Society of Civil Engineers, p. 576–582.

Lower Colorado River Authority, 1992, Water management plan for the Lower Colorado River Basin: Austin, Tex., 128 p.

______1994, Lakeside canal operating procedures: Austin, Tex., 6 p.

Marsh McBirney, Inc., 1990, MMI Model 2000 Flo-Mate portable water flowmeter instruction manual: 17 p.

______1990, Open channel profiling handbook: 18 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Riggs, H.C., 1968, Some statistical tools in hydrology: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A1, 39 p.

Texas Water Development Board, 1986, Surveys of irrigation in Texas 1958, 1964, 1969, 1974, 1979, and 1984: Texas Water Development Board Report 294, 243 p.

Table 2. Flow measurements at selected sites in the Lakeside irrigation district

[LCRA, Lower Colorado River Authority; USGS, U.S. Geological Survey; --, no measurement]

Site no.	Structure address	Date	LCRA measurements: Time	LCRA Flow (cubic feet per second): Pipe, Global Flow Probe	LCRA Flow (cubic feet per second): Water box, Computed from head difference	USGS measurements[1]: Time	USGS Flow (cubic feet per second): Price pygmy	USGS Flow (cubic feet per second): Marsh McBirney Flo-Mate	USGS Flow (cubic feet per second): Global Flow Probe
L1	CN*045	08-09-95	1035	8.47		0950	8.04	8.10	8.4
						1400	7.57	7.61	7.8
L2	CNM005	10-13-95	1009		3.91	1055	4.37	3.95	4.7
						1430	4.33	3.01	4.4
L3	CW*034	06-27-95	0958		1.89	1030	1.74	1.60	--
						1440	1.45	3.04	--
		07-05-95	0935		1.59	1010	1.44	1.46	1.6
						1640	1.33	1.34	1.5
		08-07-95	0925		.52	0945	.50	.49	--
						1530	.46	.44	--
L4	EBO005	07-11-95	0900		2.76	1000	1.88	1.94	--
						1324	1.94	1.97	--
L5	EBO007	08-24-95	0930		4.94	1145	4.42	3.87	--
						1530	4.71	4.12	--
L6	EBO008	07-11-95	0910		2.56	1127	3.21	2.55	--
						1530	2.04	2.38	--
		08-25-95	0900		4.24	1140	3.40	3.81	--
						1520	3.51	3.86	--
		10-04-95	0950		.56	1020	.56	.55	--
						1600	.58	.56	--
L7	ER*001	07-05-95	0935		6.12	1050	2.37	3.32	--
						1557	5.79	5.54	--
L8	G**052	05-16-95	0900	6.91		1030	6.43	6.46	6.8
						1417	6.43	6.43	6.8
		06-19-95	0930	5.97		0840	5.61	5.67	5.8
						1300	5.65	5.68	5.8
		07-18-95	0930	3.14		1158	2.69	2.72	2.8
						1845	2.64	2.67	2.1
L9	G**130	06-27-95	1515		3.04	0930	3.38	2.92	--
						1327	2.62	2.79	--
L10	GB*021	10-04-95	1320		2.51	0940	2.48	2.50	--
						1515	2.43	2.43	--
L11	GT*055	07-18-95	1030		3.09	1050	3.46	3.39	3.4
						1545	3.34	3.39	2.4
L12	MN*065	10-13-95	0915		2.74	1230	2.67	2.67	2.9
						1515	2.72	2.54	2.9
L13	MN*070	07-19-95	0930	3.14		0953	4.15	4.12	3.7
						1403	4.49	4.49	4.1
L14	MNM005	06-28-95	0800	3.00		1000	3.33	3.40	3.2
						1340	2.97	3.10	2.8

Footnote at end of table.

Table 2. Flow measurements at selected sites in the Lakeside irrigation district—Continued

Site no.	Structure address	Date	LCRA measurements: Time	LCRA Flow (cubic feet per second): Pipe — Global Flow Probe	LCRA Flow (cubic feet per second): Water box — Computed from head difference	USGS measurements[1]: Time	USGS Flow (cubic feet per second): Price pygmy	USGS Flow (cubic feet per second): Marsh McBirney Flo-Mate	USGS Flow (cubic feet per second): Global Flow Probe
L15	MNM015	07-28-95	0800		3.46	0945	3.23	3.26	2.6
						1340	3.37	3.47	2.9
L16	MT*005	05-22-95	1415		1.48	0945	1.48	1.45	--
						1500	1.51	1.50	--
L17	MT*05A	08-25-95	0830	3.53		1030	3.72	4.00	3.4
						1400	3.47	3.65	3.4
L18	MT*026	06-28-95	1015		2.81	1105	2.80	2.76	--
						1525	2.85	3.04	--
L19	MT*065	08-09-95	1000	2.09		1025	2.06	2.04	2.1
						1445	2.08	2.07	2.2
		08-24-95	0930	2.09		1405	2.03	2.16	1.7
						1800	2.04	1.92	1.8
L20	PCA011	06-09-95	0845		4.90	1005	3.81	4.88	--
						1336	5.51	4.82	--
L21	PC*170	06-07-95	1105	3.38		1310	2.63	2.88	2.6
						1755	2.80	3.10	3.0
		06-23-95	1400	2.56		1020	1.82	2.17	2.2
						1350	2.22	2.53	2.3
		08-31-95	1445	1.77		0925	1.92	1.98	1.8
						1315	1.74	1.77	1.7
		10-02-95	1115	3.23		0810	3.26	3.31	3.2
						1200	3.21	3.24	3.2
L22	PC*176	08-31-95	1445		1.34	1015	2.33	2.20	3.9
						1430	1.44	1.35	1.4
L23	PC*180	06-07-95	1120	2.21		1137	3.05	3.15	3.2
						1730	3.34	3.78	3.9
		08-11-95	1445	2.36		0935	4.52	5.42	4.4
						1450	2.04	2.57	2.4
		08-31-95	1445	.95		0950	1.12	1.14	1.0
						1515	1.17	1.20	1.0
		10-02-95	1100	2.68		0830	2.87	2.92	3.0
						1235	2.55	2.59	2.6
L24	PC*188	05-03-95	1030	5.48		0615	5.03	5.82	4.8
						1130	8.05	7.49	7.6
		08-11-95	1445	2.65		1224	4.00	5.09	3.4
						1927	3.24	3.70	3.1
		10-02-95	1100	2.65		0905	2.52	2.53	2.4
						1310	2.58	2.61	2.8
L25	PC*201	06-07-95	1138		1.12	1020	1.18	1.06	--
						1614	1.33	.45	--
		08-11-95	1445		2.48	1115	1.14	1.95	--
						1550	2.12	2.34	--

Footnote at end of table.

Table 2. Flow measurements at selected sites in the Lakeside irrigation district—Continued

Site no.	Structure address	Date	LCRA measurements: Time	LCRA Flow (cubic feet per second): Pipe — Global Flow Probe	LCRA Flow (cubic feet per second): Water box — Computed from head difference	USGS measurements[1]: Time	USGS Flow (cubic feet per second): Price pygmy	USGS Flow (cubic feet per second): Marsh McBirney Flo-Mate	USGS Flow (cubic feet per second): Global Flow Probe
L26	PM*112	05-16-95	1045		2.12	0853	2.24	2.25	--
						1245	2.09	2.09	--
		06-09-95	1030		2.06	0735	2.25	2.25	--
						1610	1.53	1.51	--
		06-20-95	1045		1.00	1106	1.37	1.36	--
						1510	1.75	1.72	--
L27	PN*029	06-23-95	0830	5.36		1145	5.10	5.36	4.8
						1500	5.35	5.49	5.1
L28	PT*091	06-20-95	0930	3.46		1300	3.02	2.90	2.7
						1630	3.08	3.08	2.7
L29	PTB052	06-27-95	0845	8.94		0900	8.67	8.88	8.8
						1230	8.46	8.52	8.6
		07-24-95	0845	8.07		0935	5.30	5.73	5.7
						1345	5.39	5.70	5.4
		09-29-95	0915	6.76		0940	6.59	6.64	6.9
						1423	6.88	7.03	6.9
L30	SDT009	10-04-95	1420		2.54	1125	2.52	2.54	--
						1705	2.92	3.10	--

[1] USGS morning and afternoon flow measurements at five sites are not included in this table because no same-date LCRA flow measurements were reported. The omitted USGS measurements are not used in any comparisons between USGS measurements or comparisons between LCRA and USGS measurements.

Table 3. Flow measurements at selected sites in the Gulf Coast irrigation district

[LCRA, Lower Colorado River Authority; USGS, U.S. Geological Survey; --, no measurement]

Site no.	Structure address	Date	LCRA measurements: Time	LCRA measurements: Flow (cubic feet per second) Global Flow Probe	USGS measurements[1]: Time	USGS: Flow (cubic feet per second) Price pygmy	USGS: Flow (cubic feet per second) Marsh McBirney Flo-Mate	USGS: Flow (cubic feet per second) Global Flow Probe
G1	B**030	07-27-95	0950	2.43	1325	2.06	2.14	1.8
					1718	2.15	2.08	1.8
G2	BS*040	07-06-95	1450	2.05	1000	1.85	1.86	2.0
					1500	2.09	2.12	2.0
		10-11-95	1510	1.17	1000	1.59	1.63	1.6
					1600	1.31	1.34	1.3
G3	C**228	06-26-95	1300	1.88	0935	2.02	2.07	1.9
					1340	1.84	1.84	1.8
G4	L**022	06-26-95	1000	2.16	1030	2.11	2.13	2.2
					1455	1.96	1.97	2.1
		07-09-95	0805	3.24	0830	3.21	3.25	3.3
					1620	2.79	2.86	3.0
		08-17-95	1050	2.16	1125	3.41	3.50	3.3
					1542	3.34	3.31	3.0
G5	L**075	07-09-95	0840	2.44	0925	2.49	2.52	2.4
					1710	2.19	2.20	2.3
G6	L**172	06-26-95	0930	1.33	0820	1.18	1.21	1.3
					1605	1.11	1.16	1.2
		07-10-95	1300	2.15	0910	2.15	2.17	2.2
					1317	2.13	2.13	2.2
		08-17-95	1410	1.24	1022	1.08	1.10	.9
					1654	.89	.90	.8
G7	LQ*099	06-29-95	0835	4.08	0905	4.02	4.04	4.1
					1315	3.86	3.93	4.0
		07-20-95	0740	2.04	1015	3.07	3.12	2.9
					1500	2.61	2.88	3.0
		08-17-95	1300	2.62	1203	2.25	2.29	2.2
					1817	2.48	2.50	2.4
G8	LS*019	06-29-95	1318	2.48	0825	2.43	2.43	2.5
					1200	2.44	2.45	2.5
G9	MC*024	06-21-95	0900	4.08	1235	4.14	4.16	4.2
					1700	4.55	4.62	4.7
		07-06-95	0820	1.88	0910	1.93	1.93	1.9
					1415	2.03	2.11	2.0
		07-27-95	1430	3.77	1000	4.02	3.99	3.8
					1550	3.39	3.52	3.5
G10	MFJ010	07-21-95	1020	1.51	0915	1.36	1.36	1.4
					1355	1.40	1.43	1.1
G11	NC*044	07-25-95	1200	1.26	1300	.99	1.16	.9
					1817	1.81	1.93	1.4

Footnotes at end of table.

Table 3. Flow measurements at selected sites in the Gulf Coast irrigation district—Continued

Site no.	Structure address	Date	LCRA measurements: Time	LCRA measurements: Flow (cubic feet per second): Global Flow Probe	USGS measurements[1]: Time	USGS measurements[1]: Flow (cubic feet per second): Price pygmy	USGS measurements[1]: Flow (cubic feet per second): Marsh McBirney Flo-Mate	USGS measurements[1]: Flow (cubic feet per second): Global Flow Probe
G12	NP*050	07-07-95	0850	0.57	0910	0.54	0.60	0.5
					1545	.61	.62	.6
		07-26-95	1440	1.26	1050	1.43	1.51	1.2
					1500	1.57	1.68	1.3
		08-10-95	1010	.62	1125	.55	.58	.6
					1540	.63	.63	.6
G13	NP*054	06-08-95	1750	3.77	1105	3.19	3.26	3.3
					1450	3.68	3.74	3.8
		07-07-95	0900	2.54	0940	2.59	2.66	2.5
					1520	2.01	2.02	2.0
		07-26-95	1435	2.46	1025	2.42	2.45	2.4
					1530	1.75	1.90	1.8
		08-10-95	1015	.92	1100	.82	.85	.9
					1515	.85	.86	.9
G14	NP*060	04-17-95	0810	4.71	0905	4.73	4.80	4.7
					1315	4.67	4.72	4.7
		05-19-95	1200	4.08	1158	4.02	4.21	3.5
					1510	4.08	4.11	4.4
		06-08-95	1150	1.88	1035	1.83	1.92	1.8
					1415	1.46	1.53	1.4
		07-07-95	0905	1.88	1010	1.82	1.88	1.9
					1626	1.60	1.67	1.7
		09-28-95	1405	.94	1205	.91	.94	.9
					1620	.92	.94	1.0
G15	NP*066	05-19-95	1210	4.08	1247	4.02	3.89	3.8
					1620	3.99	4.02	4.1
		06-08-95	1510	2.20	1000	2.18	2.22	2.2
					1345	2.36	2.37	2.4
		07-07-95	0910	1.88	1045	1.84	1.87	1.9
					1450	1.93	1.98	2.0
		07-26-95	1430	2.20	1125	2.02	2.05	1.6
					1610	2.13	2.16	2.2
		08-29-95	1230	3.46	1250	3.43	3.37	3.5
					1635	2.36	2.30	2.5
		09-28-95	1410	1.57	1120	1.23	1.25	1.3
					1545	1.31	1.31	1.4
		10-03-95	1010	1.26	1025	1.23	1.24	1.2
					1455	1.09	1.11	1.2
G16	NS*024	07-27-95	1040	6.60	1105	[2]6.27	6.44	6.5
					1440	[2]6.66	6.68	6.8
G17	O**186	07-27-95	1020	.94	1000	.82	.85	.8
					1300	2.11	2.11	1.6
G18	ODE506	05-04-95	0800	15.22	1010	13.99	13.75	14.0
					1330	14.25	14.09	15.0

Footnotes at end of table.

Table 3. Flow measurements at selected sites in the Gulf Coast irrigation district—Continued

Site no.	Structure address	Date	LCRA measurements: Time	LCRA measurements: Flow (cubic feet per second) Global Flow Probe	USGS measurements[1]: Time	USGS measurements[1]: Flow (cubic feet per second) Price pygmy	Marsh McBirney Flo-Mate	Global Flow Probe
G19	VK*046	07-21-95	1250	3.14	0920	1.74	1.54	1.0
					1627	1.86	1.90	1.0
G20	VM*022	05-19-95	0800	2.20	1000	2.79	3.28	3.1
					1750	2.16	2.23	2.6
		06-21-95	1600	1.88	0950	1.98	2.01	2.5
					1415	2.10	2.01	3.1
		08-28-95	0830	1.88	0905	1.94	1.90	2.0
					1700	1.82	1.79	1.9
G21	W**072	09-28-95	0905	1.26	0923	1.10	1.13	1.2
					1740	1.22	1.29	1.3
G22	W**192	07-10-95	1130	.94	1040	.93	.96	.9
					1533	.79	.81	.8
G23	ZP*116	05-05-95	1050	3.61	1145	3.74	3.83	3.5
					1515	3.05	3.86	--
G24	ZP*144	06-21-95	0725	3.07	1140	3.53	3.53	3.2
					1545	3.44	3.63	3.3
		07-06-95	1020	3.51	1120	3.35	3.38	3.4
					1645	3.09	3.14	3.0
		07-20-95	0955	3.51	0900	3.49	3.57	3.5
					1405	3.20	3.26	3.3

[1] USGS morning and afternoon flow measurements at two sites are not included in this table because no same-date LCRA flow measurements were reported. The omitted USGS measurements are not used in any comparisons between USGS measurements or comparisons between LCRA and USGS measurements.

[2] Flow measurement made with Price type AA meter.

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