STREAM GAGING PRECISION RELATED TO METER SUSPENSION AND PROCEDURAL ERROR

By

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METER SUSPENSION AND

PROCEDURAL ERROR

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To my wife, Virginia, and children, JoAnn and Terry, in recognition of their inspiration and encouragement, this thesis is dedicated.

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CHAPTER I

INTRODUCTION

Accurate records of surface runoff are valuable when flood prevention works, water recreational facilities, industries, municipalities, and agricultural enterprises that require large volumes of water are planned. Industry and agriculture desire the best available appraisal of water resources before investing capital in new plants and irrigation developments.

Precise runoff records are valuable in hydrologic research when the results depend upon detecting a small change in the water yield of a drainage basin. This type of research is being conducted by the Agricultural Research Service on the Washita River in southwestern Oklahoma. The purpose of the project is to determine the effects of such conservation treatments as farm ponds, detention reservoirs and land use on the flow regime of the Washita main stem. The research plan is to compare the hydrologic records collected before and after the conservation treatments are installed. Following are some of the questions for which answers are being sought:

1. How do the dams and various land uses in the upstream tributary watersheds affect the downstream water supply?
2. To what extent is downstream flooding reduced by upstream conservation treatment?

3. How does watershed conservation treatment affect the amount of sediment carried in a stream?

Six main-stem gaging stations are included in the hydrological instrumentation of the 1,130-square-mile study reach of the Washita watershed. The study reach extends from Alex, Oklahoma, 78 river miles upstream to Anadarko, Oklahoma. The watershed area upstream from the Anadarko gaging station is approximately three times the area of the study reach. Therefore, the discharge contributed by the study reach is usually less than one-third of the total discharge at Alex.

The results of this research obviously depend on consistent precision of the stream flow measurements. For instance, assume that the error in the daily record of discharge, or mean daily flow, is within five percent of the true mean daily flow. Hydrologists commonly consider this an "excellent" record. Assume that an error of five percent is made in one direction at Anadarko and the same error, but in the opposite direction, is made at Alex. Then the difference, or the contribution of runoff from the study reach, could possibly have an error of more than thirty percent as shown by the hypothetical data in Table 1. Therefore, to achieve the objectives of the Washita research project and many similar projects over the nation, the measurements of discharge and the rates and volumes of flow require the best possible precision.

TABLE I

POTENTIAL MAGNIFICATION OF ERROR IN COMPUTATION OF REACH RUNOFF

Location	True Mean Daily Flow (Cfs)	Measured Mean Daily Flow (Cfs)	Error (%)
Anadarko	1,000	950	-5
Alex	1,333	1,400	+5
Reach (Anad.-Alex)	333	450	+35

Accuracy implies that the estimator, discharge measurement, yields estimates, rates of flow, that average very close to the true value. Precision indicates that the estimator yields estimates that are very close together although the estimates may not be near the true value. Thus a series of discharge measurements of the same flow rate may be accurate and not precise or the measurements may be precise and not accurate. This thesis study was made in terms of precision because the true value of discharge was unknown.

The purpose of this thesis was to determine refinements in stream gaging procedure that would increase the precision of discharge measurements. The thesis was limited to study of the Price meter and current metering procedure with emphasis on comparison of meter registration on rod suspension and on cable suspension.

CHAPTER II

OBJECTIVES

The objectives of this thesis were as follows:

1. To determine coefficients for cable suspension measurements made with a meter that was rated on rod suspension.
2. To detect and determine the effect of procedural errors committed by hydrographers.
3. To estimate the precision of the A.R.S. Washita discharge measurements.

CHAPTER III

REVIEW OF LITERATURE

Development of the Price Current Meter

Focacci applied the first known current meter with a vertical-axis of rotation in Italy about 1806. (9). Robinson improved and used the vertical-axis meter as an anemometer in 1852. Several years later, Henry developed an electrical system for recording revolutions of current meters. Following the advice of Henry, Ellis constructed his own "Ellis meter" and used it on the Connecticut River about 1877. In 1882, Price, a civilian engineer of the Mississippi River Commission, developed and patented the Price meter which still bears his name.

In most parts of the world, hydrographers prefer a horizontal screw-type meter. However, in the United States, open channel flow is measured almost exclusively with the Price meter. Relative merit of the two types of meter has been a controversial subject for many years. Pierce (14) gave the following reasons why engineers of the Water Resources Branch of the United States Geological Survey prefer the vertical-axis, cup-type meter:

> (1) The vertical-axis meters will generally operate at lower velocities than the horizontal-axis meters, and the accuracy and consistency of vertical-axis meters are equal to those of horizontal-axis meters in high velocities; (2) by placing the bearings of the vertical-axis meters in air pockets it is possible to eliminate largely the entrance of silty water to

those parts, whereas an equally satisfactory method of eliminating silty water from the bearing surfaces of the horizontal-axis meters has not yet been brought to the attention of the Survey; (3) meter cups that become dented or slightly bent may be repaired readily in the field, and the relation between the velocity of the water and the rate of rotation of the bucket will not be seriously affected; whereas the effects of slight damage to the rotor of a horizontal-axis meter may seriously affect its rate of rotation, and the proper repair of such damage generally requires considerable skill; (4) the bucket wheel of a vertical-axis meter is relatively slow moving, and a single rotor serves for the entire range of velocities ordinarily found in stream gaging. In contact, the vanes of a horizontal-axis meter must be at a considerable angle (or pitch) to the current in order to assure consistent and accurate performance in low velocities. The same rotor when used in high velocities revolves too fast for use under field conditions. Consequently, two or more interchangeable rotors having vanes at different angles are occasionally required to cover the range of velocities encountered in a single measurement of discharge.

Stream Gaging Procedure

The volume of water flowing past a cross section of a stream in a unit of time is the volume rate of flow, or discharge, of the stream. Generally, the unit of discharge used is a cubic foot per second, cfs. The discharge is usually determined by the velocity-area method which includes measurement of the stream's cross-sectional area and the water velocity. The discharge is measured periodically with a current meter and related to the water surface level. Continuous records of water surface level are then converted into volumes of flow for various time intervals.

In making a current meter measurement, the total area of the cross section at the place of measurement is divided into small or partial sections, and the area and mean velocity of each section is determined separately. The small sections are each bounded by the water surface, the stream bed and two imaginary verticals midway between the verticals where the velocity is measured. Mean velocity within the vertical is measured at specific points which depend upon the flow depth.

If the stream can be safely waded, the current meter measurement is made with the meter mounted on a wading rod as shown in Figure 1. The rod is marked at .05 foot increments for convenience in measuring the water depth. The width of each incremental section of flow is observed with respect to beads on a galvanized wire strand tag-line which is streched across the stream. During a wading measurement, the hydrographer stands with the meter rod at the tag-line. He faces the bank with the water flowing against the side of his leg, from 1 to 3 inches downstream from the tag-line, and 18 inches or more from the meter rod. (4). If facing the left bank, he holds the meter rod with his left hand; if facing the right bank, he holds it with his right hand. The wading rod is held in a vertical position with the meter parallel to the direction of flow during the velocity observation. If the stream is no more than two arm lengths wide, it is desirable that the hydrographer stay out of the water during the measurement. Before taking a depth reading, the meter is placed well above or below the water surface, for if the meter is immediately below the water surface, the water will flow up over the meter and indicate a greater depth. The depth is observed from a point at right angles to the direction of flow because the water tends to pile up on the upstream side of the rod and to be depressed on the downstream side.

Before beginning the velocity count, the meter bucket wheel must be given time to overcome its inertia. This may take more than a minute in very slow velocity water. When the velocity is less than one foot per second, the velocity observation should continue at least one minute. (4).

Figure 1. Price current meter on wading rod suspension.

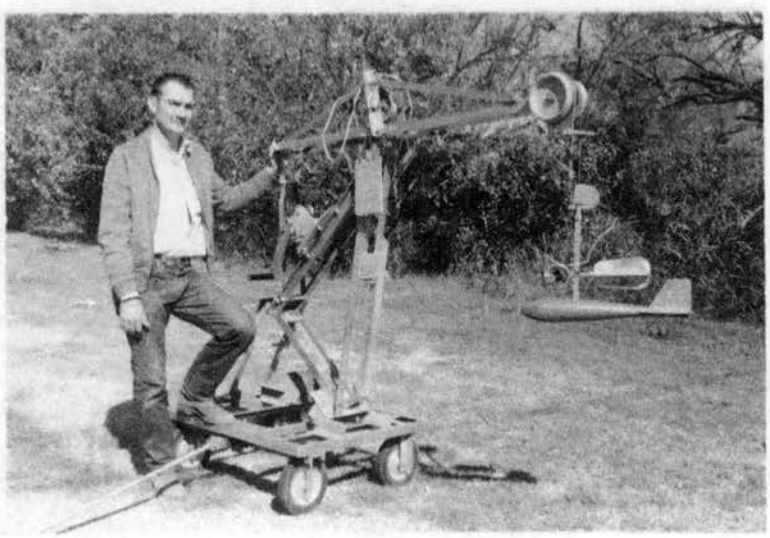

Figure 2. Price current meter and 30 lb. Columbus weight on cable suspension.

If the flow is too deep or swift to wade safely, the meter is suspended by a cable from a bridge crane, as shown in Figure 2. A cable suspended meter must have a weight on the cable to keep the meter from swinging downstream with the current. The weight is streamlined to reduce drag and affect the flow past the meter as little as possible. The cable is wound about a reel mounted on the bridge crane. On the reel is a depth indicator which can be zeroed with the meter resting at the water surface. When the meter is lowered till the weight touches the stream bed, the indicator dial shows the water depth at that vertical less the distance from the center of the meter to the bottom of the weight.

The velocity of the water is measured by timing the revolutions of the current meter bucket wheel. Each revolution is indicated by a click in the telephone headset which is connected to a small dry cell battery and a contact on the meter. The clicks are timed by a stop watch. Each meter has its own rating table similar to that shown in Figure 3, from which revolutions per time interval can be converted to water velocity in feet per second.

The hydrographer records the observations on the form shown in Figure 4, which also shows the method of computation of discharge. Numbers in the discharge column are the product of area and the mean velocity in the vertical. The horizontal angle coefficient is the cosine of the horizontal angle between a line perpendicular to the gaging cross section and the water flow line. Supplementary data are recorded on the form shown in Figure 5. Information that might be recorded on this form is discussed below.

SCS-364

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
WATERSHED & HYDROLOGIC STUDIES

N less than 1.50
V = 2.286N + 0.026
N greater than 1.50
V = 2.270N + 0.050

RATING TABLE FOR small price improved METER NO. SCS-11 36100

RATED March 27, 1956 19 AT NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C.

CONDITION OF METER New SUSPENSION Rod (double end hanger)

TIME IN SECONDS	VELOCITY IN FEET PER SECOND														TIME IN SECONDS
	5 REVS.	10 REVS.	15 REVS.	20 REVS.	30 REVS.	40 REVS.	50 REVS.	60 REVS.	70 REVS.	80 REVS.	90 REVS.	100 REVS.	150 REVS.	200 REVS.	
40	0.312	0.598	0.883	1.169	1.740	2.312	2.884	3.455	4.022	4.590	5.158	5.725	8.562	11.400	40
41	.305	.584	.863	1.142	1.699	2.257	2.815	3.370	3.925	4.479	5.033	5.586	8.356	11.123	41
42	.298	.570	.842	1.114	1.658	2.202	2.746	3.290	3.834	4.374	4.915	5.455	8.156	10.860	42
43	.291	.556	.824	1.089	1.622	2.152	2.685	3.215	3.746	4.272	4.801	5.330	7.968	10.608	43
44	.287	.545	.806	1.064	1.585	2.104	2.625	3.144	3.662	4.177	4.692	5.210	7.788	10.367	44
45	.280	.533	.787	1.041	1.551	2.058	2.566	3.073	3.582	4.084	4.590	5.094	7.616	10.138	45
46	.273	.522	.771	1.020	1.516	2.015	2.511	3.007	3.505	3.998	4.490	4.985	7.452	9.920	46
47	.268	.513	.755	1.000	1.484	1.971	2.458	2.943	3.430	3.914	4.397	4.880	7.294	9.709	47
48	.264	.501	.739	.979	1.455	1.930	2.408	2.884	3.359	3.834	4.306	4.778	7.144	9.509	48
49	.259	.492	.726	.959	1.425	1.891	2.358	2.831	3.290	3.757	4.220	4.683	6.998	9.314	49
50	.255	.483	.712	.940	1.398	1.855	2.312	2.769	3.226	3.682	4.136	4.590	6.860	9.130	50
51	.250	.474	.698	.922	1.370	1.818	2.266	2.714	3.162	3.612	4.056	4.501	6.726	8.953	51
52	.245	.465	.684	.904	1.345	1.784	2.225	2.664	3.103	3.541	3.979	4.415	6.599	8.780	52
53	.241	.458	.673	.888	1.320	1.752	2.182	2.614	3.046	3.475	3.904	4.333	6.474	8.617	53
54	.236	.449	.662	.872	1.297	1.720	2.143	2.566	2.989	3.412	3.834	4.254	6.356	8.458	54
55	.234	.442	.650	.858	1.272	1.688	2.104	2.520	2.936	3.350	3.764	4.177	6.240	8.304	55
56	.229	.433	.639	.842	1.251	1.658	2.067	2.474	2.884	3.290	3.698	4.104	6.129	8.156	56
57	.227	.426	.627	.828	1.228	1.631	2.031	2.433	2.833	3.236	3.634	4.032	6.025	8.015	57
58	.222	.419	.618	.815	1.208	1.603	1.996	2.390	2.785	3.178	3.573	3.963	5.920	7.877	58
59	.220	.412	.607	.801	1.187	1.576	1.962	2.351	2.737	3.126	3.512	3.898	5.820	7.745	59
60	.216	.408	.598	.787	1.169	1.551	1.930	2.312	2.694	3.075	3.455	3.834	5.726	7.616	60
61	.213	.401	.588	.776	1.151	1.526	1.900	2.275	2.650	3.023	3.398	3.770	5.632	7.493	61
62	.211	.394	.579	.764	1.132	1.500	1.868	2.239	2.607	2.975	3.345	3.712	5.541	7.373	62
63	.206	.389	.570	.751	1.114	1.478	1.841	2.202	2.566	2.929	3.293	3.652	5.455	7.257	63
64	.204	[illegible]	.561	.739	1.098	1.455	1.811	2.170	2.527	2.884	3.240	3.596	5.371	7.144	64
65	.202	.378	.554	.730	1.082	1.432	1.784	2.136	2.488	2.840	3.192	3.541	5.289	7.035	65
66	.200	.373	.545	.719	1.064	1.411	1.759	2.104	2.451	2.797	3.144	3.489	5.210	6.928	66
67	.197	.367	.538	.707	1.050	1.391	1.731	2.074	2.415	2.755	3.096	3.437	5.132	6.826	67
68	.195	.362	.529	.698	1.034	1.370	1.706	2.042	2.378	2.714	3.053	3.386	5.058	6.726	68
69	.190	.357	.522	.689	1.020	1.352	1.683	2.015	2.344	2.675	3.007	3.338	4.985	6.628	69
70	.188	.353	.515	.680	1.004	1.331	1.658	1.985	2.312	2.639	2.966	3.290	4.915	6.535	70
	5 REVS.	10 REVS.	15 REVS.	20 REVS.	30 REVS.	40 REVS.	50 REVS.	60 REVS.	70 REVS.	80 REVS.	90 REVS.	100 REVS.	150 REVS.	200 REVS.	

Figure 3. A sample current meter rating table.

.0 .10 .20 .30 .40 .50 .60 .70 .75

River at—

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge	
												.80
	79	4.5	REW		OG 4.83 at 1300							
1°	70	7	0.67	4	20	47		.948		4.69	4.47	.85
1°	65	5	1.08	4	25	49		1.13		5.40	6.10	
1°	60	5	1.12	4	25	44		1.26		5.60	7.06	
1°	55	5	1.18	4	30	40		1.66		5.90	9.79	.90
1°	50	4.5	1.23	4	40	53		1.67		5.54	9.24	.92
1°	46	4	1.28	4	40	52		1.70		5.12	8.70	.94
1°	42	3.5	1.42	4	40	52		1.70		4.97	8.45	
1°	39	3	1.46	4	40	50		1.76		4.38	7.71	.96
1°	36	3	1.48	4	40	49		1.80		4.44	7.99	.97
1°	33	3	1.48	4	40	47		1.88		4.44	8.35	.98
1°	30	3	1.60	2	30	43	1.54	1.80		4.80	8.64	.99
				8	40	43	2.05	3.59				
1°	27	3	1.71	2	30	43	1.54	1.84		5.13	9.44	
⊙				8	40	41	2.15	3.69				1.00
1°	24	3	1.95	2	30	45	1.47	1.81		5.85	10.6	
				8	40	41	2.15	3.62				
1°	21	3	1.99	2	30	47	1.41	1.73		5.97	10.3	.99
				8	40	43	2.05	3.46				.98
1°	18	3	2.04	2	25	43	1.29	1.62		6.12	9.91	.97
				8	40	45	1.96	3.25				.96
1°	15	3	2.00	2	25	44	1.26	1.68		6.00	10.1	
				8	40	42	2.10	3.36				.94
1°	12	3	1.80	2	25	44	1.26	1.46		5.40	7.88	.92
				8	30	40	1.66	2.92				.90
1°	9	3	1.60	2	25	46	1.20	1.39		4.80	6.67	
				8	30	42	1.58	2.78				
1°	6	2.5	1.02	4	20	50		.892		2.55	2.27	.85
	4	1	LEW		OG = 4.82 at 1345							
	——	——								——	——	
	75	75								97.1	154	.80

.0 .10 20 .30 .40 .50 .60 .70 .75

Figure 4. Discharge measurement form. The dot on the left side, the angle coefficients around the edge of the form, and a straight edge are used to measure the horizontal angle coefficient.

U. S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION
RESEARCH DIVISION

Meas. No. 169

Comp. by Hunt

Checked by ____

DISCHARGE MEASUREMENT NOTES

WASHITA RIVER NR ALEX

Date June 24, 1964 Party Price

Width 75 Area 97.1 Vel. 1.58 G. H. 4.83 Disch. 154

Method ____ No. secs. 19 G. H. change -.01 in 3/4 hrs. Susp. Rod

Method coef. ____ Hor. angle coef. ____ Susp. coef. ____ Meter No. FE 50

GAGE READINGS				
Time		Recorder	Inside	Outside
1300		4.83	4.83	4.83
1345		4.82	4.82	4.82
Weighted M. G. H.				
G. H. correction				
Correct M. G. H.				

Date rated ____ Used rating for rod ____ susp. Meter ____ ft. above bottom of wt. Tags checked OK

Spin before meas. 2+ after 2+

Meas. plots ____ % diff. from ____ rating

Wading, cable, ice, boat, upstr., downstr., side bridge 300 feet, mile, above, below gage, and ____

Check-bar, chain found ____ changed to ____ at ____

Correct ____

Levels obtained ____

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions: Cross section Sand bed

Flow Falling slowly Weather Clear, Hot, Humid

Other Very little turbulence Air ____ °F@ ____

Gage OK Water ____ °F@ ____

____ Record removed No Intake flushed ____

Observer ____

Control Channel

Remarks New recorder chart needed before 18 days.

G. H. of zero flow 2.0 ft.

SWC Form 25
April 1959

Figure 5. Form for discharge measurement supplementary data and accuracy rating. To evaluate the accuracy of the measurement, existing conditions are recorded by the hydrographer in the field.

Factors Affecting the Accuracy and Precision of Current Meter Measurements

<u>Training, experience, and interest of the hydrographer</u>: The inexperienced hydrographer must be given adequate supervision so that the correct stream gaging procedure will be acquired at the outset. As the hydrographer acquires experience, he becomes more proficient and thus is able to perform difficult discharge measurements with greater accuracy. Time is a precious asset during floods. The stream stage often changes rapidly, and many measurements are needed. Therefore, the hydrographer must be capable of working rapidly, often into and through the night.

<u>Use and care of equipment</u>: Frazier's (5) "Care and Rating of Current Meters" contains detailed instructions for servicing the current meter. The meter and stop watch are the two most delicate items of gaging equipment and must be handled and packed as such. The stop watch can be protected from moisture by keeping it in a transparent plastic bag. Should the watch become exposed to moisture, it should be thoroughly dried on the exterior before packing and examined internally for presence of moisture before storing.

The meter is given a spin test in quiet air immediately before and after each discharge measurement. Corbett (4) stated that if the velocity is less than one foot per second, the meter should have an initial spin test of at least two minutes and should not stop abruptly. A meter with a spin test of less than one minute should be used to measure high velocities only.

<u>Selection of measuring section</u>: The cross section selected for a discharge measurement should meet the following requirements if possible:

1. The section must be accessible.
2. The section should be near the stage recorder and perpendicular to the direction of stream flow.
3. There should be a straight and uniform channel for a distance upstream equal to at least five times the width of the stream and for a distance downstream equal to twice the width of the stream.
4. No more than 15 percent of the flow should have a velocity less than 0.5 foot per second, and the maximum velocity should not exceed 4 feet per second.
5. There should be no large overflow section at flood stage.

Accuracy of the Price meter is poor in flow depths less than 0.5 foot. If more than 15 percent of the flow is less than 0.5 foot deep, a pygmy meter should be used in lieu of the Price meter. If there is a large amount of flow less than 0.2 foot deep, an artificial section should be created by building a small dike out into the flow and downstream a distance which depends on the new flow width.

<u>Turbulent flow</u>: Results of research by Murphy (11), Groat (7), and Yarnell and Nagler (20) agreed that vertical-shaft, cup-type meters will overregister in turbulent flow and that horizontal-shaft, propeller-type meters will underregister. These experiments indicated that in turbulent water, the cup-type meter will usually overregister considerably more than the propeller-type meter will underregister. Groat (7, p. 821) stated, "In boilers of considerable violence the cup-meter may easily overregister by 25 percent while the screw-meter will underregister by

not more than 3 or 4 percent." Wisler and Brater (19, p. 383) and Corbett (4, p. 71) suggested that when a turbulent condition exists, the measurement be made with both a cup and a screw-type meter and the results averaged.

In some streams, a gaging section that is always free of turbulence cannot be found. Methods of gaging other than the velocity-area method may be more accurate for these streams. If piers and piling cause considerable turbulence under an existing bridge, then the engineer must weigh the need for accurate discharge measurements against the expense of spanning the stream with a special bridge or cableway.

Spacing of verticals: "Verticals should be so spaced as to disclose the real shape of the bed and the true mean velocity of the flowing water," said Corbett (4, p. 68). He also said that the channel should be divided into 20 or more parts with the exception of very small streams, and that there should preferably be not more than 5 percent of the discharge between any two verticals. This is a general rule that the United States Geological Survey applies under conditions of reasonably steady flow. However, when a condition of rapidly changing flow exists, greater accuracy is probably achieved by reducing the number of verticals in order to complete the measurement with less change in stage.

Prochazka (16, p. 506) indicated that the variation of measured mean velocity from true mean velocity varies inversely with the square of the number of measured verticals. Anderson (1) studied the error caused by nonuniform variation of depth and velocity through the gaging section and found the error to be approximately 2.5 percent when observations are made at 20 verticals.

<u>Measurement of depth</u>: Discharge is the product of area and velocity. Therefore, any inaccuracy in measurement of depth results in a corresponding error in area and discharge. Causes of error in determination of depth are: (1) Repeated churning of the stream bed by raising and lowering the meter assembly before the depth is read, (2) failure to correct for vertical angle caused by insufficient weight on the cable, (3) changes in depth caused by movement of dunes through the section, (4) failure to measure or record the depth correctly, and (5) incorrect zeroing of the meter. The first two sources of error can be easily corrected if their existence is known. When dunes are moving through the section, the accuracy of a discharge measurement probably could be improved by averaging the depths measured before and after the velocity observation. Incorrect reading and recording of observations and zeroing of the meter can be overcome only by conscientious effort on the part of the hydrographer.

<u>Vertical and horizontal motion of meter</u>: The cable suspended current meter always has a certain amount of vertical and horizontal motion. Insufficient weight on the meter permits it to sway. When it swings in any direction, it operates nearer the surface and, therefore, will usually indicate a velocity greater than that at the selected point in the vertical. Corbett (4) considered the horizontal motion to be relatively insignificant because each cycle is compensating. This hypothesis is probably correct for motion parallel to the direction of flow. However, motion of the meter in any other direction probably tends to increase the registered velocity of a cup-type meter. Movement of the meter can be partially overcome by using larger weights.

Wind: Wind may affect the vertical velocity distribution, the horizontal angle coefficient, and the position of the meter in the vertical. Corbett (4, p. 75) stated, "It is generally recognized that severe wind precludes accurate current meter measurements, as either upstream or downstream wind may seriously affect the movement of the water near the surface."

Drift and aquatic growth in channel: Drift and aquatic growth in the stream may reduce the meter registration and alter the vertical velocity profile. Under these conditions, frequent meter inspections and spin tests must be made.

Velocity pulsations: Murphy (11, p. 11) reported, "Lesser velocity fluctuations have a duration of 30 to 60 seconds and larger ones 5 to 10 minutes." Murphy also observed that these pulsations below the surface are not synchronous with the surface fluctuations and are smaller at the surface than near the bottom of the channel. "Harlacher found the velocity near the surface of the Rhine to vary 20 percent in a few seconds, and near the bottom, he found it to vary 50 percent in the same period," Murphy stated. Murphy made no conjecture concerning the cause of these velocity pulsations, but Lidell (10, p. 12) speculated, "These pulsations are probably due to the movement through the water of the eddies and vortices in such a way as to bring about a constant interchange of paths or currents moving at different speeds." The author believes that movement of debris and sand dunes along the stream bed is the primary cause of large pulsations in velocity.

Anderson (1) compared the mean velocity at a point for short time periods with the mean for a 2-hour period. He found the measurement velocity pulsation error was $4.3/\sqrt{n}$ when individual velocities were observed for a 45-second time period and the 0.2-0.8 depth method of velocity observation was used at n locations within the cross section.

Distribution of velocity in the vertical: To locate the thread of mean velocity, the United States Geological Survey (4) made extensive studies of variation of velocity with depth of flow. Location of the thread of mean velocity is given for various flow depths in Table II. Total depth and distance to points within the vertical are measured down from the water surface.

TABLE II

LOCATION OF MEAN VELOCITY WITHIN A VERTICAL

Flow Depth (feet)	Depth of Mean Velocity below the Water Surface
Less than 0.5	0.5
0.5 - 1.5	0.6
Greater than 1.5	Avg. of 0.2 and 0.8

Murphy (11) concluded that the distance of the thread of mean velocity below the surface increases with the ratio of depth to width of the stream. He said that generally the thread of mean velocity is located at about 0.55 to 0.65 of the depth.

Change of stage during measurement: A significant change in stage and rate of discharge usually occurs during a measurement of storm run-off from a small watershed. Thus, determining the appropriate stage for a discharge measurement is difficult. Following are three possible solutions to this problem:

1. Install the gaging station at an existing stable control; or if none exists, construct an artificial control and establish the stage-discharge relation by modeling.
2. Apply the integral section rating procedure.
3. Reduce the time required for a discharge measurement.

Development of the stage-discharge relation by modeling the control and approach topography is satisfactory if the control is nearly complete. The modeling method is often used on small, flashy watersheds.

In the integral section rating procedure, the channel is divided into a number of predetermined sections. During the period of storm runoff, the velocity is observed at each section a sufficient number of times to adequately define a rating curve for each section. The section rating curves are then combined to make up a composite or integrated rating curve for the station. The procedure requires considerable extra computation time.

The following four methods are used to reduce the time required to complete a discharge measurement:

1. Use two or more sets of equipment.
2. Reduce the number of velocity observations in a vertical, 0.2 method.
3. Reduce the number of sections.
4. Reduce the duration of velocity observation.

The first method is the most suitable if gaging accuracy is of major importance and sufficient equipment and personnel are available. Each of the latter three methods undoubtedly reduces the measurement accuracy compared to the accuracy of a measurement made using the normal procedure under a condition of steady flow. In the second method the velocity is observed at 0.2 depth only, and a suitable coefficient is applied to the measured velocity to obtain the mean velocity in the vertical. This coefficient may vary with station in the section and flow depth. If only a limited number of measurements have been made at a gaging station, the necessary coefficients may not be available.

Angle of current: The horizontal angle is the complement of the angle between the direction of water movement and the gaging section. The correction coefficient, or cosine of the horizontal angle, is determined by holding the discharge data form parallel to the gaging section, then placing a straightedge or pencil over the pivot point and lining the pencil up with the direction of water movement. The angle cosine may be observed under the straightedge on the side of the paper opposite the pivot point.

Errors of one percent or more can easily be made if the angle cosine is less than 0.97. Therefore, the gaging section should be nearly perpendicular to the stream flow lines. An assumption in the correcting procedure is that the angle observed on the surface of the water is representative of the one prevailing throughout the vertical. This assumption is probably fallacious when conditions of turbulence or strong winds exist.

<u>Suspension coefficient</u>: Current meters are usually rated on rod suspension only. Coefficients are applied to rod suspension ratings to obtain appropriate ratings for cable suspension measurements. One of the conclusions Murphy (11) made was, "When the most accurate results are desired the meter should be held with a rod and not given freedom to tip." He also stated, "A small Price meter will revolve faster in moving water of a given velocity when held with a rigid rod than when held with a cable. Hence the same rating table will not answer for both."

If the coefficient is significant, Frazier (5) recommended applying it directly to figures of velocity or discharge during the computation of a cable suspension measurement because this eliminates the necessity of carrying a large number of rating tables on field trips. Frazier's report contained a table of recommended coefficients for various sizes of weight and velocities of flow. For the Columbus type weights these coefficients ranged from 0.995 to 1.02.

The W. & L. E. Gurley Company made the following notation on rating tables supplied with their 622 type Price current meter, "This table applies when measurements are made with meter suspended by cable. When measurements are made with meter suspended by rod, reduce the tabular velocities by 2 percent." This recommendation tends to agree with those of Murphy and Frazier.

Precision of Current Meter Measurements

In the United States the stream gaging standards of the Surface Water Branch of the U.S. Geological Survey are commonly accepted. The Survey has established the following criteria for rating the accuracy of a discharge measurement: (1) Excellent, 2%; (2) good, 5%; (3) fair, 8%; and (4) poor, over 8% from the true discharge rate.

Anderson (1) found that if the velocity and depth are observed at 20 or more locations in the cross section, the error in the total discharge is expected to be less than 3 percent for 67 percent of the discharge measurements. Furness (6) reported an average deviation of 3.3 percent and a standard error of estimate of 4.9 percent for 28 replicated measurements of shallow flow with a pygmy meter. This indicates that measurements of low flow rates may be less precise than those at higher rates.

The U.S. Geological Survey classifies records of mean daily flow as "excellent" if, in general, the error in the daily records is believed to be less than 5%; "good," less than 10%; "fair," less than 15%; and "poor," probably more than 15%. Trestman (18) implied that Russian hydrographers had available in 1960, techniques which would reduce the margin of error of runoff determinations to ± 3 to 5 percent, but that the techniques were not being utilized.

CHAPTER IV

PROCEDURE

Comparison of Rod and Cable Suspension Measurements

This experiment was designed to achieve all three of the stated objectives. Discharge measured by the cable suspension method was compared to discharge measured by the rod suspension method. In the first test, eleven hydrographers each made one cable suspension measurement and one rod suspension measurement of flow at the gaging station on the Washita River near Chickasha (4th St.), shown in Figure 6. Depth of flow during this test averaged about 2.0 feet and the mean velocity was in the range from 1.0 to 1.5 feet per second.

A difference detected between the methods was first attributed to incorrect gaging procedure. Therefore, a second test was planned. The gaging station on the Washita River at Anadarko (Figure 7) was selected for the second test because at that station the stream had a rock bed. Before the test at Anadarko, the author believed that more accurate measurements could be made on the rock, and thus the experimental error should be reduced. The depth of flow during the Anadarko test averaged about 2.0 feet, same as during the previous test at 4th Street; but the mean velocity ranged from 2.4 to 2.9 feet per second. Fewer hydrographers were available for this test, so only six rod and cable suspension comparisons were made.

Figure 6. Location of gaging station on Washita River near Chickasha (4th St.). The arrow points to a limb which caused reverse flow along the right bank in the cable suspension section.

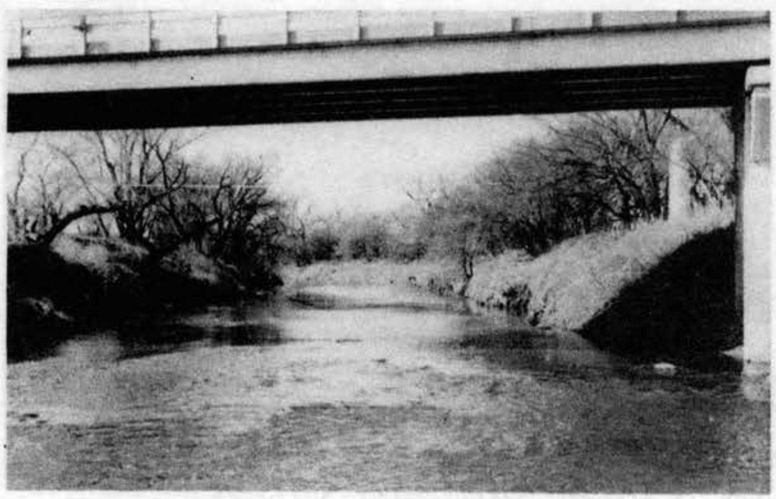

Figure 7. Location of gaging station on Washita River at Anadarko. The water flows over a sandstone bedrock.

Restrictions on the stream gaging procedure were minimized to avoid introducing bias that would hinder accomplishing objectives 2 and 3. The gagers were each permitted to assemble their own equipment, select the number and location of the verticals at which the velocity would be observed, and in general, proceed with their normal stream gaging procedure. To minimize environmental and learning bias, half of the group made the rod measurement first, and the other half made the cable measurement first.

The experiment had some necessary restrictions as follows:

1. The flow depth was deep enough to be practical for crane measuring and yet shallow enough for wading.
2. All measurements were made without a significant change in stage or probable shift in control.
3. Measurements were made in daylight between 8:00 a.m. and 5:00 p.m.
4. The weather was mild.

Each hydrographer was instructed to make both measurements with the same meter and work independently of other gagers. The 30-pound Columbus weight with 0.5 foot between the meter and the bottom of the weight was used for all cable suspension measurements. All gagers used the same type non-self setting rod, shown in Figure 1. At 4th Street, three sets of nearly identical cable suspension equipment were used; but at Anadarko, two different types of crane with different boom lengths were used. The cable suspension measurements were made from the upstream side of the bridge at both 4th Street and Anadarko. At 4th Street, the wading measurements were made in 5 different sections within 200 feet of the cable suspension section. At Anadarko, 5 of the rod suspension measurements were made in two sections about 80 and 120 feet upstream from the cable suspension section, and one rod suspension measurement was made in the cable suspension section.

Special measurements were made as follows:

1. Velocity was measured at ten evenly spaced locations in each of three verticals at 4th Street.
2. Flow depth was carefully measured with the wading rod at two foot intervals in the long crane boom section at Anadarko.

The stage changed slightly during both tests. Therefore, to make each measurement be an estimate of a common discharge, the measurements in each test were adjusted to a common stage. The 4th Street measurements were adjusted to a stage of 8.88 feet. The Anadarko measurements were similarly adjusted to a stage of 7.82 feet. Figure 8 shows the adjustment method. The slope of the slanting adjustment lines was determined from the station stage-discharge relation within the range of stage shown.

Comparison of Meter Registration on Rod and Cable Suspension

This experiment was planned specifically for achievement of objective 1. The experimental design was a factorial arrangement of treatments in a completely randomized experiment. The time required for 40 revolutions of the meter was recorded at four locations within the vertical, 2/10, 4/10, 6/10, and 8/10 depth. Tests were made with the 30- and 50-pound weight and the meter on cable suspension and with the meter on rod suspension. Each test was replicated 3 times. Observations were also made with the 30-pound weight and the meter blocked to prevent tipping.

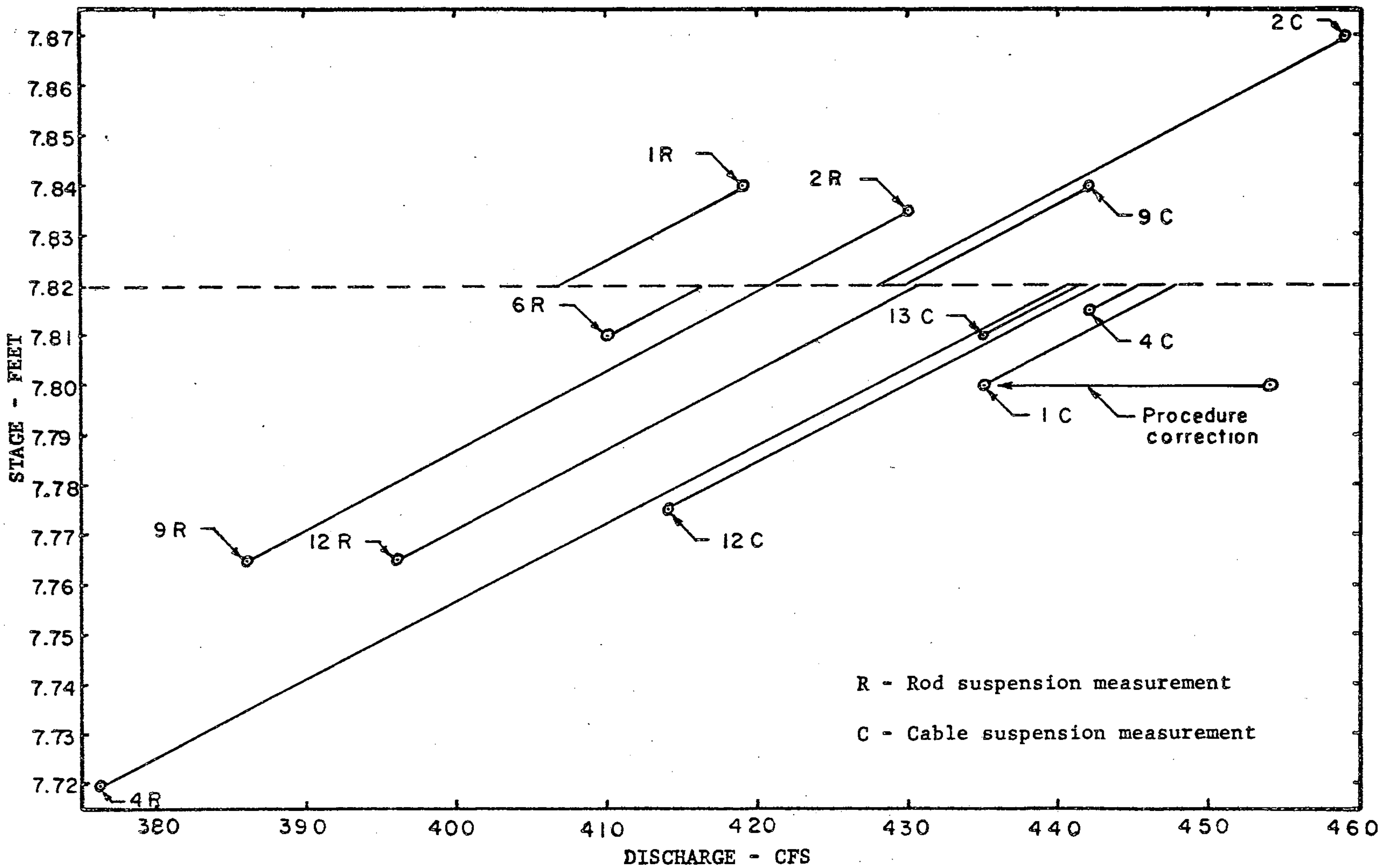

Figure 8. Adjustment of the Anadarko discharge measurements to a common stage. Slope of the adjustment lines was obtained from the station rating. A number was assigned to each hydrographer.

This experiment was conducted in the Washita River near Chickasha (4th St.) where there was suitable flow depth, 2.6 feet.

Placement of the meter at the same location by both rod and cable suspension was achieved by raising the cable supported weight to a location where the bottom of the weight was slightly more than four feet above the stream bed. The wading rod was then held under the weight with the rod six inches downstream from the cable and the rod base resting on the stream bed.

Precision of Current Meter Measurements at Weir Control Stations

To determine the probable error in random discharge measurements, 168 discharge measurements made at five tributary, weir controlled gaging stations were analyzed. A typical weir control is shown in Figure 9. The V-notch weir partially stabilizes the stage-discharge relation.

Depth of flow in feet was plotted against measured discharge in cubic feet per second. The measurements at each gaging station were plotted on separate sheets of log-log paper. If the points did not appear to define one straight line, breaks in the series of points were selected so that the points were grouped about two or more line segments. A logarithmic transformation was applied to the depths and discharges and a line segment was fitted to each series of points by the method of least squares programmed for an electronic computer. The computer also prepared a rating table for each gaging station.

The percent of deviation of the measured discharge from the rating table discharge and the average deviation of measurements at each gaging station were computed. To further evaluate the degree to which the

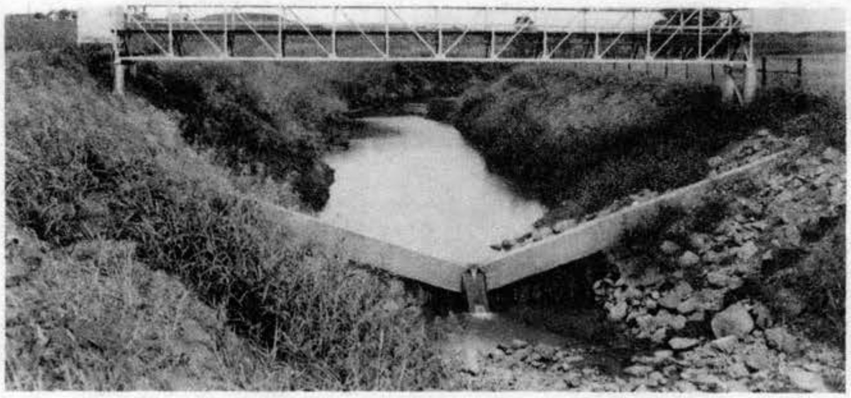

Figure 9. A typical weir control. This is the East Bitter Creek V-notch weir which has a slope of 3:1.

measured discharge deviated from the rating table, the probable error, σ, was calculated from the formula (18),

$$\sigma = 0.674\sqrt{\Sigma(\Delta x)^2/n}$$

where x is the deviation expressed as a percentage (see Appendix C) and n is the total number of measurements. The probable error was also computed for discharge measurements greater than one cfs.

CHAPTER V

RESULTS

Rod Versus Cable Suspension Measurements

Analysis of variance: Analysis of variance for both the 4th St. and Anadarko tests indicated a significant difference at the 95 percent confidence level between the rod and cable suspension discharge estimates. The coefficient of variation of the difference at 4th St. and Anadarko was 5.29 percent and 3.33 percent, respectively. Examination of the data in Appendix A revealed that in all comparisons except one, the cable suspension measurement gave a greater discharge than the corresponding rod suspension measurement. The average difference was about 4.3 percent. All of the cable suspension measurements were reduced 4.3 percent. The deviation of each measurement, rod and cable, from the mean discharge of its respective test was computed. Then the accumulated percent of discharge measurements that deviated from the mean discharge less than certain indicated amounts was plotted. The result is shown in Figure 10.

Standard deviations of the cable measurements at 4th St. and Anadarko were 3.6 and 2.0 percent, respectively. The corresponding standard deviations for the rod measurements were 2.4 and 2.8 percent. This indicates that some improvement was made in the second test in the cable suspension measuring precision, but not in the rod suspension measuring precision.

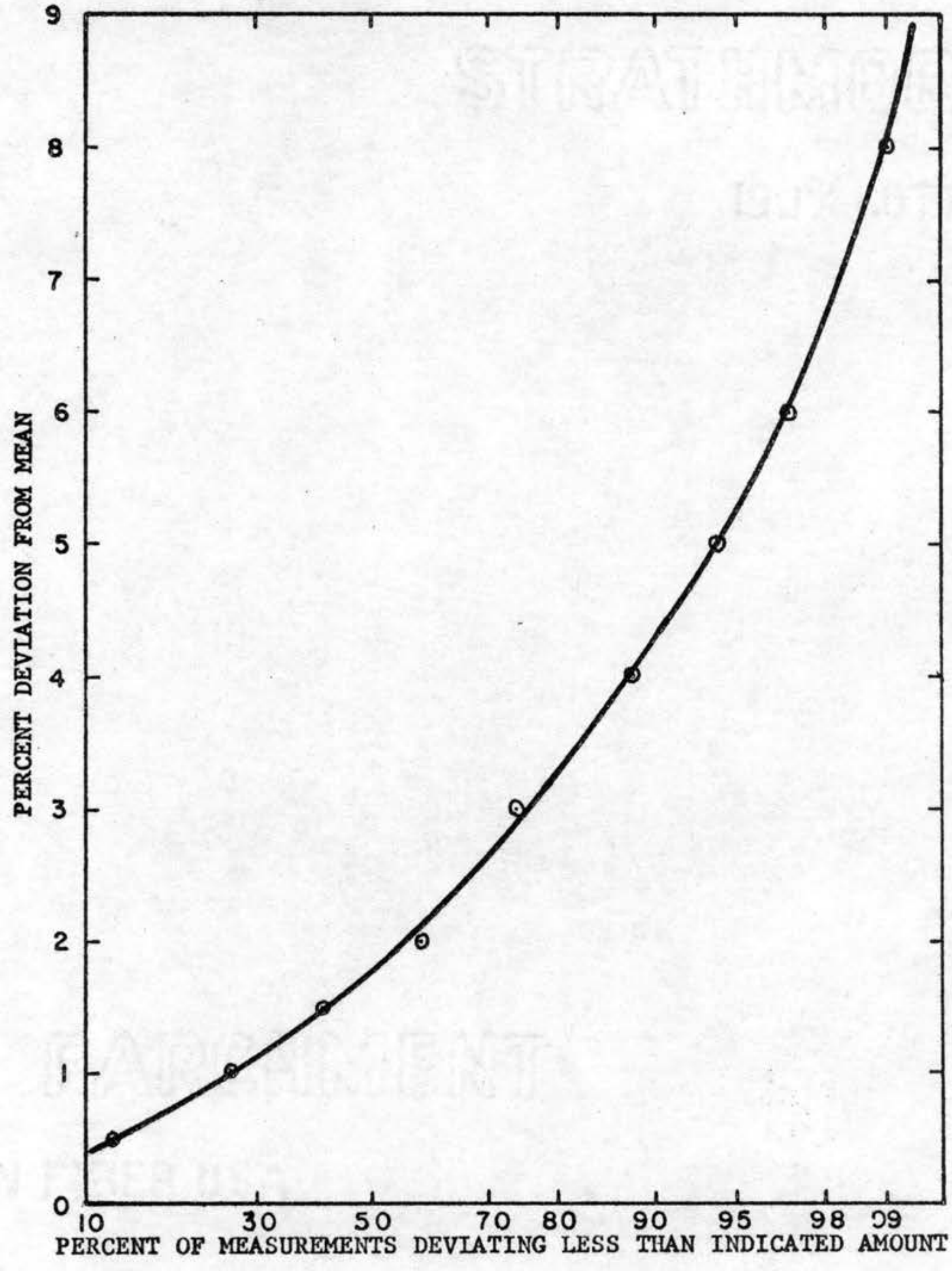

Figure 10. Accumulated percent of Anadarko and 4th St. test discharge measurements that deviated from the respective mean discharge less than indicated amounts.

The unexpected lack of greater precision in the rod suspension measurements at Anadarko may have been caused by the higher velocity which tends to reduce the precision of the depth measurements. However, the average deviation (rod and cable) was less at Anadarko than at 4th St.

Stream gaging experience of the hydrographers who participated in these tests varied greatly. However, the analysis of variance indicated there is very little if any difference in measuring precision among hydrographers. Examination of the discharge measurement summaries in Appendix A did not indicate a correlation between gaging experience and measurement precision. Failure to detect a difference in precision among hydrographers may have been influenced by the presence of an observer and the other hydrographers and also by the lack of replication in the experimental design.

Procedural errors: During the 4th St. test, two or three of the hydrographers were often seen standing directly behind the wading rod while taking a velocity observation. Nothing was said about this during the experiment. Hydrographer no. 10 stood behind the wading rod throughout most of his measurement. Appendix A shows that his rod suspension measurement gave the lowest estimate of discharge of all measurements in the 4th St. test which is what might be expected.

The distance from the center of the meter cups to the bottom of the 30-pound Columbus weight is 0.5 foot. Therefore, if the depth was less than 2.5 feet, the velocity should have been observed at 0.6 depth in lieu of 0.2 and 0.8 depth. Four of the eleven cable suspension measurements made at 4th St. included two or more 0.2 and 0.8 depth velocity observations where the depth was less than 2.3 feet. These observations were probably taken with the weight in a scour hole or with a slack cable.

The only procedural error noted during the Anadarko test was that hydrographer no. 1 took velocity observations at 0.4 rather than 0.6 depth in his cable suspension measurement. This type of error has often occurred on the Washita project because most of the hydrographers gage storm flow only, and thus fail to remember the detailed procedure after perhaps several months with no gaging experience. Probably, this type of error is usually detected; therefore, an adjustment as shown in Figure 8 seemed to be justified before computing the analysis of variance. The adjustment had to be made in 10 of the 18 verticals. The average velocity determined at each of those verticals by the other cable suspension measurements was substituted for the incorrect value.

Velocity: Comparison of velocities in different cross sections is meaningless because the true average velocities probably were not equal. However, in the cable suspension section at 4th St., the mean measured velocity was 1.256 feet per second. The standard deviation of the mean measured velocities was .090; the standard error of estimate was .027; and the coefficient of variation was 7.13 percent.

Profiles of velocity estimated with the meter on rod suspension at three verticals in section number 5 at 4th St. are shown in Figures 11, 12, and 13. Duration of each velocity observation was 40 to 50 seconds. Failure of the points to define a smooth curve was probably caused by velocity pulsations and inaccuracy of the meter near the water surface and stream bed. If the observation periods had been longer and a pygmy meter used instead of the Price meter, more accurate profiles of velocity probably would have been obtained. To estimate the mean velocity in the vertical, three methods were used: (1) Ten point, equally spaced; (2) one point, 0.6 depth; (3) two point, 0.2-0.8 depth. See Table III.

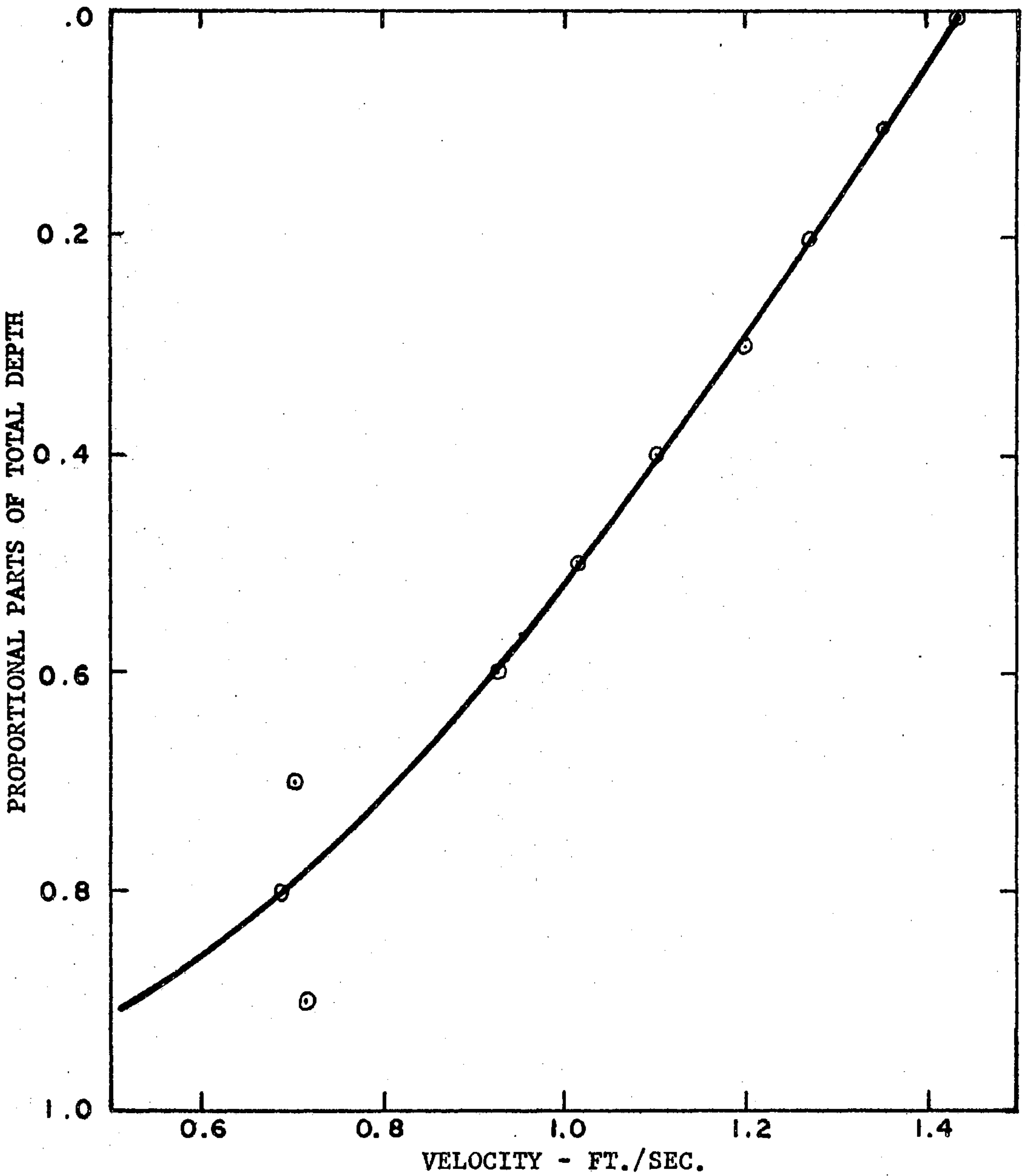

Figure 11. Vertical velocity profile at station 17.5 in cross section No. 5 of the Washita River near Chickasha (4th St.), Oklahoma.

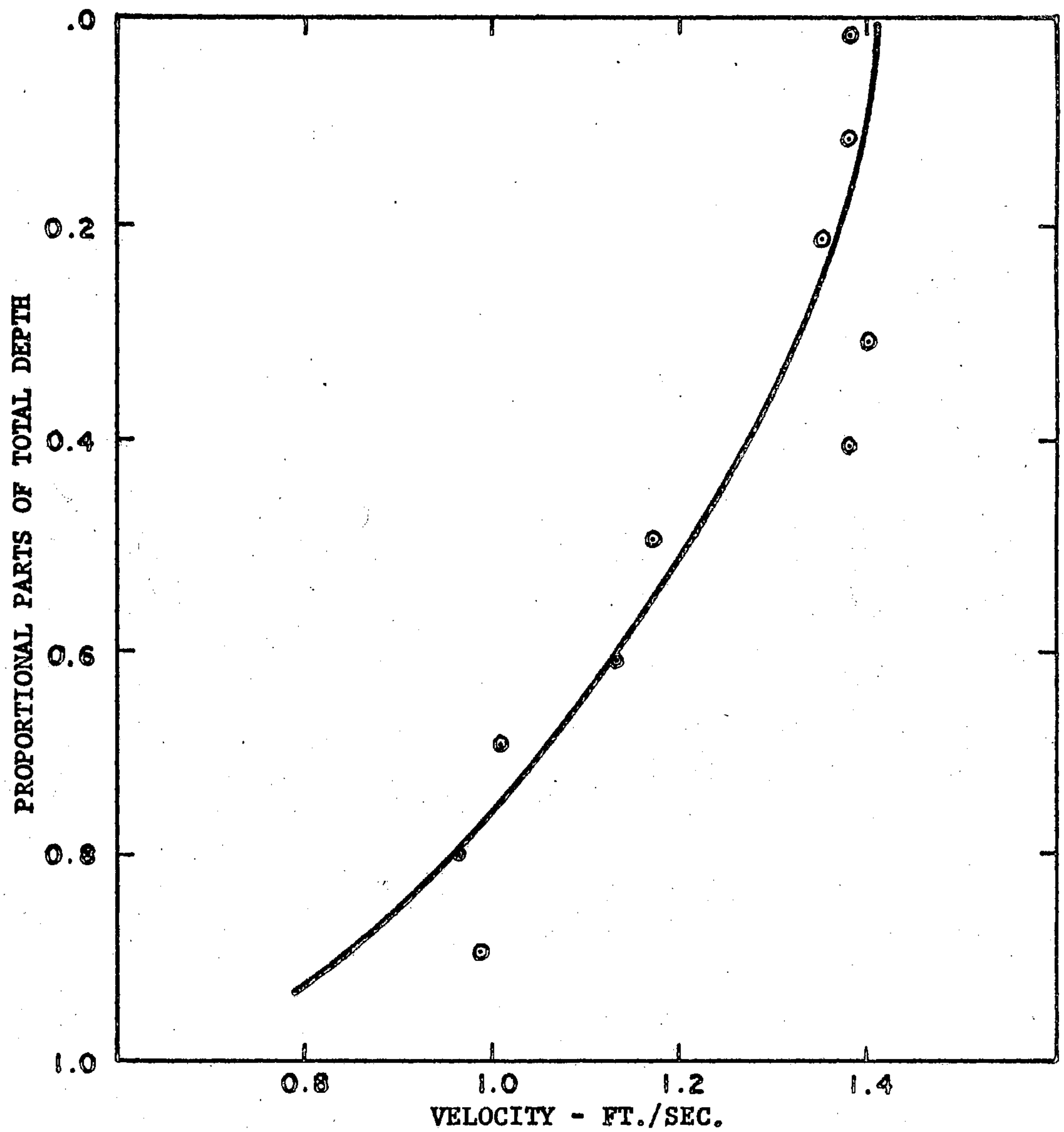

Figure 12. Vertical velocity profile at station 19 in cross section No. 5 of the Washita River near Chickasha (4th St.), Oklahoma.

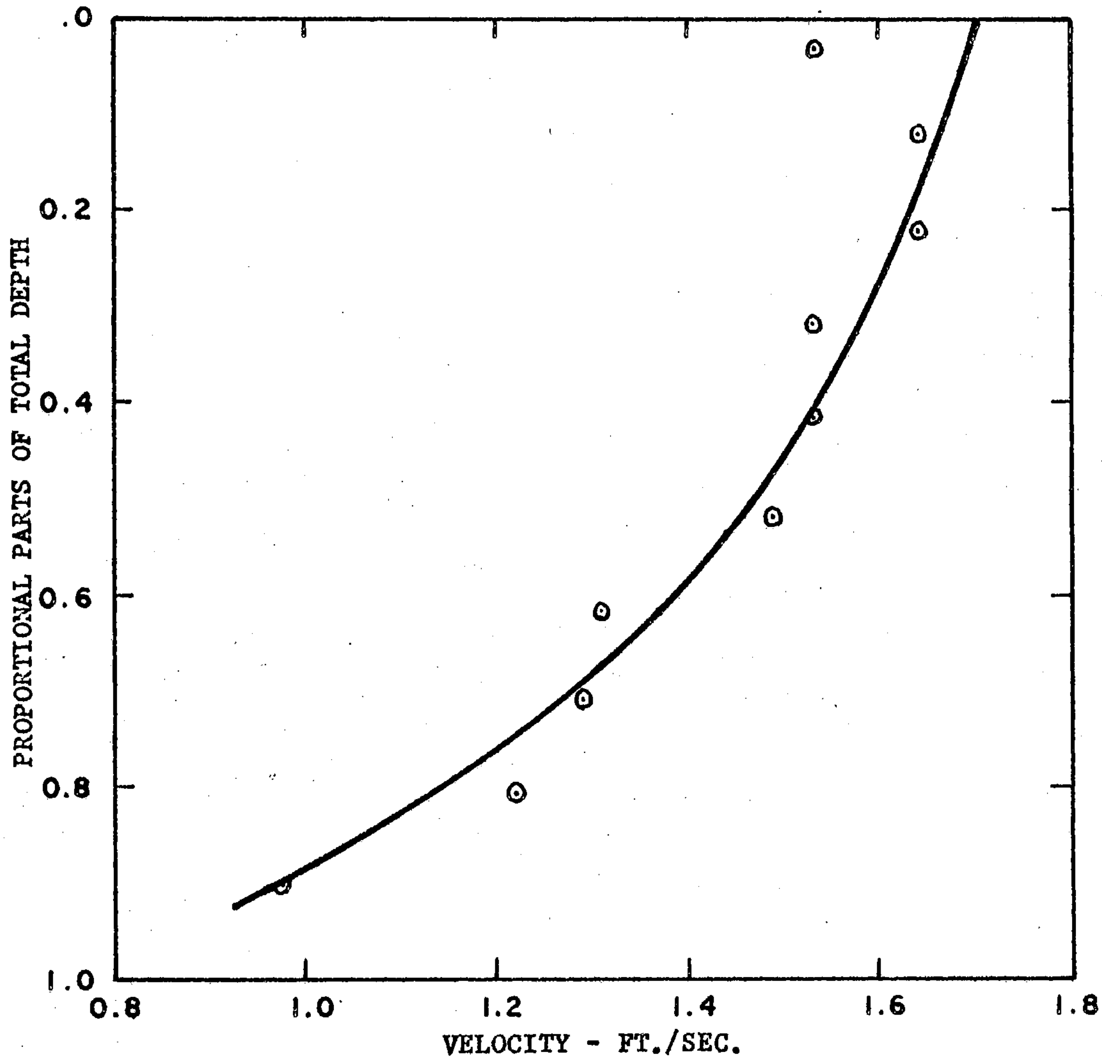

Figure 13. Vertical velocity profile at station 20 in cross section No. 5 of the Washita River near Chickasha (4th St.), Oklahoma.

The ten point method may not have been as accurate as the two point method because the Price meter is inaccurate near the water boundary. As the flow depth decreased, the velocity estimated by the two point method was successively greater than that estimated by the one point method.

The preceding discussion reveals that the average discharge measured by cable suspension would have been greater if the two point method had been used in nearly all of the verticals as it was in the rod suspension measurements. The average difference between the cable and rod suspension measurements would then have been even greater than the existing 4.3 percent.

TABLE III

COMPARISON OF METHODS OF MEAN VERTICAL VELOCITY ESTIMATION IN CROSS SECTION NO. 5 AT 4TH ST.

		Method of estimation of mean velocity in the vertical			
Station no.	Flow depth	Ten point (1)	One point 0.6 depth (2)	Two point 0.2-0.8 depth (3)	% Difference between col's. (2) and (3)
17.5	3.02	1.04	.925	.978	5.4
19	2.78	1.21	1.13	1.16	2.6
20	2.48	1.42	1.37	1.40	2.1

Width: Measured width in the cable suspension section at both 4th St. and Anadarko varied over a range of three feet. If the hydrographer's judgment indicated that a more accurate measurement of flow in the end section would result by calling the edge of the water somewhat different from that which was observed, it was permissible to do so. However, the difference in width was probably unintentional error resulting from the hydrographer's great distance (about 30 feet) above the water. In contrast, the width for all measurements in the rod suspension section at Anadarko was 80 feet.

Depth: Hydrographer no. 12 carefully measured the depth of flow at two feet intervals in the long boom, cable suspension section at Anadarko, and hydrographer no. 5 made a rod suspension measurement in the same section. The difference between discharge measurements made by rod and cable suspension apparently did not result from a consistent bias in cable suspension depth measurements as indicated in Table IV. The mean depths were each adjusted to a common gage height, 7.82 feet. The average difference between depths measured by the two suspension methods was less than one percent.

TABLE IV

MEAN DEPTH OF ANADARKO, LONG BOOM SECTION MEASUREMENTS ADJUSTED TO GAGE HEIGHT, 7.82 FEET

Hydrographer no.	Mean depth, cable suspension	Mean depth, rod suspension
2	1.98	
3	2.07	
5	1.99	2.02
6	2.09	
12		2.08
	Avg. 2.03	Avg. 2.05

Horizontal angle coefficients: The weighted angle coefficients for the cable suspension section at 4th St. and the two sections at Anadarko are shown in Table V. The weighted angle coefficients were computed by summing the products of angle coefficients and discharge for each section of the gaging cross section and then dividing by the total discharge.

TABLE V

WEIGHTED HORIZONTAL ANGLE COEFFICIENTS

Hydrographer no.	Weighted angle coefficients: 4th St. Cable section	Weighted angle coefficients: Anadarko Rod section	Weighted angle coefficients: Anadarko Cable section
1	.990	.997	.984
2	.989	.999	.985
3	.967		
4	.975		.980
4			.968*
5	.989		
6	.991	.997	
7	.996		
8	.987		
8	.989		
9	.988	.997	.978
11	.989		
12		.988	.976
13			.976

*Rod suspension measurement in cable suspension section

Table V shows that when the angle coefficient is larger than about 0.97 there is little variation in the coefficient observation among hydrographers. However, the author believes there was a tendency for the station hydrographers to over estimate the angle coefficient. For instance, in the 4th St. cable suspension section, the coefficient observations of hydrographers no. 3 and 4 were probably nearer the true value than the observations of the other hydrographers. This overestimation of the cable suspension, horizontal angle coefficients probably compensated for the error discussed under the heading of <u>Velocity</u> on pages 34 and 38.

<u>Area</u>: Measured area in the cable suspension section at 4th St. varied from 70.3 to 91.8 square feet. This great variation was largely the result of difference in measuring an area of reverse flow along the right bank. Four of the eleven hydrographers did not indicate a reverse flow in their notes, and, therefore, measured somewhat more flow in the first few sections.

<u>Number of sections</u>: The mean number of sections per measurement at 4th St. was 19.9 and at Anadarko the mean number was 22.7. Although this was not enough sections to abide with the rule of having no more than five percent of the flow in any one section, the time required for additional sections probably could not be justified especially in a flat-bottomed section such as that at Anadarko.

<u>Time</u>: The average time required per section was computed for each of the 4th St. measurements. The average time per section varied from 2-3/4 minutes to 6-3/4 minutes. The more experienced hydrographers completed their measurements in the least time. The data did not show any consistent relationships between total time required for a measurement and measurement precision; however, in the 4th St. test the most precise measurements were made by hydrographer no. 4 (See Appendix A). Examination of the discharge notes revealed that the duration of his

velocity observations was seldom less than 50 seconds, and the duration of velocity observations of the other hydrographers was seldom greater than 50 seconds.

Gage readings: There was considerable dispersion of the outside gage readings at both 4th St. and Anadarko. Gage readings taken during the 4th St. and Anadarko tests are shown in Figures 14 and 15, respectively. Although the gage height reading does not affect the accuracy of a discharge measurement, it does affect the accuracy of the stage-discharge relation. At 4th St., hydrographer no. 1 apparently reversed some of the recorder and outside gage readings. This would not have been noticed if the other readings had not been available for comparison.

Comparison of Meter Registration on Rod and Cable Suspension

Registration of the meter varied little with size of weight and blocking of the meter to prevent tipping. Although the difference was not statistically significant, blocking of the meter did reduce the measured velocity slightly at each of the four test locations as shown in Figure 16. At 0.6 and 0.8 depth, the measured velocities did not indicate a significant difference between rod and cable suspension. However, the difference in registration was great, about nine percent, at 0.2 and 0.4 depth. Using the 0.2 and 0.8 depth method, the mean velocity measured by cable suspension was about 0.87 feet per second and by rod suspension about 0.83 feet per second, with a difference of 4.7 percent. This difference was somewhat greater than the average difference, 4.3 percent, in discharge measured by rod and cable suspension at 4th St. and Anadarko.

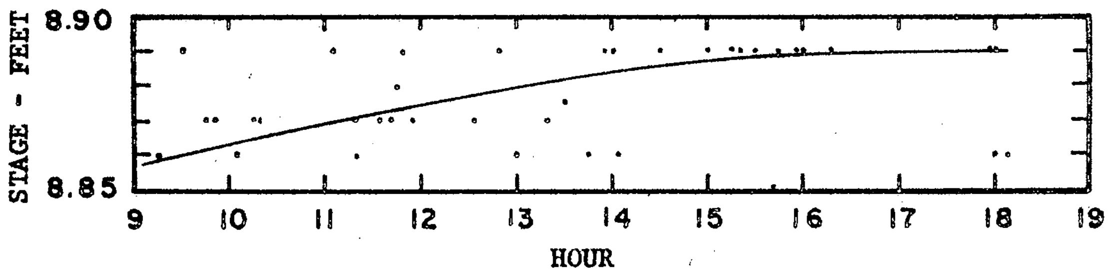

Figure 14. Outside gage observations by individual hydrographers during the 4th St. test. The stage recorder chart indicated a rising stage during the test.

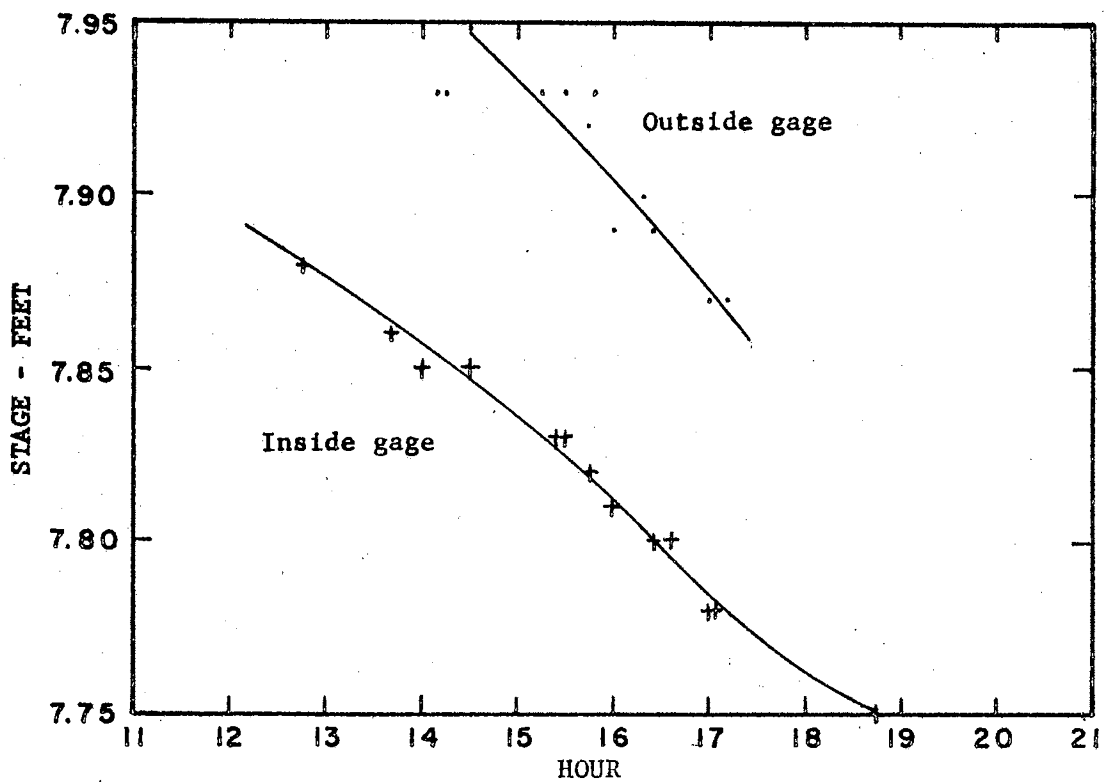

Figure 15. Gage observations by individual hydrographers during the Anadarko test.

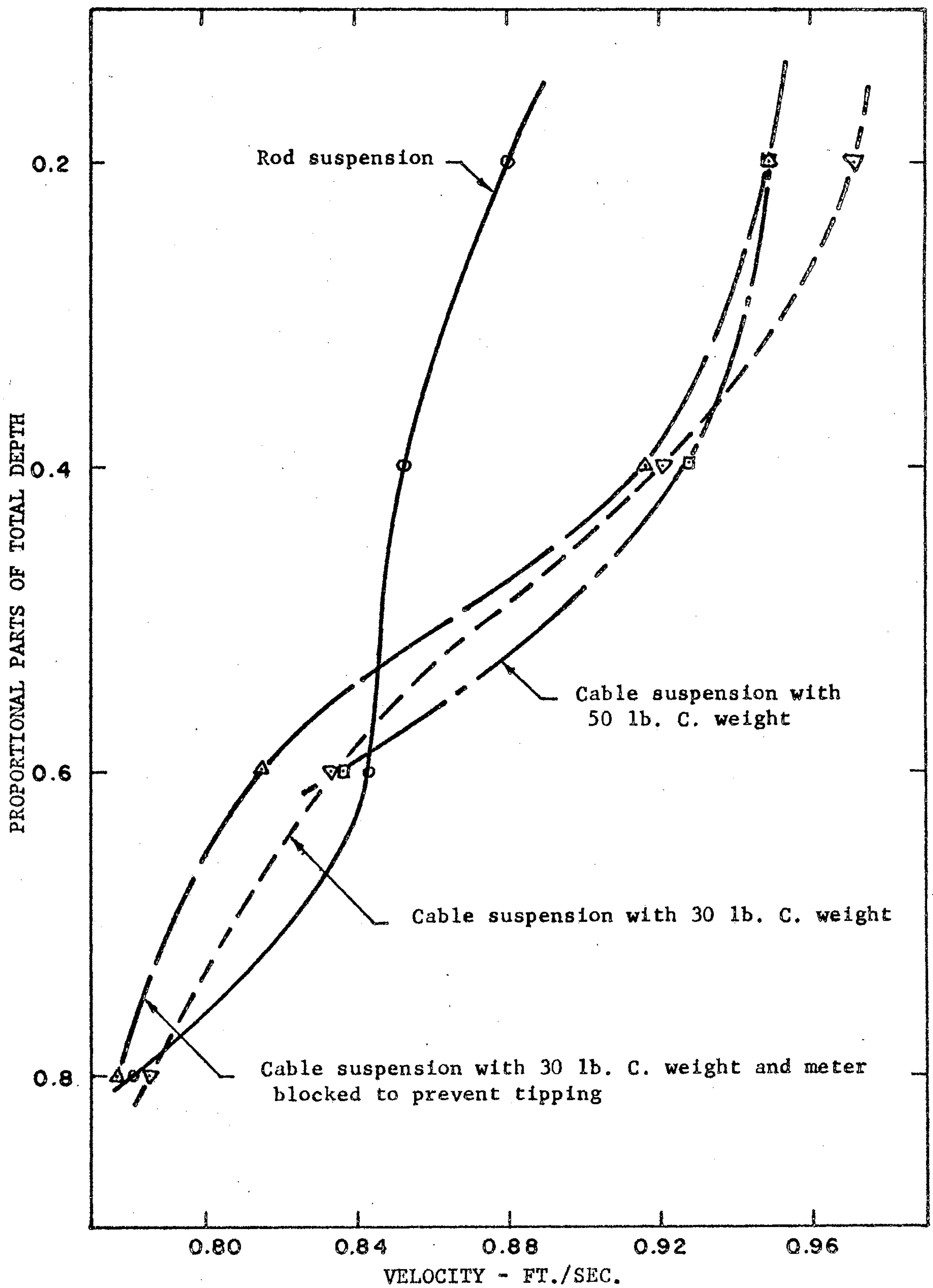

Figure 16. Effect of current meter suspension method on a vertical velocity profile in the Washita River near Chickasha (4th St.).

Over-registration of the meter at 0.2 and 0.4 depth was probably caused by deflection of the flow around the weight. The deflection imparted a vertical flow component to the rotor causing it to turn faster. Murphy (11) and Groat (7) determined that vertical flow causes the Price meter to over-register. Perhaps no vertical flow component was imparted to the meter cups at 0.6 and 0.8 depth because the velocity was somewhat slower at those points.

Measurements at Weir Control Stations

Measurements at the Tonkawa, Delaware, West Bitter, East Bitter, and Winter Creek gaging stations were selected for this analysis because these stations have weir controls which have partially stabilized the stage-discharge relation. Thus the shifting control variable was restricted. The effect of submergence on any of the measurements used in the analysis was considered negligible. Cable suspension measurements were made from bridges at the Tonkawa, Delaware, and East Bitter Creek stations; but cable suspension measurements were made from cableways at the West Bitter and Winter Creek stations.

The accumulated percent of the 168 measurements deviating from the station rating less than indicated amounts and the accumulated percent of the Anadarko and 4th St. test measurements deviating from the mean less than indicated amounts are shown in Figure 17. The area between the two curves represents the following sources of error: (1) Gage height; (2) time of measurement (Measurements were often made at night and during storms.); (3) rapidly changing stage; (4) shallow flow; (5) shift in control as sediment deposited in the channel upstream from the weir; (6) difference

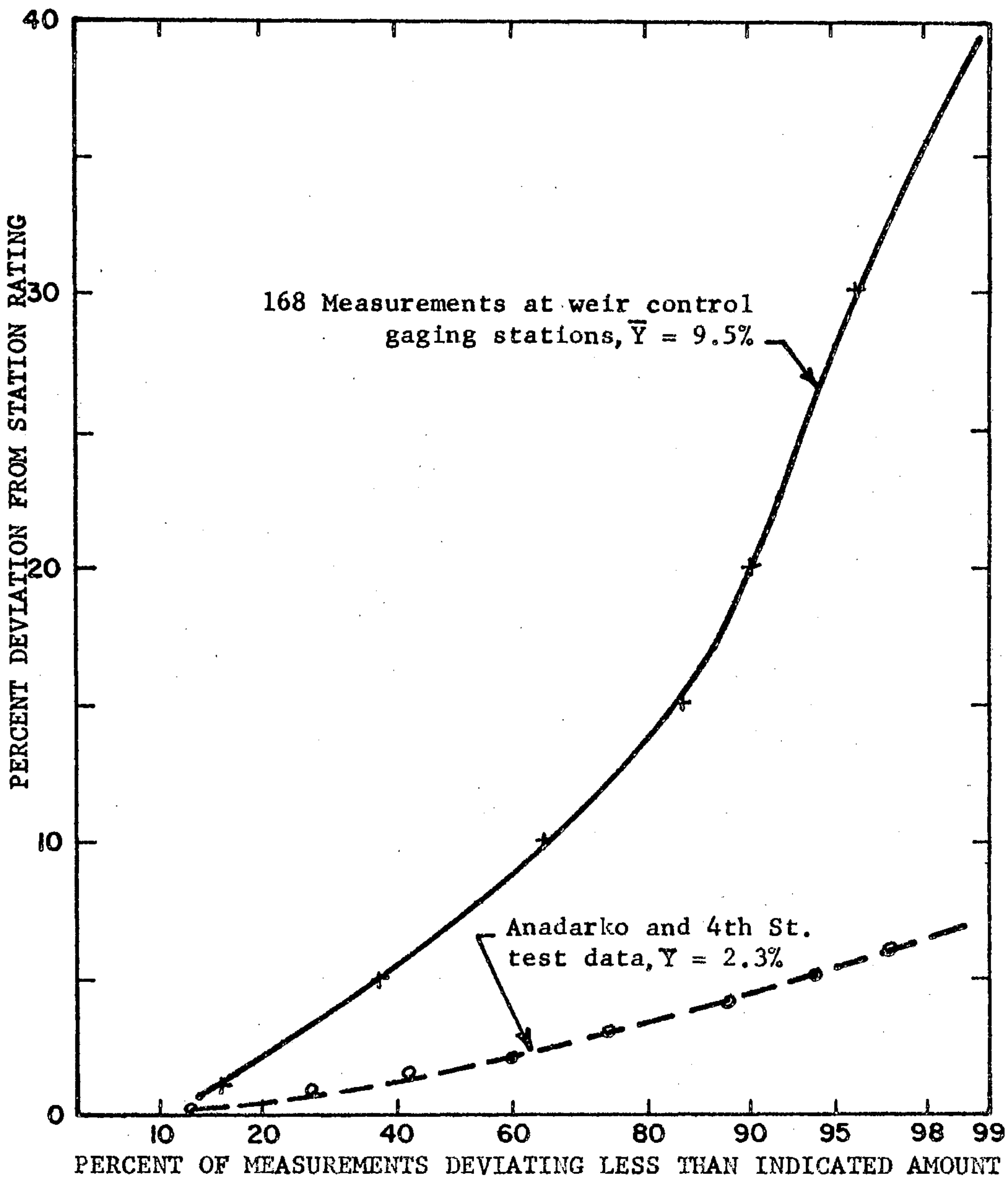

Figure 17. Accumulated percent of discharge measurements deviating from the station rating less than the indicated amount.

between cable and rod suspension flow estimates; (Cable suspension measurements at Anadarko and 4th St. were reduced 4.3 percent.); (7) highly turbulent flow; and (8) debris.

A summary of the tabulations in Appendix C is presented in Table VI. The Winter Creek measurements deviated more from the line of best fit than the measurements at any other station. This was expected for the following reasons:

1. The Winter Creek channel is more than 100 feet wide and has a sand bed.
2. Low flow shifts from one side of the channel to the other with time and is usually very shallow compared to the width of flow.
3. Storm flows are characterized by rapidly changing stage, sand dunes, high velocity, and fine debris which clogs the meter.

TABLE VI

AVERAGE DEVIATION AND PROBABLE ERROR OF MEASURED VS. RATING DISCHARGE

Gaging station	Total no. mea's.	Average deviation (%)	Probable error (%)	
			All mea's.	All mea's. > 1.0 cfs.
Tonkawa (111)	28	9.7	8.7	6.9
Delaware (131)	22	8.8	8.7	4.6
W. Bitter (511)	41	8.1	7.6	6.2
E. Bitter (512)	43	8.1	8.1	5.9
Winter (621)	34	13.2	13.5	8.0
Weighted average		9.5	9.2	6.4

Variation among the average deviations at the other stations, excluding Winter Creek, was small, ranging from 8.1 to 9.7 percent. The probable error given by Trestman (18) and credited to Gauss was generally slightly less than the average deviation. Trestman said the probable error should be less than two to four percent. The probable error of measurements greater than one cubic foot per second approached the standard recommended by Trestman.

In 1964, about one-fourth of the surface runoff from these five tributaries flowed at a rate less than three cubic feet per second. Therefore, a great improvement could be made in the accuracy of water yield estimates from these tributaries by tying down the lower end of the station ratings with periodic volumetric measurements of flows up to about one cubic foot per second. Periodic volumetric measurements should be continued indefinitely or until stability of the control at low flow is confirmed. The controls have not been completely stable at low flow in the past because the amount of fill immediately upstream from the weirs has varied between storms.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

An intensive review of the stream gaging literature was made to determine the exact procedure for accurate and precise measurement of open channel flow and the accuracy and precision that is expected in random discharge measurements by experienced hydrographers. Literature from previous studies indicated that the standard deviation of random discharge measurements is about three percent and that "good" records of mean daily flow are generally within five percent of the true value.

Two tests were conducted to determine the relationship of flow velocities measured with a Price meter on cable and rod suspension and to detect and determine the effect of incorrect gaging procedure. The tests were conducted at Agricultural Research Service gaging stations on the Washita River near Chickasha and at Anadarko, Oklahoma. Seventeen comparisons were made of discharge estimates made with the meter on rod suspension and on cable suspension. The discharge estimated by the cable measurements averaged 4.3 percent greater than that estimated by the rod measurements. Apparently the difference was not caused by consistent errors in measurement of width or depth.

Registrations of a Price meter on rod and cable suspension were compared. Depth of flow in the vertical tested was 2.6 feet. Registration of the meter varied little with size of weight and blocking of the meter to prevent tipping. At 0.6 and 0.8 depth, there was no significant difference between velocities registered by the meter on rod suspension and cable suspension. However, at 0.2 and 0.4 depth, the cable suspended meter registered about 9 percent greater velocity than did the rod suspended meter.

One hundred and sixty-eight discharge measurements at five weir control gaging stations were used to determine a probable error or average deviation of measurements from the respective station rating. The mean probable error of all these measurements was about 9.2 percent. The mean probable error for measurements greater than one cubic foot per second, however, was only 6.4 percent.

Conclusions

The following conclusions were drawn from this study:

1. There is a significant difference at the 95+ percent confidence level between estimates of discharge made by a Price current meter on rod suspension and on cable suspension when using a rod rating only.
2. The accuracy of cable suspension discharge measurements can be improved by making the following corrections:
    a. Reduce the mean measured velocity 4.5 percent at each vertical where the 0.2-0.8 depth method is used.
    b. Increase the measured velocity a percentage equal to the depth of flow at each vertical where the 0.6 depth method is used.

3. The percent of difference in velocity measured by rod and cable suspension is greater in the upper half of a vertical than in the lower half and is the same for the 30 and 50 pound weights.
4. About 60 percent of the Washita rod suspension measurements deviate no more than 2 percent from the station rating and 90 percent deviate no more than 5 percent if the station control remains stable.
5. The probable deviation from the station rating of unsubmerged flow measurements at the ARS Washita weir control stations is about 9.2 percent. For measurements greater than one cubic foot per second, the probable deviation is about 6.4 percent.

Implications of the Study

The following recommendations are suggested as a result of this study:

1. Cable suspension discharge measurements should be adjusted as suggested in conclusion no. 2.
2. If the stream stage is not changing rapidly, the duration of each velocity observation should extend at least 50 seconds.
3. If a hydrographer has not made a discharge measurement for several months, he should be given refresher training before he is expected to make routine discharge measurements.
4. Weir control gaging stations should be rated volumetrically at low flow.
5. Extensive use of the Price meter suggests additional study of its accuracy.

Suggestions for Future Study

1. Determine if the weight affects the flow net at the meter cups by introducing visible detritus into the flow in a transparent enclosure.
2. Compare the velocities registered by a Price meter on rod and cable suspension with the meter rotor set about six inches farther forward than its present position on cable suspension and with a longer tailpiece.
3. Determine the precision of measurements made from a cableway.
4. Determine the effect of length of cable from crane to meter on measurement accuracy.
5. Additional comparisons of cup and screw type meter performance should be made.

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A P P E N D I C E S

APPENDIX A

SUMMARY OF DISCHARGE MEASUREMENTS

AND ANALYSIS OF VARIANCE

APPENDIX A

SUMMARY OF DISCHARGE MEASUREMENTS WASHITA RIVER NEAR CHICKASHA (4TH ST.) MAY 28, 1963

Hydrographer no.*	Width (Feet)	Area (Sq.ft.)	Mean velocity (Fps)	Gage height (Feet)	Discharge (Cfs)	Discharge adjusted to GH = 8.88	Deviation from mean (%)	Number meas. sections	Time (Hr)	Cross section no.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1 R	46.0	90.8	1.08	8.89	97.9	96.5	- 4	22	1 2/3	3
1 C	46.0	81.0	1.25	8.89	101.2	99.8	- 1	20	2 1/4	2
2 R	41.8	82.1	1.17	8.865	96.2	98.3	- 2	20	1 1/12	1
2 C	44.0	82.2	1.22	8.87	100.0	101.4	+ 1	20	1 1/4	2
3 C	44.0	86.0	1.15	8.89	98.5	97.1	- 3	20	1 1/3	2
3 R	43.5	94.4	1.10	8.89	103.9	102.5	+ 2	21	1 1/12	5
4 C	45.0	84.8	1.21	8.89	102.8	101.4	+ 1	20	1 1/3	2
4 R	40.0	82.4	1.23	8.89	101.3	99.9	- 0.5	20	1 2/3	1
5 C	43.0	86.4	1.20	8.87	103.5	104.9	+ 4	20	1 3/4	2
5 R	42.5	92.1	1.06	8.87	97.7	99.1	- 1	16	5/6	5
6 C	44.0	70.3	1.48	8.89	104.0	102.6	+ 2	19	1 1/2	2
6 R	46.0	90.3	1.13	8.89	102.5	101.1	+ 1	20	1 3/4	3
7 R	45.5	89.4	1.07	8.87	95.1	96.5	- 4	16	1 1/4	4
7 C	44.0	91.8	1.20	8.875	110.4	111.1	+10	21	1 11/12	2
8 C	44.5	80.4	1.22	8.87	97.9	99.3	- 1	20	1 1/4	2
8 R	43.7	91.8	1.03	8.87	94.9	96.3	- 4	20	1	5
9 R	43.7	93.6	1.05	8.89	98.2	96.8	- 4	20	2	5
9 C	45.0	81.4	1.29	8.89	104.4	103.0	+ 3	19	2 1/12	2
10 C	44.5	90.5	1.25	8.93	113.0	106.0	+ 6	18	5/6	2
10 R	46.0	86.6	1.08	8.87	93.1	94.5	- 6	22	1 1/3	3
11 C	45.0	75.4	1.35	8.87	101.3	102.7	+ 2	21	2	2
11 R	46.0	89.2	1.08	8.87	96.1	97.5	- 3	22	1 1/3	3
						Total 2,208.3				
						Mean 100.4				

* C - Cable Suspension
R - Rod Suspension

APPENDIX A

SUMMARY OF DISCHARGE MEASUREMENTS WASHITA RIVER AT ANADARKO JUNE 2, 1964

Hydrographer no.*	Width (Feet)	Area (Sq.ft.)	Mean velocity (Fps)	Gage height (Feet)	Discharge (Cfs)	Discharge adjusted to GH = 7.82	Deviation from mean (%)	Number meas. sections	Time (Hr)	Cross section no.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1 R	80	157	2.67	7.84	419	407	- 6.0	22	1 1/3	1
1 C	78	154	2.91	7.80	435	448	7.9	18	1 1/12	2
2 R	80	163	2.64	7.835	430	421	- 2.8	24	1 1/4	1
2 C	76	154	2.98	7.87	459	428	- 1.2	20	11/12	2
9 R	80	159	2.43	7.765	386	421	- 2.8	25	1 1/12	1
9 C	76	159	2.78	7.84	442	429	- 1.2	22	1	2
12 R	80	156	2.54	7.765	396	431	- 0.5	25	1 2/3	1
4 C	79	157	2.82	7.815	442	445	2.8	26	1 1/6	2
6 R	80	161	2.55	7.81	410	416	- 3.9	20	1 1/2	1
13 C	77	160	2.72	7.81	435	442	2.1	26	1 1/12	2
4 R	77	148	2.54	7.72	376	441	1.8	26	3	2
12 C	78	147	2.82	7.775	414	443	2.3	18	5/6	2
						Total 5,172				
						Mean 431				

* C - Cable Suspension
R - Rod Suspension

APPENDIX A

ANALYSIS OF VARIANCE TABLES

AOV (Anadarko Test)

Source	Degrees freedom	Sum of squares	Mean square	Variance ratio	Sign. level
Total	21	312			
Procedure	1	115	115	8.27	98
Hydrographer	10	58	5.8	.42	< 75
Remainder	10	139	13.9		
			$.19\% \leq \mu \leq 7.27\%$		95

AOV (4th St. Test)

Source	Degrees freedom	Sum of squares	Mean square	Variance ratio	Sign. level
Total	11	1,864			
Procedure	1	800.3	800.3	7.77	95
Hydrographer	5	549	110	1.07	< 75
Remainder	5	514.7	102.9		
			$.30\% \leq \mu \leq 7.28\%$		95

APPENDIX B

EFFECT OF TYPE OF SUSPENSION ON METER REGISTRATION AND ANALYSIS OF VARIANCE

APPENDIX B

EFFECT OF TYPE OF SUSPENSION ON METER REGISTRATION

Depth* (ft.)	Cable: 30 lb. C = 0.5'	Cable: 30 lb. (b)** C = 0.5'	Rod	Sum
	Time (sec.) for 40 revolutions of Meter #FE50			
2.0 (8/10)	116	117.5	115.5	
	111.5	113	109.3	
	114.5	115.2	119.5	
	342.0	345.7	344.3	1,032.0
1.5 (6/10)	116	114.5	103.5	
	102	105.5	112	
	104.5	110	102.5	
	322.5	330	318	970.5
1.0 (4.10)	94	99	111.5	
	98	95.5	102.0	
	98.5	97.2	101.5	
	290.5	291.7	315.0	897.2
0.5 (2/10)	92.5	92.5	106.5	
	93	95	99	
	89	93.8	99	
	274.5	281.3	304.5	860.3
Sum	1,229.5	1,248.7	1,281.8	3,760

* Depths measured down from water surface

** Weight blocked to prevent tipping

AOV

Source	Degrees freedom	Sum of squares	Mean square	Variance ratio	Sign. level
Total	35	2,683.95			
Treat. Combination	11	2,272.08			
Depth	3	1,953.13	651.04	37.94	>.99
Procedure	2	116.65	58.32	3.40	.95
Depth x Procedure	6	202.30	33.71	1.96	<.90
Error	24	411.87	17.16		

APPENDIX B

EFFECT OF TYPE OF SUSPENSION ON METER REGISTRATION

Depth* (ft.)	Cable: 30 lb. C = 0.5'	Cable: 50 lb. C = 0.9'	Rod	Sum
	Time (sec.) for 40 revolutions of meter #FE50			
	116	109	103.5	
1.5	102	104.5	112	
(6/10)	104.5	107.5	102.5	
	322.5	321.0	318.0	961.5
	94	96	111.5	
1.0	98	96	102.0	
(4/10)	98.5	96	101.5	
	290.5	288	315.0	893.5
	92.5	91	106.5	
0.5	93	95	99	
(2/10)	89	95.5	99	
	274.5	281.5	304.5	860.5
Sum	887.5	890.5	937.5	2,715.5

*Depths measured down from water surface

AOV

Source	Degrees freedom	Sum of squares	Mean square	Variance ratio	Sign. level
Total	26	1,216.85			
Treat. Combination	8	905.52			
Depth	2	589.40	294.70	17.03	>99.5
Procedure	2	174.74	87.37	5.05	97.9
Depth x Procedure	4	141.38	35.34	2.04	< .90
Error	18	311.33	17.30		

APPENDIX C

DEVIATION OF MEASURED DISCHARGE
FROM RATED DISCHARGE

APPENDIX C

DEVIATION OF MEASURED DISCHARGE FROM RATING DISCHARGE

Tonkawa Creek (111)

Stage	Measured Discharge Q_m (cfs)	Rated Discharge Q_r (cfs)	Absolute Deviation $Q_m - Q_r = \Delta Q$	% Deviation $\frac{\Delta Q}{Q_r} \times 100$
1.24	.22	.31	- .09	-29.0
1.29	.47	.48	- .01	- 2.1
2.39	34.8	29.1	5.7	19.6
1.73	4.59	5.00	- .41	- 8.2
1.37	.85	.87	- .02	- 2.3
1.44	1.34	1.34	0	0
1.41	1.28	1.12	.16	14.3
1.46	1.46	1.50	- .04	- 2.7
1.86	6.86	7.78	- .92	-11.8
1.87	6.25	8.02	-1.77	-22.1
1.49	1.94	1.76	.18	10.2
1.49	1.82	1.76	.16	3.4
1.51	2.07	1.95	.12	6.2
1.52	2.24	2.05	.19	9.3
1.49	1.91	1.76	.15	8.5
1.45	1.57	1.42	.15	10.6
1.75	5.90	5.38	.52	9.7
2.18	21.70	18.5	3.2	17.3
2.80	53.6	60.1	-6.5	-10.8
1.79	5.43	6.18	- .75	-12.1
1.24	.42	.31	.11	35.5
1.35	.68	.76	- .08	-10.5
4.15	300.0	296.	4.	1.3
3.92	242.0	238.	4.	1.7
1.88	8.35	8.28	.07	.8
1.85	7.20	7.53	- .33	- 4.4
1.55	2.22	2.37	- .15	- 6.3
1.70	4.46	4.47	- .01	- .2

APPENDIX C

DEVIATION OF MEASURED DISCHARGE FROM RATING DISCHARGE

Delaware Creek (131)

Stage	Measured Discharge Q_m (cfs)	Rated Discharge Q_r (cfs)	Absolute Deviation $Q_m - Q_r = \Delta Q$	% Deviation $\frac{\Delta Q}{Q_r} \times 100$
1.52	1.89	1.78	.11	6.2
1.26	.34	.32	.02	6.2
1.29	.44	.41	.03	7.3
1.29	.56	.41	.15	36.6
1.35	.60	.65	- .05	- 7.7
2.05	12.5	11.4	1.1	9.6
2.11	13.2	13.2	0	0
2.20	15.9	16.3	- .4	- 2.5
1.59	2.32	2.46	- .14	- 5.7
1.56	1.86	2.15	- .29	-13.5
1.58	2.19	2.35	- .16	- 6.8
1.57	2.18	2.25	- .07	- 3.1
1.49	1.47	1.52	- .05	- 3.3
1.40	.98	.91	.07	7.7
2.23	17.9	17.5	.4	2.3
2.11	13.5	13.2	.3	2.3
3.26	98.3	92.6	5.7	6.2
3.26	83.1	92.6	-9.5	-10.3
1.24	.20	.32	- .12	-37.5
2.21	16.9	16.7	.2	1.2
1.63	2.79	2.92	- .13	- 4.5
1.90	8.43	7.52	.91	12.1

APPENDIX C

DEVIATION OF MEASURED DISCHARGE FROM RATING DISCHARGE

West Bitter Creek (511)

Stage	Measured Discharge Q_m (cfs)	Rated Discharge Q_r (cfs)	Absolute Deviation $Q_m - Q_r = \Delta Q$	% Deviation $\frac{\Delta Q}{Q_r} \times 100$
1.53	2.36	2.46	- .10	- 4.1
1.53	2.12	2.46	- .34	-13.8
1.41	1.19	1.25	- .06	- 4.8
3.55	131.	117.	14.	12.0
1.87	8.43	8.60	- .17	- 2.0
1.34	.74	.76	- .02	- 2.6
1.45	1.21	1.60	- .39	-24.4
3.63	129.	126.	3.	2.4
1.17	.09	.08	.01	12.5
1.46	1.52	1.70	- .18	-10.6
1.49	2.03	2.00	.03	1.5
1.36	.97	.88	.09	10.2
1.38	1.08	1.02	.06	5.9
2.16	18.8	17.5	1.3	7.4
1.47	2.13	1.80	.33	18.3
1.47	1.85	1.80	.05	2.8
1.45	1.62	1.60	.02	1.2
1.50	1.80	2.11	- .31	-14.7
1.36	1.13	.88	.25	28.4
1.37	1.11	.95	.16	16.8
2.20	18.2	19.0	- .8	- 4.2
3.58	121.	120.	1.	.8
2.27	20.5	21.8	- 1.3	- 6.0
1.32	.72	.64	.08	12.5
3.74	109.	138.	-29.	-21.0
4.22	228.	203.	25.	12.3
4.53	232.	253.	-21.	- 8.3
3.25	93.4	86.5	6.9	8.0
1.71	4.56	5.18	- .62	-12.0
1.40	1.24	1.17	.07	6.0
3.74	145.	138.	7.0	5.1
4.16	193.	194.	- 1.0	- .5
3.04	64.7	68.4	- 3.7	- 5.4
4.64	254.	272.	-18.	- 6.6
4.51	273.	250.	23.	9.2
4.56	282.	258.	24.	9.3
4.63	276.	270.	6.	2.2
9.69	1,210.	1,175.	35.	3.0
9.27	1,070.	1,083.	-13.	- 1.2
9.56	1,120.	1,146.	-26.	- 2.3
7.80	792.	784.	8.	1.0

APPENDIX C

DEVIATION OF MEASURED DISCHARGE FROM RATING DISCHARGE

East Bitter Creek (512)

Stage	Measured Discharge Q_m (cfs)	Rated Discharge Q_r (cfs)	Absolute Deviation $Q_m - Q_r = \Delta Q$	% Deviation $\frac{\Delta Q}{Q_r} \times 100$
1.45	1.17	.82	.35	42.7
1.13	.05	.05	0.	0.
1.19	.10	.11	- .01	- 9.1
1.80	3.37	3.65	- .28	- 7.7
2.21	12.2	11.1	1.1	9.9
1.63	1.90	1.95	- .05	- 2.6
1.73	3.34	2.87	.47	16.4
1.74	2.63	2.97	- .34	-11.4
1.68	2.47	2.38	.09	3.8
2.11	9.32	8.80	.52	5.9
2.22	11.7	11.4	.30	2.6
1.69	2.67	2.47	.20	8.1
1.68	2.50	2.38	.12	5.0
1.67	2.36	2.29	.07	3.0
1.74	2.63	2.97	- .34	-11.4
1.63	2.25	1.95	.30	15.4
1.58	1.89	1.57	.32	20.4
2.97	39.2	42.4	- 3.2	- 7.5
2.33	12.8	14.4	- 1.6	-11.1
5.43	353.	410.	-57.	-13.9
1.62	1.97	1.87	.10	5.4
3.98	133.	134.	- 1.	- .7
4.38	190.	191.	- 1.	- .5
4.19	167.	163.	4.	2.4
3.74	101.	106.	- 5.	- 4.7
2.16	10.1	9.92	.18	1.8
5.60	493.	455.	38.	8.4
5.26	400.	367.	33.	9.0
4.34	195.	185.	10.	5.4
3.99	139.	136.	3.	2.2
3.42	72.9	75.2	- 2.3	- 3.0
4.41	201.	196.	5.	2.6
3.33	67.2	67.6	- .4	- .6
4.92	301.	290.	11.	3.8
4.05	142.	144.	- 2.	- 1.4
3.37	70.4	70.9	- .5	- .7
1.42	.44	.69	- .25	-36.2
1.50	1.04	1.07	- .03	- 2.8
2.16	7.48	9.92	- 2.44	-24.6
1.65	2.15	2.11	.04	1.9
3.77	111.	110.	1.	.9
2.32	13.0	11.4	1.6	14.0
2.10	9.14	8.59	.55	6.4

APPENDIX C

DEVIATION OF MEASURED DISCHARGE FROM RATING DISCHARGE

Winter Creek (621)

Stage	Measured Discharge Q_m (cfs)	Rated Discharge Q_r (cfs)	Absolute Deviation $Q_m - Q_r = \Delta Q$	% Deviation $\frac{\Delta Q}{Q_r} \times 100$
1.25	.76	.40	.36	90.0
1.49	2.23	2.42	- .19	- 7.8
1.83	7.91	8.99	- 1.08	-12.0
1.88	8.52	10.4	- 1.88	-18.1
1.17	.09	.10	- .01	-10.0
1.55	3.42	3.25	.17	5.2
1.44	2.08	1.84	.24	13.0
1.63	4.97	4.56	.41	9.0
1.40	1.61	1.44	.17	11.8
1.51	2.55	2.68	- .13	- 4.8
2.09	18.9	17.4	1.5	8.6
2.44	36.7	33.7	3.0	8.9
1.52	3.12	2.82	.3	10.6
1.53	3.22	2.96	.26	8.8
1.52	2.70	2.82	- .12	- 4.2
1.52	2.60	2.82	- .22	- 7.8
1.50	2.64	2.55	.09	3.5
1.45	2.66	1.95	.71	36.4
1.87	9.05	10.1	- 1.05	-10.4
1.82	8.36	8.72	- .36	- 4.1
1.89	8.50	10.6	- 2.1	-19.8
1.82	6.67	8.72	- 2.05	-23.5
3.98	224.	186.	38.	20.4
2.79	65.2	56.4	8.8	15.6
3.27	97.1	98.4	- 1.3	- 1.3
2.78	49.9	55.6	- 5.7	-10.2
3.87	160.	170.	-10.	- 5.9
2.91	68.5	65.6	2.9	4.4
1.85	7.55	9.52	- 1.97	-20.7
1.31	.60	.73	- .13	-17.8
3.47	124.	120.	4.	3.3
3.08	88.8	80.2	8.6	10.7
1.37	1.09	1.17	- .08	- 6.8
2.06	16.5	16.2	.3	1.8

VITA

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Candidate for the Degree of

Master of Science

Thesis: STREAM GAGING PRECISION RELATED TO METER SUSPENSION AND PROCEDURAL ERROR

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Biographical:

Personal Data: Born near Council Grove, Kansas, March 18, 1932, the son of Roy H. and Maggie E. Schoof.

Education: Attended grade school in Morris County, Kansas; and high school at Council Grove, Kansas. Received the Bachelor of Science degree in Agricultural Engineering in May 1955, from Kansas State University. Completed the requirements for the Master of Science degree in May 1965.

Professional Experience: Entered the United States Army Signal Corps in 1955 and served as a Meteorological Project Officer at Fort Huachuca, Arizona, and Natick, Massachusetts. Employed by the Kansas Division of Water Resources for administration of the Kansas water law from 1957 through 1959. Worked part time at the ARS Outdoor Hydraulics Laboratory and attended Oklahoma State University in 1960. Employed since 1960 by USDA, ARS, SWC, at the Southern Plains Hydrology Research Watershed, Chickasha, Oklahoma, as a Hydraulic Engineer in surface water research.

Organizations: Member of the American Geophysical Union; member of Sigma Tau, honorary engineering fraternity.