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UNITED STATES
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A COMPARATIVE STUDY OF MEAN-SECTION AND MID-SECTION METHODS FOR COMPUTATION OF DISCHARGE MEASUREMENTS

Prepared by
Kenneth B. Young

February 1950

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REPORT
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SYNOPSIS

In February, 1949, Mr. J. V. B. Wells, Chief of the Surface Water Branch, appointed a committee of three hydraulic engineers assigned to the Washington office to make a comparative study of the relative merits of the mean-section and mid-section methods of computing discharge measurements. This was done in order that there might be a basis for either adhering to the present "official" method, or adopting another method as the "official" one. This study is based on a collection of field data consisting of discharge measurements made with approximately four times the usual number of observations. There was a total of 213 of these special measurements made by all the district offices.

The two methods of computation were examined as to accuracy and time savings. This was done by selecting observation stations from the special measurements to arrive at a synthetic measurement with the usual number of observations. This normal measurement was then computed by both the mean-section and mid-section method of computation for a comparison

of results in discharge. A record was kept of the time consumed for computing and checking measurements so that any time savings in either method could be found. Much of the computation work was done in four of the district offices, with a variety in personnel as to grade and to experience in the use of the two methods.

A review is made of previous investigations and discussions on the subject of methods of computing discharge measurements, particularly one by J. C. Stevens in 1908 which apparently was the basis of the adoption of the mean-section method as the "official" method. This portion of the study also serves as a sort of bibliography relating to papers on discharge computation methods.

The results of the study showed that, in general, the mid-section method is slightly more accurate than the mean-section method. Also, there is a considerable time savings in computing and checking measurements as a result of using the mid-section method.

INTRODUCTION

In the Water Resources Division of the Geological Survey, the method of computing current meter discharge measurements, in use since about 1908, is generally known as the "mean-section" method. This method is described in WSP 888, (pp 13-14) as follows: "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 the mean velocity of each is determined separately. The small sections are each bounded by the water surface, the stream bed, and two imaginary lines, called verticals. Each vertical, therefore, being a common dimension for two adjoining sections, fixes the point at which observations are made. Sufficient velocity observations are made to establish the mean velocity in each of the two verticals forming the side boundaries of a section, and the velocities in the two verticals are then averaged to determine the mean velocity in the section. The product of the mean velocity thus obtained and the area of the section, which in turn is the product of the distance between the two verticals and the mean of their depths, is the discharge in the sections. The sum of the discharges in all the partial sections is the discharge of the stream."

Another method of computation known as the "mid-section" method has become increasingly popular in recent years among some of the district offices of the Surface Water Branch. This method differs from the "mean-section" in that observations of depth and velocity are used directly without any averaging. Observations of depth and velocity are made in the same manner and at the same points as in the mean-section method. The values of depth and velocity at each observation point apply to a cross-sectional area whose width extends half way to the preceding and following observation points. Consequently, in this computation, the process of averaging velocities to obtain a mean in section, and averaging depths to obtain a mean depth, are eliminated.

The mid-section method of computation is not new. It was in use in the early years of the Geological Survey's water resources investigations but apparently was dropped after the adoption of the mean-section as the "standard method". At various times through the years since 1908 advocates of the mid-section method have urged its adoption as the "standard". The advantages of one method over the other have been discussed at length in the Water Resources Bulletin, (an official memorandum for use of Water Resources Division personnel) in a rather theoretical manner. There have been many statements made favoring the use of the mean-section method, and many favoring the adoption of the mid-section method as the "official" one. There was little question that a saving of time was possible using the mid-section method, but the matter of relative accuracy had not been definitely determined. Due to a lack of evidence to judge the merits of each method, and due to the advisability of having and using one official method of discharge measurement computation, it was decided to conduct a study to produce the necessary evidence which would show the facts.

In February, 1949, Mr. J. V. B. Wells, Chief of the Surface Water Branch, appointed a committee, consisting of Hollister Johnson, F. J. Flynn, and J. E. McCall, hydraulic engineers assigned to the Washington office, to make a comparative study of the mean-section and mid-section methods of computation. This committee decided a study based on actual field data was necessary for the formation of any conclusive opinions or decisions as to the merits of the methods. Accordingly, a plan of procedure was drawn up and a memorandum dated March 7, 1949, was sent to all district offices. This memorandum requested that each principal surface water field office furnish four current meter discharge measurements, each containing four times the usual number of sections and computed by both mean-section and mid-section methods. The committee felt that a measurement with four times the usual number of sections would be an accurate determination of the discharge, and that the computed discharge of the abnormally long special measurements would be practically the same by both methods. The request for these special measurements specified that each type of current meter measurement be included; that is, cable, boat, bridge, and wading measurements. Also, the cross-section of three measurements should be typical of the region, and the fourth should have an irregular cross-section and velocity distribution. In this way, it was hoped to avoid any bias as to types of measurements and conditions, as well as to assure that results of the tests would be applicable to all types of measurements and all geographical locations.

The committee conducting this study realized that much extra work was entailed in making these special measurements and carrying the project through to a finish. There were 213 measurements submitted for this study, and the cooperation of the districts in complying with this request is greatly appreciated. Four districts furnished the time and services of a considerable number of their personnel for two days in conducting computation time studies. The committee's appreciation and gratitude for this service go to the Boston, Charlottesville, College Park, and Columbus districts. Several engineers on detail in the Annual Reports Section of the Washington office assisted to a great extent in the computation time studies and their work is also much appreciated. Members of the Technical Coordination Branch gave suggestions in the statistical analysis of the data. The assignment of carrying out the work of compilation, computation, and analysis under the general supervision of the committee was given to K. B. Young, Hydraulic Engineer, in July 1949.

PROCEDURE

Plotting Depths and Velocities

As the special measurements were received from the field offices, the depths and velocities were plotted to give a graphical picture of the cross-section and velocity distribution for each measurement. These plots were used later as a guide in selecting observation stations from each special measurement for use in deriving a synthetic measurement, hereinafter called "normal measurement", having the customary number of observations, or sections.

Selection of Observation Stations

In selecting the observation stations for a normal measurement, consideration was given to the number of sections used in the past at the gaging station concerned, to the practice of keeping the partial discharge in each section under 5 percent of the total discharge for the measurement, and to the cross-section and velocity distribution as plotted. Observation stations were selected as close as would be reasonable to banks and piers. An attempt was made to visualize what an engineer would do for each particular measurement in the matter of selecting the observation points. Where applicable, stations were selected to correspond to graduations, or multiples thereof, on the cable, bridge, or tagline. In other words, if 10 foot widths were satisfactory for defining the cross-section and flow, stations were picked at points 20, 30, 40, etc., and not 22, 32, 42, etc. The plotted depths and velocities served as a picture to furnish knowledge of river conditions that an engineer actually measuring could see, or remember from previous measurements. In this way the section widths could be varied to get adequate definition around piers, boulders, banks, and other channel irregularities.

Previous to this study there seemed to be a general acceptance of a theory that to get an accurate discharge determination by the mid-section method, an engineer had to select observation stations with the thought in mind that the mid-section method of computation would be used. This theory, or belief, was that in making a discharge measurement for mid-section computation, it was necessary to avoid the "breaks" in cross-section and velocity. Accordingly, measurement 27W was treated in such a way that a combination of observation stations was selected for a mean-section computation, and another combination was selected which was felt would give a better mid-section combination. This was the only measurement for which a different set of observation data was used for each method because it was felt that this theory is erroneous to a great extent and would lead to much extra work if observed. Therefore the practice of selecting points which give the best area definition should be used with due attention being given to velocity distribution.

When the observation stations for a normal measurement were selected, the basic field data including distances, depths, and mean velocities in the verticals were copied from the special measurement on regular discharge measurement note forms. Two identical sets of such data were made for each measurement, one for computation by the mean-section method and the other, by the mid-section method. Special front sheets as shown in Fig. 1 were made up to attach to note forms so that

File No.____

COMPUTATION BY MEAN-SECTION

Width________ Area________ Disch.________

No. Secs.________ Susp. coef.________

	Compute	Check	Recheck
Name			
Grade			
District			
Date			
Yrs. used mean			
Yrs. used mid			
Time start			
Time finish			
Working time			

Remarks____

____

____

____

____

Sheet No.____ of____ sheets.

FIGURE 1.– Front sheet for use with normal measurement data.

SAMPLE OF DISCHARGE MEASUREMENT NOTES COMPUTED BY MID-SECTION METHOD

Angle coefficient	Dist. from initial point	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	VELOCITY Mean in section	Area	Mean depth	Width	Discharge
	L.E.W. at 9:05 A.M.											
	0	0		0			0		0		3	0
	6	2.6	.6	7	52	0.30	0.30		18.2		7	5.5
	14	5.9	.2	20	54	.81	.68		47.2		8	32.1
			.8	15	60	.55						
	22	7.1	.2	25	47	1.16	.95		49.7		7	47.2
			.8	20	59	.74						
	28	8.2	.2	30	52	1.26	1.11		49.2		6	54.6
			.8	25	57	.96						
	34	9.0	.2	40	57	1.53	1.28		54.0		6	69.1
			.8	25	53	1.03						
	40	9.2	.2	40	54	1.61	1.40		50.6		5.5	70.8
			.8	25	46	1.18						
	45	9.3	.2	40	52	1.67	1.52		46.5		5	70.7
			.8	40	63	1.38						
	50	9.4	.2	40	48	1.81	1.64		47.0		5	77.1
			.8	40	59	1.47						
	55	9.5	.2	40	49	1.77	1.70		47.5		5	80.8
			.8	40	53	1.64						
	60	9.7	.2	40	44	1.97	1.78		48.5		5	86.3
			.8	30	41	1.59						
	65	9.7	.2	50	52	2.09	1.82		48.5		5	88.3
			.8	40	56	1.55						
	70	10.0	.2	40	43	2.02	1.82		50.0		5	91.0
			.8	40	54	1.61						
	75	10.3	.2	40	44	1.97	1.72		41.2		4	70.9
			.8	30	44	1.48						
	78	est. 10.0		est. 0.9 of sta. 75			1.55		15.0		1.5	23.2
	PIER		9:50 A.M. 10:00 A.M.									
	92	est. 6.5		est. 0.9 of sta. 95			.97		9.8		1.5	9.5
	95	6.8	.2	30	51	1.28	1.08		30.6		4.5	33.0
			.8	20	50	.87						

FIGURE 1a.— Sample discharge measurement notes showing computation by mid-section method.

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information resulting from the measurement computation could be recorded systematically. Fig. 1a shows a sample mid-section method computation.

Computation of Normal Measurements

After the basic field measurement data for the 213 pairs of normal measurements were assembled and ready for computation, the first tests of measurement computation were made using personnel in the Washington office, especially engineers on detail in the Annual Reports Section. In this way, the proposed method of handling the computations was given a test to see if the procedure was clear and if all information needed for analysis was being obtained. Later, computation sessions were held at the Boston, Charlottesville, College Park, and Columbus district offices using district personnel under the supervision of one of the committee members who was present to furnish instruction and information.

In choosing the districts to conduct the computation studies, the thought was to try to get personnel who were experienced in using the mid-section as well as the mean-section method, and to get a variety in the grades of personnel. It was difficult to get a very large percentage of those experienced only in the mid-section method as most engineers who were using the mid-section method had changed over from the mean-section method and had thus become experienced in both methods. A majority of those used in the computations were engineers experienced in mean-section method, having had little contact with the mid-section method. Due to this fact, the average time saving shown by this study is probably somewhat lower than the saving that would be possible if all personnel were equally familiar with the mid-section method.

The time (measured with stop watches) recorded for computation included only the processes from averaging the velocities (in the case of the mean-section method) to obtaining the partial discharges. Other operations such as determining the mean velocity in the verticals, adding the partial areas and discharges, and filling out the front sheet which would be identical in both methods were not included in the time recorded. To have based this time study on the computation of an entire measurement, beginning with the application of velocities from the meter rating table, would have doubled the time required to carry out the procedure of getting the measurements computed. Therefore, the times measured are not the times needed to compute measurements, but give an indication of the difference in time between the two methods. Each person computed a measurement by both the mean-section and mid-section method. Later another person checked this "set". Thus assuming that the computer or checker worked at the same pace for each method, the difference in time between methods was clearly indicated. After the measurements were computed and checked, they were examined for any remaining inconsistencies.

Compilation of Measurement Data

The measurements were separated into three groups of (1) Bridge, (2) Wading, and (3) Cable or Boat. They were numbered in their respective groups with the letter W, B, or C added to indicate the type of measurement. The measurements of each group were listed in descending order of magnitude of the discharge as found in the special measurements (see Table 1). The necessary data were recorded in the proper columns, which are self-explanatory. Since there is a difference in the number of sections in the mean-section and mid-section computations, it was decided to use a column heading of "number of observations" instead of the usual "number of sections". In this way, the figure would be the same for both methods. When identical observation points are used, the mid-section method has one more section, or partial discharge, than the mean-section method for each channel measured. In the case of most wading and cable measurements this difference is only one, but in bridge measurements the difference depends upon the number of channels.

The remaining columns were filled in by computation of the necessary items. The percent difference figure for discharge under each normal measurement is the percent difference from the true discharge which has been assumed to be the average of the mean-section and mid-section computation of the special measurement. The percent difference column for area is the difference of the normal-measurement area from the special-measurement area. The difference column under computation and checking time shows the saving of time in minutes by the mid-section method compared to the mean-section method. A negative figure indicates that the mid-section method took longer to compute or check than the mean-section method. A symbol was placed with the grade designation of the computers in order to classify them into three groups.

TABLE 1 - COMPILATION OF DISCHARGE MEASUREMENT DATA

BRIDGE MEASUREMENTS

7P051

Gaging Station			Special Measurement					Normal Measurement							Computation				Checking			
															Time in Minutes				Time in Minutes			
River	Place	File No.	No. Obs.	Area	Mean-Sec.	Mid-Sec.	Average	Mean-Sec.	Percent Diff.	Mid-Sec.	Percent Diff.	Area	Percent Diff.	No. Obs.	Mean-Sec.	Diff.	Mid-Sec.	Grade	Mean-Sec.	Diff.	Mid-Sec.	Grade
Mississippi	St. Louis, Mo.	1B	172	43,470	152,175	152,241	152,208	151,876	-0.2	152,473	+0.2	43,384	-0.2	51	66.0	32.0	34.0	† SP-5	26.8	7.0	19.8	*† P-2
Mississippi	Keokuk, Iowa	2B	95	27,450	106,721	105,847	106,284	103,843	-2.3	103,748	-2.4	27,208	-0.9	67	63.8	4.9	58.9	* P-3	57.5	13.5	44.0	* P-2
Arkansas	Van Buren, Ark.	3B	168	22,146	72,495	72,685	72,590	69,650	-4.0	70,680	-2.6	21,864	-1.3	54	79.1	38.6	40.5	* P-2	23.1	2.0	21.1	* SP-7
Missouri	Boonville, Mo.	4B	145	15,247	54,283	54,387	54,335	53,744	-1.1	54,374	+0.1	15,040	-1.4	49	40.1	12.3	27.8	† HFA	39.3	9.1	30.2	† P-4
Red	Shreveport, La.	5B	166	13,182	46,694	46,570	46,632	45,780	-1.8	46,000	-1.4	13,180	0	43	32.0	11.0	21.0	* P-4	19.8	4.3	15.5	*† P-3
Tennessee	Chattanooga, Tenn.	6B	175	18,241	33,268	33,335	33,302	33,233	-0.2	33,331	+0.1	18,191	-0.3	53	31.8	6.3	25.5	* SP-4	31.0	4.8	26.2	*State
Kansas	Topeka, Kans.	7B	105	6,318	32,761	32,803	32,782	31,974	-2.5	32,275	-1.7	6,233	-1.3	39	27.0	5.0	22.0	† HFA	24.8	10.0	14.8	* P-3
Potomac	Point of Rocks, Md.	63B	207	8,213	28,959	28,920	28,940	28,078	-3.0	28,283	-2.3	8,142	-0.9	65	52.0	6.0	46.0	*† P-3	26.2	6.2	22.0	* P-4
Missouri	Pierre, S. D.	8B	118	9,723	28,268	28,346	28,307	28,300	0	28,229	-0.3	9,950	+2.3	38	49.8	14.8	35.0	* SP-5	26.0	-2.5	28.5	* P-2
Alabama	Selma, Ala.	9B	106	9,810	27,324	27,307	27,316	26,903	-1.5	27,016	-1.1	9,772	-0.4	35	24.8	5.5	19.3	* P-4	17.9	4.0	13.9	*† P-3
Allegheny	Kittanning, Pa.	10B	120	10,372	25,036	25,076	25,056	25,127	+0.3	25,294	+1.0	10,390	+0.2	39	20.7	-0.4	21.1	* P-4	17.4	0.2	17.2	* P-4
Missouri	Bismarck, N. D.	11B	191	9,989	24,349	24,349	24,349	24,802	+1.9	24,716	+1.5	10,042	+0.5	50	36.5	10.5	26.0	* P-3	28.4	8.2	20.2	* P-2
Arkansas	Muskogee, Okla.	12B	85	8,358	22,228	22,285	22,256	22,457	+0.9	22,580	+1.4	8,366	+0.1	52	33.2	3.2	30.0	* P-3	20.7	5.5	15.2	*† P-3
Yellowstone	Billings, Mont.	13B	103	3,752	20,701	20,750	20,726	20,697	-0.1	20,971	+1.2	3,728	-0.6	29	21.4	6.0	15.4	* P-2	15.5	4.0	11.5	* P-1
Sabine	Bon Weir, Texas	14B	102	7,360	19,112	19,146	19,129	19,204	+0.4	19,263	+0.7	7,448	+1.2	35	38.5	3.0	35.5	† P-2	21.5	3.3	18.2	† SP-5
Skagit	Mt. Vernon, Wash.	15B	120	4,972	15,478	15,488	15,483	14,848	-4.1	15,031	-2.9	4,894	-1.6	46	45.3	14.6	30.7	* P-3	16.5	-4.5	21.0	* P-2
Allegheny	Franklin, Pa.	16B	123	4,732	15,153	15,221	15,187	15,263	+0.5	15,339	+1.0	4,782	+1.1	42	22.0	4.8	17.2	* P-4	18.2	-0.4	18.6	* P-4
Des Moines	Keosauqua, Iowa	17B	65	4,135	14,932	15,032	14,982	14,103	-5.9	14,313	-4.5	4,032	-2.5	33	22.3	8.1	14.2	* P-2	18.8	5.5	13.3	* P-1
Delaware	Trenton, N. J.	18B	316	5,525	12,070	12,080	12,075	12,112	+0.3	12,125	+0.4	5,536	+0.2	91	61.5	9.0	52.5	† P-2	59.0	11.5	47.5	† SP-3
Delaware	Port Jervis, N.Y.	19B	127	3,524	11,824	11,832	11,828	11,801	-0.2	11,832	0	3,554	+0.9	34	20.9	5.8	15.1	* P-3	11.6	-0.1	11.7	* P-4
Susquehanna	Vestal, N. Y.	20B	109	4,832	9,722	9,724	9,723	9,715	-0.1	9,757	+0.3	4,794	-0.8	33	16.8	-2.1	18.9	* P-3	14.4	-0.8	15.2	* P-3
Wabash	Terre Haute, Ind.	21B	104	5,785	7,770	7,790	7,780	7,563	-2.8	7,687	-1.2	5,768	-0.3	41	35.7	11.5	24.2	* P-1	24.0	6.0	18.0	* P-2
James	Scottsville, Va.	22B	109	3,482	7,544	7,557	7,550	7,302	-3.3	7,296	-3.4	3,452	-0.9	37	23.6	0.9	22.7	* P-2	22.0	4.3	17.7	* P-2
Chippewa	Durand, Wis.	23B	153	2,813	6,942	6,941	6,942	6,933	-0.1	6,985	+0.6	2,780	-1.2	50	37.3	6.4	30.9	† P-2	37.0	15.7	21.3	† P-2
Mohawk	Cohoes, N. Y.	24B	122	5,226	6,548	6,543	6,546	6,588	+0.6	6,608	+1.0	5,178	-0.9	46	18.5	-3.0	21.5	* P-3	18.7	-0.5	19.2	* P-3
Leaf	McLain, Miss.	25B	97	3,453	6,354	6,359	6,356	6,379	+0.4	6,434	+1.2	3,488	+1.0	33	29.9	9.4	20.5	* P-3	12.2	3.2	9.0	* SP-7
Pee Dee	Peedee, S. C.	26B	104	3,706	6,256	6,254	6,255	6,286	+0.5	6,240	-0.2	3,716	+0.3	33	22.0	8.8	13.2	*† P-3	13.7	2.9	10.8	* P-3
Barren	Bowling Green, Ky.	27B	121	1,955	5,539	5,543	5,541	5,391	-2.7	5,437	-1.9	1,968	+0.7	33	14.0	2.4	11.6	* P-3	13.2	3.2	9.0	* P-3
Maumee	Waterville, Ohio	28B	150	1,618	4,942	4,938	4,940	4,899	-0.8	4,937	-0.1	1,620	+0.1	39	33.8	9.6	24.2	* SP-5	22.1	1.2	20.9	* P-2
Rogue	Grants Pass, Ore.	29B	110	1,396	3,939	3,928	3,934	3,855	-2.0	3,892	-1.1	1,372	-1.7	37	33.8	8.0	25.8	* P-2	13.4	2.4	11.0	* SP-7
Mississippi	Elk River, Minn.	30B	94	2,433	3,877	3,873	3,875	3,812	-1.6	3,855	-0.5	2,428	-0.2	35	19.9	3.4	16.5	*† P-2	17.2	1.2	16.0	† HFA
Ocmulgee	Macon, Ga.	31B	83	3,870	3,613	3,614	3,614	3,726	+3.1	3,739	+3.5	3,833	-1.0	31	21.8	4.1	17.7	*† P-3	15.2	0.7	14.5	* SP-4
Juniata	Newport, Pa.	32B	116	2,211	3,280	3,276	3,278	3,247	-0.9	3,314	+1.1	2,137	-3.4	35	13.6	0.1	13.5	* P-4	10.9	-0.7	11.6	* P-4
Yadkin	Yadkin College, N. C.	33B	114	1,289	3,185	3,189	3,187	3,199	+0.4	3,230	+1.4	1,280	-0.7	33	26.0	11.1	14.9	* P-2	10.0	0.6	9.4	*SP-7
Sangamon	Oakford, Ill.	34B	106	1,458	3,106	3,116	3,111	3,102	-0.3	3,123	+0.4	1,436	-0.8	33	19.6	6.2	13.4	* P-2	14.7	0.5	14.2	* P-1
Tualatin	Willamette, Oreg.	35B	82	3,208	2,993	2,991	2,992	3,052	+2.0	3,074	+2.7	3,210	+0.1	26	24.8	7.8	17.0	* P-2	8.8	2.4	6.4	*SP-7
French Broad	Newport, Tenn.	36B	131	1,553	2,886	2,892	2,889	2,896	+0.2	2,883	-0.2	1,559	+0.4	42	22.4	4.7	17.7	*SP-4	19.8	1.9	17.9	*State
Grand River	Grand Rapids, Mich.	37B	120	1,752	2,808	2,805	2,806	2,763	-1.5	2,765	-1.5	1,717	-2.0	31	18.2	4.7	13.5	* P-2	14.5	2.0	12.5	* SP-5
Arkansas	Arkansas City, Kans.	38B	126	1,115	2,742	2,759	2,750	2,546	-7.4	2,594	-5.7	1,100	-1.4	44	21.8	7.0	14.8	*† P-3	23.8	10.0	13.8	*† P-2
Saco	Cornish, Me.	39B	122	980	2,461	2,461	2,461	2,491	+1.2	2,506	+1.8	984	+0.4	42	37.5	13.0	24.5	† P-1	29.8	9.4	20.4	† P-2
Rio Grande	San Felipe, N. M.	62B	129	673	2,277	2,292	2,284	2,262	-1.0	2,275	-0.4	675	+0.3	37	24.8	4.6	20.2	*† P-4	13.2	2.4	10.8	*† P-4
Licking	Blue Lick Springs, Ky.	40B	115	1,124	2,269	2,276	2,272	2,250	-1.0	2,277	+0.2	1,114	-0.9	33	14.5	4.8	9.7	* P-3	14.0	4.6	9.4	* P-3
Senaca	Anderson, S. C.	41B	105	1,370	2,143	2,143	2,143	2,103	-1.9	2,107	-1.7	1,361	-0.7	36	19.6	4.4	15.2	*† P-3	16.5	3.4	13.1	* P-4
Chickasawhay	Enterprise, Miss.	42B	81	599	2,002	2,005	2,004	1,975	-1.4	2,004	0	596	-0.5	27	22.2	3.0	19.2	* P-3	6.7	1.0	5.7	* P-2
Ossipee	Effingham Falls, N. H.	43B	100	1,768	1,881	1,886	1,884	1,847	-2.0	1,856	-1.5	1,752	-0.9	30	17.6	6.0	11.6	*† P-4	17.5	4.7	12.8	† P-2

* Experienced in mean-section method

† Experienced in mid-section method

*† Experienced in both methods

TABLE 1 - Continued

Gaging Station			Special Measurement					Normal Measurement							Computation				Checking			
															Time in Minutes				Time in Minutes			
River	Place	File No.	No. Obs.	Area	Mean-Sec.	Mid-Sec.	Average	Mean-Sec.	Percent Diff.	Mid-Sec.	Percent Diff.	Area	Percent Diff.	No. Obs.	Mean-Sec.	Diff.	Mid-Sec.	Grade	Mean-Sec.	Diff.	Mid-Sec.	Grade
French Broad	Asheville, N. C.	44B	162	740	1,730	1,729	1,730	1,718	-0.7	1,735	+0.3	736	-0.5	43	17.0	3.8	13.2	*† P-3	15.5	3.7	11.8	* P-4
Cheyenne ‡	Eagle Butte, S. D.	45B	126	619	1,662	1,665	1,664	1,653	-0.7	1,674	+0.6	614	-0.8	29	14.6	9.0	5.6	* P-2	12.9	3.1	9.8	* P-1
Choctawhatchee	Newton, Ala.	46B	101	441	1,560	1,559	1,560	1,552	-0.5	1,556	-0.3	445	+0.9	32	23.8	8.9	14.9	* P-4	15.6	6.5	9.1	*† P-3
Tygart	Colfax, W. Va.	47B	123	1,133	1,442	1,443	1,442	1,437	-0.3	1,441	0	1,124	-0.8	32	12.7	-5.5	18.2	*State	9.9	0.4	9.5	*State
Gila	Calva, Ariz.	48B	121	528	1,383	1,386	1,384	1,368	-1.2	1,382	-0.1	531	+0.6	42	36.7	10.8	25.9	*State	16.0	1.5	14.5	*† P-3
St. Johns	Sanford, Fla.	49B	120	4,390	1,319	1,318	1,318	1,300	-1.4	1,308	-0.8	4,384	-0.1	38	29.3	5.4	23.9	†HFA	18.0	5.8	12.2	* P-3
Bighorn	Rairden, Wyo.	50B	89	402	1,309	1,313	1,311	1,312	+0.1	1,312	+0.1	401	-0.2	29	18.2	7.7	10.5	† P-2	17.1	5.6	11.5	† P-2
Colorado	Wharton, Tex.	51B	86	783	1,302	1,304	1,303	1,306	+0.2	1,312	+0.7	785	+0.3	28	14.5	3.4	11.1	*† P-3	7.9	1.0	6.9	* P-2
Kalamazoo	Comstock, Mich.	52B	111	706	1,129	1,130	1,130	1,141	+1.0	1,125	-0.4	707	+0.1	30	12.0	2.5	9.5	*† P-3	16.8	10.5	6.3	†HFA
Red Cedar	Menomonie, Wis.	53B	105	1,095	1,070	1,070	1,070	1,057	-1.2	1,064	-0.6	1,100	+0.5	30	16.8	4.7	12.1	† P-2	8.4	1.0	7.4	* P-3
Colorado	LaGrange, Tex.	54B	77	732	909	914	912	873	-4.3	885	-3.0	717	-2.0	28	36.0	17.0	19.0	† SP-5	10.3	2.2	8.1	* P-3
Chatooga	Clayton, Ga.	55B	148	329	911	909	910	885	-2.7	890	-2.2	329	0	33	14.6	5.3	9.3	* SP-4	12.4	4.4	8.0	*State
Taylor	Almont, Colo.	56B	68	188	819	818	818	819	+0.1	826	+1.0	187	-0.5	27	11.3	1.1	10.2	* P-4	11.0	3.0	8.0	*† P-3
Amite	Denham Springs, La.	57B	82	684	725	725	725	713	-1.1	724	-0.1	673	-1.6	23	9.0	1.5	7.5	* P-3	9.4	2.3	7.1	* P-3
Scioto	Dublin, Ohio	58B	117	815	525	524	524	517	-1.3	520	-0.8	806	-1.1	33	25.2	6.4	18.8	* P-3	9.6	3.8	5.8	* P-2
Taunton	State Farm, Mass.	59B	104	640	522	522	522	514	-1.5	516	-1.1	634	-0.9	32	20.0	3.0	17.0	† P-2	8.6	1.5	7.1	* P-3
Oklawaha	Ocala, Fla.	60B	99	429	341	341	341	345	+1.2	349	+2.3	430	+0.2	27	15.4	4.6	10.8	* SP-4	10.6	1.0	9.6	*State
Colorado	Ballinger, Tex.	61B	61	353	256	256	256	251	-2.0	251	-2.0	351	-0.6	32	20.4	5.4	15.0	† P-2	6.8	1.6	5.2	* P-3
								WADING MEASUREMENTS														
Cedar	Waterloo, Iowa	1W	64	993	2,314	2,315	2,314	2,302	-0.4	2,306	-0.3	993	0	28	21.6	6.3	15.3	* P-2	13.0	2.7	10.3	* P-1
Kankakee	Wilmington, Ill.	2W	136	1,129	2,200	2,219	2,210	2,200	-0.5	2,218	+0.4	1,132	+0.3	35	30.5	16.0	14.5	* P-2	18.2	4.4	13.8	* P-2
Platte	Grand Island, Neb.	75W	232	839	1,607	1,615	1,611	1,647	+2.2	1,662	+3.2	853	+1.7	62	28.1	2.8	25.3	* P-4	37.0	1.0	36.0	*† P-3
Tallapoosa	Ofelia, Ala.	3W	110	476	1,153	1,155	1,154	1,177	+2.0	1,178	+2.1	477	+0.2	29	16.2	7.1	9.1	*†P-3	20.0	8.7	11.3	* P-4
Little Missouri	Medora, N. D.	4W	93	396	935	936	936	901	-3.7	909	-2.9	385	+2.9	26	13.3	4.7	8.6	*†P-3	12.2	1.0	11.2	† SP-5
Chehalis	Grand Mound, Wash.	5W	120	341	868	868	868	862	-0.7	867	-0.1	340	-0.3	29	23.0	6.3	16.7	* P-3	7.2	1.2	6.0	* P-2
Gila	Winkelman, Ariz.	6W	85	218	705	706	706	698	-0.8	702	-0.6	218	0	26	16.0	6.0	10.0	*State	9.6	2.4	7.2	*† P-3
Raystown Br. Juniata	Saxton, Pa.	7W	124	299	675	677	676	694	+2.7	702	+3.8	296	-1.0	31	21.6	4.3	17.3	* P-4	8.5	2.0	6.5	* P-3
Gila	Kelvin, Ariz.	8W	78	179	669	670	670	669	-0.1	673	+0.4	179	0	24	10.5	1.9	8.6	*State	8.2	-0.4	8.6	*State
Little	Walland, Tenn.	9W	140	302	620	619	620	619	-0.2	624	+0.6	300	-0.7	32	17.9	6.9	11.0	*†P-3	12.2	0.7	11.5	*State
Wind	Crowheart, Wyo.	10W	134	224	612	612	612	609	-0.5	614	+0.3	226	+0.9	29	16.0	2.7	13.3	*†P-4	15.6	7.2	8.4	† P-1
Illinois	Tahleguah, Okla.	11W	66	304	571	571	571	566	-0.9	571	0	303	+0.3	27	15.5	2.5	13.0	* P-3	7.8	2.1	5.7	*† P-3
Licking	Newark, Ohio	12W	128	225	520	521	520	512	-1.6	517	-0.6	222	+1.3	28	21.3	5.1	16.2	*SP-5	8.7	2.1	6.6	* SP-7
Oconalufty	Cherokee, N. C.	13W	121	336	510	510	510	510	0	512	+0.4	336	0	34	24.0	10.0	14.0	†HFA	11.1	1.6	9.5	*† P-2
Penns	Penns Creek, Pa.	14W	114	237	454	454	454	464	+2.2	468	+3.1	234	-1.3	30	19.3	2.0	17.3	* P-4	7.2	1.0	6.2	* P-3
Patapsco	Hollofield, Md.	76W	130	170	435	436	436	436	0	439	+0.7	171	+0.6	27	14.0	4.3	9.7	* P-3	10.4	4.0	6.4	* P-2
Provo	Vivian Park, Utah	15W	102	185	429	430	430	427	-0.7	433	+0.7	181	-2.2	24	17.6	7.8	9.8	*SP-4	7.6	2.9	3.8	* SP-4
Big Piney	Big Piney, N. D.	16W	102	195	427	427	427	440	+3.0	442	+3.5	195	0	26	15.2	2.2	13.0	*†P-3	16.5	3.5	13.0	† SP-3
Ninnescah	Peck, Kans.	17W	134	208	395	395	395	380	-3.8	382	-3.3	204	-1.9	28	15.5	5.7	9.8	*†P-2	13.0	3.0	10.0	†HFA
Colorado	Robert Lee, Tex.	18W	94	209	355	356	356	356	0	358	+0.6	209	0	26	11.3	2.4	8.9	*†P-3	13.5	3.7	9.8	† P-2
Cheyenne	Wasta, S. D.	19W	82	183	347	347	347	348	+0.3	352	+1.4	182	-0.5	25	10.8	3.3	7.5	* P-2	8.6	2.7	5.9	* P-1
Milk	Eastern Crossing, Mont.	20W	97	116	341	342	342	337	-1.5	340	-0.6	115	-0.9	29	14.7	8.1	6.6	*SP-4	8.9	2.2	6.7	* SP-4
South Tyger	Reidville, S. C.	21W	93	202	339	339	339	335	-1.2	335	-1.2	200	-1.0	27	19.0	6.3	12.7	*†P-3	14.5	0.8	13.7	* P-4

* Experienced in mean-section method
† Experienced in mid-section method
*† Experienced in both methods
‡ Used that portion measured from bridge

TABLE 1 - Continued

Gaging Station		Special Measurement						Normal Measurement							Computation				Checking			
															Time in Minutes				Time in Minutes			
River	Place	File No.	No. Obs.	Area	Mean-Sec.	Mid-Sec.	Average	Mean-Sec.	Per-cent Diff.	Mid-sec.	Per-cent Diff.	Area	Per-cent Diff.	No. Obs.	Mean-Sec.	Diff.	Mid-Sec.	Grade	Mean-Sec.	Diff.	Mid-Sec.	Grade
Smith	Philpott, Va.	22W	91	197	334	334	334	328	-1.8	330	-1.2	194	-1.5	25	17.9	4.3	13.6	* P-2	10.1	0.6	9.5	* P-2
Pecos	Puerto de Luna, N. M.	23W	135	126	302	302	302	299	-1.0	300	-0.7	126	0	30	19.6	3.8	15.8	*† P-4	10.4	3.1	7.3	*† P-4
Powder	Arvada, Wyo.	24W	109	92.4	298	298	298	294	-1.3	295	-1.0	918	-0.6	25	11.3	3.5	7.8	† P-2	15.6	8.4	7.2	† P-2
Farmington	Riverton, Conn.	25W	88	306	289	289	289	287	-0.7	289	0	302	7.3	29	18.5	4.9	13.6	† P-2	8.6	1.4	7.2	* P-3
Cedar	East Lansing, Mich.	26W	109	209	279	280	280	280	0	284	+1.4	207	-1.0	27	9.9	4.2	5.7	*† P-3	12.0	4.2	7.8	† P-2
Farmington	New Boston, Mass.	27W	101	130	280	281	281	265	-5.7	272	-2.9	127	+2.3	30	22.2	6.7	15.5	* P-4	9.2	1.7	7.5	* P-3
W. Fork San Jacinto	Humble, Tex.	28W	114	244	274	274	274	271	-1.1	272	-0.7	245	+0.4	27	10.0	2.7	7.3	* P-3	12.0	3.8	8.2	* SP-4
Little Pigeon	Sevierville, Tenn.	29W	78	205	272	271	272	270	-0.7	272	0	209	+1.9	23	10.0	2.0	8.1	*† P-3	8.5	1.7	6.8	*State
San Joaquin	Fre. Ford Br., Calif.	30W	85	302	260	260	260	261	+0.4	263	+1.2	299	-1.0	24	18.0	5.8	12.2	*State	7.5	1.4	6.1	* SP-4
No. Canadian	El Reno, Okla.	31W	77	153	244	244	244	241	-1.2	244	0	153	0	23	13.3	2.9	10.4	*† P-2	8.2	1.6	6.6	*† P-3
Little Coal	Danville, W. Va.	32W	119	239	240	240	240	237	-1.2	238	-0.8	235	-1.7	27	12.5	3.5	9.0	* P-1	8.6	2.6	6.0	* P-2
Guadalupe	New Braunfels, Tex.	33W	113	258	234	234	234	231	-1.3	231	-1.3	257	-0.4	27	23.0	9.0	14.0	† SP-5	9.0	2.5	6.5	†HFA
Reed Creek	Grahams Forge, Va.	34W	111	246	232	232	232	230	-0.9	230	-0.9	242	-1.6	29	18.8	-4.2	23.0	* SP-5	12.9	3.7	9.2	* SP-7
Zumbro	Zumbro Falls, Minn.	35W	76	105	224	224	224	224	0	224	0	105	0	27	12.8	1.8	11.0	† P-2	14.6	3.8	10.8	*† P-4
Mills	Mills River, N. C.	36W	85	121	205	205	205	202	-1.5	203	-1.0	121	0	26	11.8	5.0	6.8	*† P-3	11.9	4.8	7.1	† SP-6
Tobesofkee	Macon, Ga.	37W	78	133	202	202	202	201	-0.5	203	+0.5	134	+0.7	23	11.3	0.7	10.6	*† P-3	5.2	1.4	3.8	* SP-4
Animas	Tacoma, Colo	77W	127	93.4	177	177	177	161	-9.0	160	-9.6	91.2	-2.4	31	21.0	7.1	13.9	* P-2	8.2	1.5	6.7	* P-3
Casselman	Markelton, Pa.	38W	136	201	202	201	202	188	-6.9	190	-6.0	197	-2.0	28	9.7	0.4	9.3	* P-4	8.6	-0.1	8.7	* P-4
Homochitto	Eddiceton, Miss.	39W	97	121	189	189	189	186	-1.6	186	-1.6	120	+0.8	28	15.4	1.7	13.7	* P-1	9.9	2.5	7.4	* P-2
Wallkill	Unionville, N. Y.	40W	103	101	179	178	178	175	-1.7	175	-1.7	102	+1.0	28	15.7	5.3	10.4	* P-3	6.4	0	6.4	* P-4
Tickfaw	Holden, La.	41W	93	111	165	166	166	167	+0.6	168	+1.2	111	0	25	15.3	2.8	12.5	* P-4	12.1	4.8	7.3	*† P-3
San Antonio	Falls City, Tex.	42W	92	112	162	162	162	155	-4.3	158	-2.5	110	-1.8	26	8.8	2.0	6.8	* P-3	9.2	4.4	4.8	† SP-4
Richland	Dayton, Tenn.	43W	91	84.0	156	156	156	157	+0.6	156	0	84.9	+1.1	26	18.0	6.5	11.5	† P-2	9.0	2.0	7.0	*† P-3
Blackfoot	Blackfoot, Idaho	44W	79	70.5	150	150	150	151	+0.7	152	+1.3	70.2	-0.4	20	13.9	6.1	7.8	* SP-4	4.1	1.6	2.5	* SP-4
Still	Robertsville, Conn.	45W	88	114	149	149	149	154	+3.2	153	+2.7	115	+0.9	29	15.0	1.0	14.0	* P-3	12.1	5.4	6.7	†HFA
E. Walker	Yerington, Nev.	46W	116	70.8	145	145	145	146	+0.7	147	+1.4	70.8	0	29	21.1	3.7	17.4	*State	14.8	5.6	9.2	*† P-3
Fall	Ithaca, N; Y.	47W	102	64.8	143	143	143	142	-0.7	142	-0.7	64.4	-0.6	27	12.5	1.9	10.6	* P-3	10.4	3.4	7.0	* P-3
Bean Blosson	Dolan, Ind	48W	99	73.4	142	142	142	140	-1.4	142	0	73.2	+0.3	25	11.3	3.4	7.9	* P-2	8.5	2.5	6.0	* P-1
No. Br. Rancocas	Pemberton, N. J.	49W	97	150	140	140	140	139	-0.7	139	-0.7	148	-1.3	25	15.5	8.0	7.5	† P-2	9.8	3.8	6.0	* P-3
Pequest	Pequest, N. J.	50W	91	107	137	137	137	134	-2.2	135	-1.5	107	0	26	16.8	6.8	10.0	† SP-6	12.0	3.5	8.5	† P-2
Gales	Forest Grove, Oreg.	51W	79	111	132	133	132	132	0	133	+0.8	110	+1.0	22	8.5	0.8	7.7	* P-2	6.6	-0.1	6.7	* P-1
Austin	Bingham, Me.	52W	88	92.8	118	118	118	118	0	119	+0.9	92.4	-0.4	23	11.6	4.5	7.1	† P-1	4.2	1.0	3.2	* P-3
So. Br. Waits	Bradford, Vt.	53W	102	49.7	115	115	115	119	+3.4	120	+4.3	49.7	0	28	13.5	2.5	11.0	*† P-4	11.9	6.3	5.6	† SP-4
English	Kalona, Iowa	54W	82	120	113	113	113	113	0	114	+0.9	120	0	22	13.0	1.5	11.5	* P-2	9.4	2.4	7.0	* SP-5
Cannon	Welch, Minn.	55W	77	91.8	103	103	103	101	-2.0	102	-1.0	91.3	-0.5	28	14.2	3.2	11.0	† P-2	13.0	2.0	11.0	*† P-4
Pecatonica	Darlington, Wis.	56W	89	63.2	102	102	102	100	-2.0	101	-1.0	62.1	-1.7	27	13.7	4.7	9.0	† P-2	7.0	0.6	6.4	* P-3
Laurel Hill	Ursina, Pa.	57W	126	78.6	96.2	96.1	96.2	96.0	-0.2	96.3	+0.1	77.8	-1.0	29	12.4	0.4	12.0	* P-4	8.9	-2.8	11.7	* P-4
Sangamon	Mahomet, Ill.	58W	80	102	88.6	88.8	88.7	87.5	-1.4	88.4	-0.3	97.9	-4.0	25	9.5	1.3	8.2	* P-2	8.5	0.9	7.6	* P-1
Busseron	Carlisle, Ind.	59W	103	44.2	86.3	86.5	86.4	87.5	+1.3	88.1	+2.0	44.0	-0.5	28	12.1	1.9	10.2	* P-1	10.1	3.3	6.8	* P-2
Petit Jean	Booneville, Ark.	60W	79	54.0	81.0	81.1	81.0	80.0	-1.2	80.7	-0.5	53.9	-0.2	25	19.8	2.9	16.9	* P-2	12.4	3.1	9.3	* SP-5
Saint Mary's	Great Mills, Md.	78W	118	32.2	74.2	74.2	74.1	73.6	-0.7	74.4	+0.4	32.0	-0.6	29	13.2	3.1	10.1	* P-2	13.0	3.6	9.4	* P-3
Kayaderosseros	W. Milton, N. Y.	61W	98	97.0	73.5	73.6	73.6	72.7	-1.2	72.9	-1.0	96.0	-1.0	32	16.0	3.4	12.6	* P-3	7.2	0.6	6.6	* P-4
Santa Ana	Prado Dam, Calif.	62W	63	21.4	70.0	70.1	70.0	70.4	+0.6	70.7	+1.0	21.4	0	18	5.6	0.6	5.0	* P-3	6.9	1.1	5.8	* P-2
Santa Ana	Prado, Calif	63W	108	43.4	69.3	69.6	69.4	67.7	-2.4	68.7	-1.0	43.0	-0.9	28	18.0	8.5	9.5	† P-2	9.9	0.1	10.0	*† P-4

* Experienced in mean-section method
† Experienced in mid-section method
*† Experienced in both methods

TABLE 1 - Continued

Gaging Station			Special Measurement					Normal Measurement							Computation				Checking			
															Time in Minutes				Time in Minutes			
River	Place	File No.	No. Obs.	Area	Mean-Sec.	Mid-Sec.	Average	Mean-Sec.	Percent Diff.	Mid-Sec.	Percent Diff.	Area	Percent Diff.	No. Obs.	Mean-Sec.	Diff.	Mid-Sec.	Grade	Mean-Sec.	Diff.	Mid-Sec.	Grade
Elkhorn	Frankfort, Ky.	64W	108	65.4	66.7	66.6	66.6	66.1	-0.8	66.5	-0.1	65.8	+0.6	28	6.6	-0.2	6.8	* P-3	6.6	2.0	4.6	* P-3
Warm	Colton, Calif.	65W	58	28.3	59.0	59.2	59.1	58.9	-0.3	59.2	+0.2	28.15	-0.5	18	10.8	-0.2	11.0	*† P-2	6.2	2.0	4.2	*† P-3
Hanapepe	Koula, Hawaii	66W	59	91.3	51.0	51.4	51.2	49.8	-2.7	50.6	-1.2	90.4	-1.0	34	19.8	9.9	9.9	* SP-4	11.2	4.5	6.7	*State
Little Camas Canal	Bennett, Idaho	67W	116	29.7	45.2	45.2	45.2	45.1	-0.2	45.4	+0.4	29.3	-1.3	28	17.9	1.3	16.6	*State	8.6	2.1	6.5	* SP-4
Withlacooche	Trilby, Fla.	68W	90	66.0	44.3	44.3	44.3	44.0	+0.7	44.0	+0.7	66.0	0	26	22.3	6.6	15.7	†HFA	11.3	2.3	9.0	* P-4
Eno	Hillsboro, N. C.	69W	93	46.5	44.1	44.0	44.0	44.0	0	44.2	+0.5	45.5	-2.1	28	21.5	6.8	14.7	† SP-6	8.1	1.5	6.6	*† P-3
North Concho	San Angelo, Tex.	70W	75	21.4	35.3	35.3	35.3	35.4	+0.3	35.5	+0.6	21.3	-0.5	31	23.0	9.7	13.3	† P-2	11.5	5.0	6.5	* P-2
Warm	Colton, Calif.	71W	56	20.7	33.0	33.0	33.0	32.7	-0.9	32.9	-0.1	20.7	0	22	12.5	5.4	7.1	*† P-2	6.8	2.0	4.8	*† P-3
Tub Springs	Scotts Bluff, Neb.	79W	58	20.8	30.2	30.3	30.25	29.9	-1.2	30.5	+0.8	20.3	-2.4	15	5.4	0.8	4.6	* P-4	5.3	1.7	3.6	*† P-3
Evitts	Bedford Valley, Pa.	80W	118	24.5	25.9	25.9	25.9	26.4	+1.9	26.4	+1.9	24.7	+0.8	27	9.8	1.5	8.3	* P-3	6.1	0.5	5.6	* P-2
Green	Gladstone, N. D.	72W	92	19.7	18.6	18.6	18.6	18.65	+0.3	18.7	+0.5	19.55	-0.8	28	12.3	3.2	9.1	*† P-3	10.8	2.6	8.2	† SP-5
Honokohau	Honokahau, Hawaii	73W	45	35.3	17.0	17.0	17.0	17.0	0	16.9	-0.6	35.05	-0.7	23	18.2	1.4	16.8	†HFA	8.5	0.6	7.9	* P-3
Kahakuloa	Honokahau, Hawaii	74W	53	27.6	8.32	8.33	8.32	8.44	+1.3	8.46	+1.7	28.2	+2.2	27	20.3	-4.3	24.6	*State	13.1	3.1	10.0	*† P-3
CABLE AND BOAT MEASUREMENTS																						
Columbia	Trinidad, Wash.	1C	119	16,642	57,324	57,368	57,346	57,310	0	57,500	+0.3	16,582	-0.4	32	26.0	7.4	18.6	* P-1	15.1	3.4	11.7	* P-2
Missouri ‡	Ft. Randall Dam, S. D.	2C	100	11,240	26,970	27,039	27,004	27,060	+0.2	27,350	+1.3	11,271	+0.3	28	22.6	4.9	17.7	* P-1	11.7	1.7	10.0	* P-2
Arkansas ‡	Van Buren, Ark.	3C	86	7,260	22,950	22,962	22,956	22,549	-1.8	22,696	-1.1	7,240	-0.3	34	32.5	13.1	19.4	* P-2	18.0	0.9	17.1	* SP-7
Snake	Weiser, Idaho	4C	104	6,568	21,896	21,911	21,904	21,865	-0.2	21,954	+0.2	6,532	-0.5	32	17.7	1.1	16.6	*State	13.0	6.8	6.2	* SP-4
Colorado	Lees Ferry, Ariz.	5C	82	3,053	21,095	21,102	21,098	20,913	-0.9	21,042	-0.3	3,016	-1.2	24	30.3	8.1	22.2	*State	10.4	-3.3	13.7	*† P-3
Muskingum	McConnelsville, Ohio	6C	84	7,260	12,036	12,044	12,044	11,883	-1.3	11,998	-0.4	7,202	-0.8	25	18.2	4.3	13.9	* P-1	14.2	3.4	10.8	* P-2
Colorado	Hite, Utah	7C	124	3,724	11,246	11,250	11,248	11,079	-1.5	11,182	-0.6	3,691	-0.9	31	22.6	7.2	15.4	* SP-4	7.6	2.3	5.3	* SP-4
Brazos	Richmond, Tex.	8C	79	3,688	10,101	10,135	10,118	10,010	-1.1	10,071	-0.5	3,671	-0.5	29	30.0	13.5	16.5	† SP-5	9.6	-1.2	10.8	* P-2
Payette	Horseshoe Bend, Idaho	9C	118	1,868	10,046	10,049	10,048	9,937	-1.1	9,986	-0.6	1,852	-0.9	28	13.7	4.0	9.7	*State	9.5	3.4	6.1	* SP-4
Merrimack	Lowell, Mass.	10C	125	4,275	9,926	9,949	9,938	9,907	-0.3	9,951	+0.1	4,276	0	36	34.5	10.2	24.3	† P-2	14.2	4.8	9.4	* P-3
Wabash ‡	Riverton, Ind.	11C	99	4,418	8,980	9,017	8,998	8,932	-0.7	8,974	-0.3	4,389	-0.7	28	20.2	5.2	15.0	* P-1	12.0	0.2	11.8	* P-2
Puyallup	Puyallup, Wash.	12C	120	1,622	8,280	8,284	8,282	8,229	-0.6	8,275	-0.1	1,615	-0.4	28	16.7	6.9	9.8	* P-1	10.2	3.7	6.5	* P-2
Neosho ‡	Ft. Gibson, Okla.	13C	77	2,797	8,092	8,105	8,098	7,977	-1.5	8,022	-0.9	2,781	-0.6	25	15.0	2.5	12.5	* P-3	7.3	1.9	5.4	*† P-3
Snake	Neeley, Idaho	14C	180	2,085	7,959	7,976	7,968	7,874	-1.2	7,863	-1.3	2,095	+0.5	46	28.7	9.5	19.2	* SP-4	19.5	2.1	17.4	*State
Brazos	Whitney, Tex.	15C	93	2,218	7,013	7,012	7,012	7,017	+0.1	7,020	+0.1	2,186	-1.4	26	23.1	2.0	21.1	† P-2	9.6	1.4	8.2	* P-3
Broad	Richtex, S. C.	16C	110	3,375	6,785	6,785	6,785	6,706	-1.2	6,697	-1.3	3,302	-2.2	29	14.3	3.6	10.7	*† P-3	9.6	-0.7	10.3	* P-4
Chenango	Chenango Forks, N. Y.	17C	113	1,858	6,525	6,536	6,530	6,537	+0.1	6,605	+1.1	1,855	-0.2	30	19.2	7.0	12.2	* P-3	8.6	-0.3	8.9	* P-4
San Juan	Farmington, N. M.	18C	113	1,028	6,440	6,440	6,440	6,388	-0.8	6,401	-0.6	1,026	-0.2	28	19.9	2.1	17.8	*† P-4	14.7	3.4	11.3	† P-1
French Broad	Hot Springs, N. C.	19C	101	1,555	5,611	5,615	5,613	5,562	-0.9	5,611	0	1,530	-1.6	27	15.9	3.9	12.0	*† P-2	11.0	4.0	7.0	* P-3
Brazos	Bryan, Tex.	20C	93	1,706	4,674	4,676	4,675	4,662	-0.3	4,687	+0.3	1,702	-0.2	29	17.8	8.6	9.2	*† P-3	14.0	4.0	10.0	†HFA
Flathead	Polson, Mont.	21C	87	2,721	4,368	4,374	4,371	4,355	-0.4	4,387	+0.4	2,710	-0.4	24	12.0	0.2	11.8	* P-2	12.2	2.4	9.8	* P-2
Cheat	Rowlesburg, W. Va.	22C	125	1,704	4,313	4,314	4,314	4,280	-0.8	4,316	0	1,697	-0.4	29	14.5	-2.4	16.9	*State	11.4	2.6	8.8	*State
Shenandoah	Millville, W. Va.	38C	152	2,189	4,013	4,020	4,016	4,040	+0.6	4,050	+0.8	2,168	-1.0	33	21.9	7.1	14.8	* P-2	14.3	3.9	10.4	* P-3
Neuse	Kinston, N. C.	23C	87	1,830	3,932	3,933	3,932	3,872	-1.5	3,896	-0.9	1,822	-0.1	27	21.0	7.5	13.5	† SP-6	7.8	2.6	5.2	*† P-3
Cowlitz	Kosmos, Wash.	24C	110	1,244	3,905	3,898	3,902	3,847	-1.4	3,871	-0.8	1,242	-0.2	29	24.3	7.6	16.7	* P-3	8.6	2.6	6.0	* P-2
Snake	Milner, Idaho	25C	131	2,039	3,893	3,889	3,891	3,960	+1.8	3,946	+1.4	2,031	-0.4	39	21.4	5.0	16.4	* SP-4	22.0	3.2	18.8	*State
Stanislaus	Ripon, Calif.	26C	95	1,585	3,617	3,620	3,618	3,552	-1.8	3,606	-0.3	1,588	+0.2	28	18.6	1.3	17.3	*State	12.9	3.3	9.6	* SP-4
Deep	Moncure, N. C.	27C	130	2,045	3,570	3,568	3,569	3,548	-0.6	3,553	-0.4	2,050	+0.2	35	22.0	9.5	12.5	† SP-6	11.4	2.6	8.8	*† P-3
Gasconade ‡	Jerome, Mo.	28C	91	986	3,500	3,504	3,502	3,482	-0.6	3,509	+0.2	963	-2.4	29	21.7	3.9	17.8	†HFA	29.0	16.0	13.0	†HFA

* Experienced in mean-section method
† Experienced in mid-section method
*† Experienced in both methods
‡ Boat Measurements

TABLE 1 - Continued

Gaging Station			Special Measurement					Normal Measurement							Computation				Checking			
River	Place	File No.	No. Obs.	Area	Mean-Sec.	Mid-Sec.	Average	Mean-Sec.	Percent Diff.	Mid-Sec.	Percent Diff.	Area	Percent Diff.	No. Obs.	Time in Minutes: Mean-Sec.	Time in Minutes: Diff.	Time in Minutes: Mid-Sec.	Grade	Time in Minutes: Mean-Sec.	Time in Minutes: Diff.	Time in Minutes: Mid-Sec.	Grade
Tuolumne	LaGrange, Calif.	29C	90	893	3,285	3,284	3,284	3,270	-0.4	3,276	-0.2	890	-0.3	28	22.3	7.8	14.5	† P-2	10.3	3.7	6.6	* P-3
Gauley	Belva, W. Va.	30C	133	1,846	3,187	3,199	3,193	3,153	-1.3	3,154	-1.2	1,836	-0.5	30	13.5	0.8	12.7	*State	11.2	2.2	9.0	*State
Bayou Macon ‡	Delhi, La.	31C	81	3,684	3,174	3,172	3,173	3,117	-1.8	3,131	-1.3	3,695	+0.3	26	10.5	3.0	7.5	* P-3	11.1	2.8	8.3	* P-3
Snake	Heise, Idaho	32C	150	1,023	2,928	2,931	2,930	2,945	+0.5	2,950	+0.7	1,022	-0.1	39	15.1	5.8	9.3	*SP -4	10.8	1.3	9.5	*State
Cumberland	Cumberland Falls, Ky.	33C	117	1,473	2,926	2,930	2,928	2,948	+0.7	2,940	+0.4	1,484	+0.7	34	18.6	1.5	17.1	* P-3	10.3	-0.7	11.0	* P-4
Ocmulgee ‡	Jackson, Ga.	34C	114	2,801	2,808	2,808	2,808	2,700	-3.8	2,708	-3.7	2,787	-0.5	27	21.6	6.3	15.3	*† P-3	10.3	1.0	9.3	* SP-4
Rio Chama	Parkview, N. M.	35C	123	526	2,762	2,759	2,760	2,805	+1.6	2,832	+2.6	532	+1.1	35	23.4	6.8	16.6	*† P-4	17.6	6.4	11.2	† P-1
Farmington	Rainbow, Conn.	36C	89	676	2,617	2,610	2,614	2,623	+0.3	2,639	+1.0	676	0	24	15.6	6.1	9.5	† P-2	23.8	16.3	7.5	† P-2
Verde	Bartlett Dam, Ariz.	37C	102	505	2,484	2,495	2,490	2,449	-1.6	2,480	-0.4	504	-0.2	28	14.2	3.4	10.8	* State	14.7	0.4	14.3	*State
Red River of the North	Grand Forks, N. D.	39C	101	1,622	2,239	2,239	2,239	2,239	0	2,256	+0.8	1,625	+0.2	27	22.5	9.0	13.5	† SP-5	14.0	4.5	9.5	* P-3
Housatonic	Gaylordsville, Conn.	40C	96	1,016	2,179	2,181	2,180	2,182	0	2,193	+0.6	1,012	-0.4	25	16.8	2.1	14.7	† P-2	14.2	7.8	6.4	† SP-4
Rappahannock	Fredericksburg, Va.	41C	113	2,204	2,164	2,163	2,164	2,130	-1.6	2,127	-1.7	2,206	0	29	26.5	8.3	18.2	* P-3	17.1	5.0	12.1	* SP-5
Connecticut	No. Stratford, N. H.	42C	103	652	2,126	2,127	2,126	2,142	+0.8	2,146	+0.9	661	+1.4	28	17.3	1.0	16.3	*† P-4	16.0	6.2	9.8	† SP-4
Colorado	Cameo, Colo.	43C	110	565	2,116	2,122	2,119	2,112	-0.3	2,127	+0.4	565	0	27	20.7	3.8	16.9	*† P-3	11.1	1.8	9.3	* P-4
Williamson	Chiloquin, Ore.	44C	103	993	2,010	2,010	2,010	1,998	-0.6	2,017	+0.3	989	-0.4	27	19.8	8.0	11.8	* P-2	13.1	6.6	6.5	* SP-5
Salt	Roosevelt, Ariz.	45C	103	611	1,943	1,947	1,945	1,941	-0.2	1,967	+1.1	619	+1.3	28	14.7	2.1	12.6	*State	14.2	1.2	13.0	*State
Clinch	Tazewell, Tenn.	46C	105	1,214	1,942	1,943	1,942	1,934	-0.4	1,949	+0.4	1,210	-0.3	28	15.6	3.7	11.9	*† P-3	12.7	1.5	11.2	*State
Sacandaga	Hope, N. Y.	47C	101	692	1,708	1,705	1,706	1,697	-0.5	1,705	0	691	-0.1	29	13.6	0.6	13.0	* P-3	12.1	4.0	8.1	* P-3
Perdido ‡	Barrineau Park, Fla.	48C	97	683	1,703	1,700	1,702	1,698	-0.2	1,704	+0.1	681	-0.3	24	9.8	3.5	6.3	* SP-4	6.7	1.8	4.9	*State
Current	Eminence, Mo.	49C	107	588	1,650	1,654	1,652	1,647	-0.3	1,655	+0.2	585	-0.5	29	16.8	4.8	12.0	* P-3	10.0	2.0	8.0	†HFA
Raritan ‡	Bound Brook, N. J.	50C	88	915	1,216	1,226	1,221	1,205	-1.3	1,212	-0.1	902	-1.4	26	21.0	10.0	11.0	† P-2	8.9	1.1	7.8	*† P-2
Choccolocco	Lincoln, Ala.	51C	125	882	1,221	1,221	1,221	1,200	-1.7	1,205	-1.3	886	+0.5	28	18.0	5.2	12.8	* P-4	11.4	3.4	8.0	*† P-3
Neosho	Iola, Kans.	52C	108	1,069	1,165	1,166	1,166	1,141	-2.1	1,150	-1.4	1,064	-0.5	26	13.1	2.9	10.2	*† P-2	12.0	3.0	9.0	†HFA
Allegheny	Kinzua, Pa.	53C	119	1,169	1,133	1,135	1,134	1,124	-0.9	1,133	0	1,166	-0.3	31	20.1	2.5	17.6	* P-4	9.6	3.1	6.5	* P-3
Mulberry	Mulberry, Ark.	54C	76	662	1,030	1,030	1,030	1,036	+0.6	1,038	+0.8	656	-0.9	26	14.3	3.9	10.4	* P-2	9.2	1.1	8.1	* SP-7
Sevier	Juab, Utah	55C	100	455	1,002	1,003	1,002	992	-1.0	999	-0.3	452	-0.7	26	13.7	4.6	9.1	* SP-4	7.0	1.1	5.9	* SP-4
Youghiogheny	Confluence, Pa.	56C	127	808	999	1,000	1,000	1,026	+2.6	1,031	+3.1	814	+0.7	27	19.6	3.2	16.4	* P-4	8.9	2.5	6.4	* P-3
Kalamazoo	Battle Creek, Mich.	57C	117	581	985	986	986	990	+0.4	996	+1.0	580	-0.2	27	15.7	5.1	10.6	*† P-2	13.0	3.0	10.0	† P-2
Neversink	Oakland Valley, N. Y.	58C	107	416	942	941	942	926	-1.7	927	-1.6	411	-1.2	28	12.2	0.7	11.5	* P-3	8.9	2.2	6.7	* P-3
Chippewa	Bruce, Wis.	59C	100	545	785	785	785	788	+0.4	791	+0.8	541	-0.7	26	19.0	5.0	14.0	†HFA	14.7	3.4	11.3	†HFA
Tuolumne	Hetch Hetchy, Calif.	60C	125	523	775	775	775	774	0	774	0	522	-0.2	36	16.5	2.0	14.5	*State	12.7	2.2	10.5	*† P-3
So. Chickamauga	Chickamauga, Tenn.	61C	90	405	669	669	669	665	-0.6	669	0	405	0	25	11.7	2.5	9.2	* SP-4	9.6	-2.1	11.7	*State
Millers	So. Royalston, Mass.	62C	97	318	634	634	634	642	+1.3	644	+1.6	322	+1.3	27	21.5	6.3	15.2	† P-2	7.8	1.8	6.0	* P-3
Vermilion	Danville, Ill.	63C	82	427	507	510	508	502	-1.2	506	-0.4	420	+1.6	25	19.2	1.3	17.9	* SP-5	13.2	3.7	9.5	* P-2
Truckee	Reno, Nev.	64C	100	292	482	482	482	495	+2.7	488	+1.2	291	-0.3	30	14.6	3.3	11.3	*State	13.2	3.9	9.3	*† P-3
Shoshone	Byron, Wyo.	65C	94	277	465	466	466	457	-1.9	460	-1.3	276	-0.4	27	12.6	-1.1	13.7	*† P-4	10.2	1.1	9.1	† P-1
Carrabassett	No. Anson, Me.	66C	94	389	389	389	389	382	-1.8	385	-1.0	384	-1.3	27	17.0	5.9	11.1	† P-1	7.7	0.4	7.3	* P-4
Pearl ‡	Edinburg, Miss.	67C	106	229	294	294	294	292	-0.7	296	+0.7	229	0	24	14.8	5.4	9.4	* P-1	7.3	1.2	6.1	* P-2
Rum	St. Francis, Minn.	68C	106	427	275	275	275	277	+0.7	279	+1.4	424	-0.7	26	16.5	6.0	10.5	† P-2	10.0	1.5	8.5	† SP-5
Gallatin	Gallatin Gateway, Mont.	69C	93	137	271	271	271	271	0	275	+1.5	137	0	26	12.1	4.9	7.2	* SP-4	8.4	2.8	5.6	* SP-4
Diamond	Wentworth Location, N. H	70C	83	198	179	179	179	175	-2.8	174	-2.8	199	+0.5	26	17.5	8.0	9.5	† P-2	7.2	2.7	4.5	*† P-3

* Experienced in mean-section method
† Experienced in mid-section method
*† Experienced in both methods
‡ Boat Measurements

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Special Study for Few Measurements

The tabulation and computations were checked and examined for errors. The ten normal measurements in which discharge differed 4 percent or more from the true discharge were singled out for further study to determine if possible whether the large error was due to poorly-selected observation stations, or to irregular cross-section and velocity. For three of these measurements, 27W, 38W, and 42W, an attempt was made to select stations to improve the accuracy of computed discharge, still keeping within the limitations of number of observations, etc. as previously described. Later for all measurements, observation stations for corresponding new normal measurements were selected generally as the next adjacent stations on the right of those selected for the original normal measurement. A third normal measurement was derived in a similar manner. This method perhaps gave a set of points in some cases that would not be taken in the field, but it gave an idea of the variation which might occur with different selections of observation stations.

In addition, from each type of measurement one normal measurement that compared favorably with the special measurement for accuracy was selected for a similar study of the result of varying the combinations of observation stations. This was done to see if the same range in errors could be produced in those which appeared to be nearly correct in the original selection, as existed in those which were over 4 percent. The same procedure of progressive selection of observation stations was followed.

ANALYSIS OF RELATIVE ACCURACY

Average Percent Differences

The two essential elements to be compared in this study are the relative accuracy of results obtained by the two methods of computation and the time saved in using one method instead of the other. The question of accuracy will be taken up first in this analysis.

The simplest and easiest picture for comparing the accuracy element is the average of the percent differences. The data for percent differences for all measurements shown in Table 1 have been summarized in Table 2. The first half of the table shows the average percent difference without regard

Table 2.--Comparison of percent differences from true discharge for types of measurement

Type	No. of Meas. in Group	Average Percent Diff. Without Regard to Sign		Average Percent Diff. With Regard to Sign	
		Mean-Sec.	Mid-Sec.	Mean-Sec.	Mid-Sec.
Bridge	63	1.46	1.22	-0.97	-0.37
Wading	80	1.38	1.24	-0.66	-0.04
Cable	70	0.98	0.82	-0.54	-0.03
Ave.	213	1.27	1.09	-0.72	-0.15

to algebraic sign, and is the sum of the percent difference figures divided by the number of measurements. Those figures show the average of deviations from the true discharge for types of measurements regardless of direction. The second half of the table shows the average percent difference taking into account the sign. These figures were obtained from the algebraic total of the percent differences divided by the number of measurements, and are more important in what they show than those in the previous half of the table. Although it is necessary to have both averages to get a true comparison, the latter are more important because in the actual use of discharge measurements for rating curves, the direction of the deviation is considered. The rating curve essentially is an average of the measurements taking into account the algebraic sign. The average percent difference without regard to sign for the measurements used in this study is smaller by about 0.2 percent for the mid-section method. Likewise, the average percent difference with regard to sign for the mid-section method is about 0.6 percent smaller. It is interesting to note that the results of the cable measurements seem to be the most accurate for the three groups, with wading second, and bridge third. This may be explained in part by the fact that cableways are usually located at better cross-sections for discharge measurements.

The maximum plus percent differences and maximum negative percent differences for a pair of computations in each group are shown in Table 3. Except for measurement 56C "mean-section", these figures are also the highest individual percent differences in the groups. Measurement 64C had a percent difference of 2.7 for the "mean-section". It is apparent from a study of this table that there is not much difference in the two methods of computation when for some reason a measurement is off a large amount. Again the cable group shows the smallest range in percent difference.

Table 3.--Comparison of extremes in percent differences from true discharges for types of measurements

Type	Maximum Plus Percent Difference			Maximum Negative Percent Difference			Range	
	Meas. No.	Mean-Sec.	Mid-Sec.	Meas. No.	Mean-Sec.	Mid-Sec.	Mean-Sec.	Mid-Sec.
Bridge	31B	3.1	3.5	38B	7.4	5.7	10.5	9.2
Wading	53W	3.4	4.3	77W	9.0	9.6	12.4	13.9
Cable	56C	2.6	3.1	34C	3.8	3.7	6.4	6.8

Graphical Comparison of Percent Differences

In order to show these data graphically, the percent difference of the mid-section was plotted against the percent difference of the mean-section method for each group (see Figs. 2, 3, and 4). A line was drawn through the plotted points in such a way as to delineate the average of the group. For comparative purposes a dashed line was drawn through the origin and at a slope of unity to indicate a line of equal percent difference. It can be seen from this line that if a relationship existed between the plotted points such that a line through them had a slope less than one the mean-section method would have the higher degree of accuracy. Also, if the slope of the line was greater than one, the mid-section method would have the higher accuracy. The slope of these relationship lines as drawn through the plotted points does not differ greatly from unity, but if anything, it is in the direction indicating a slightly greater accuracy for the mid-section method as far as a general relationship is concerned. The important thing to note here is the fact that the average error of these group samples is not zero, as also shown in the comparison of error

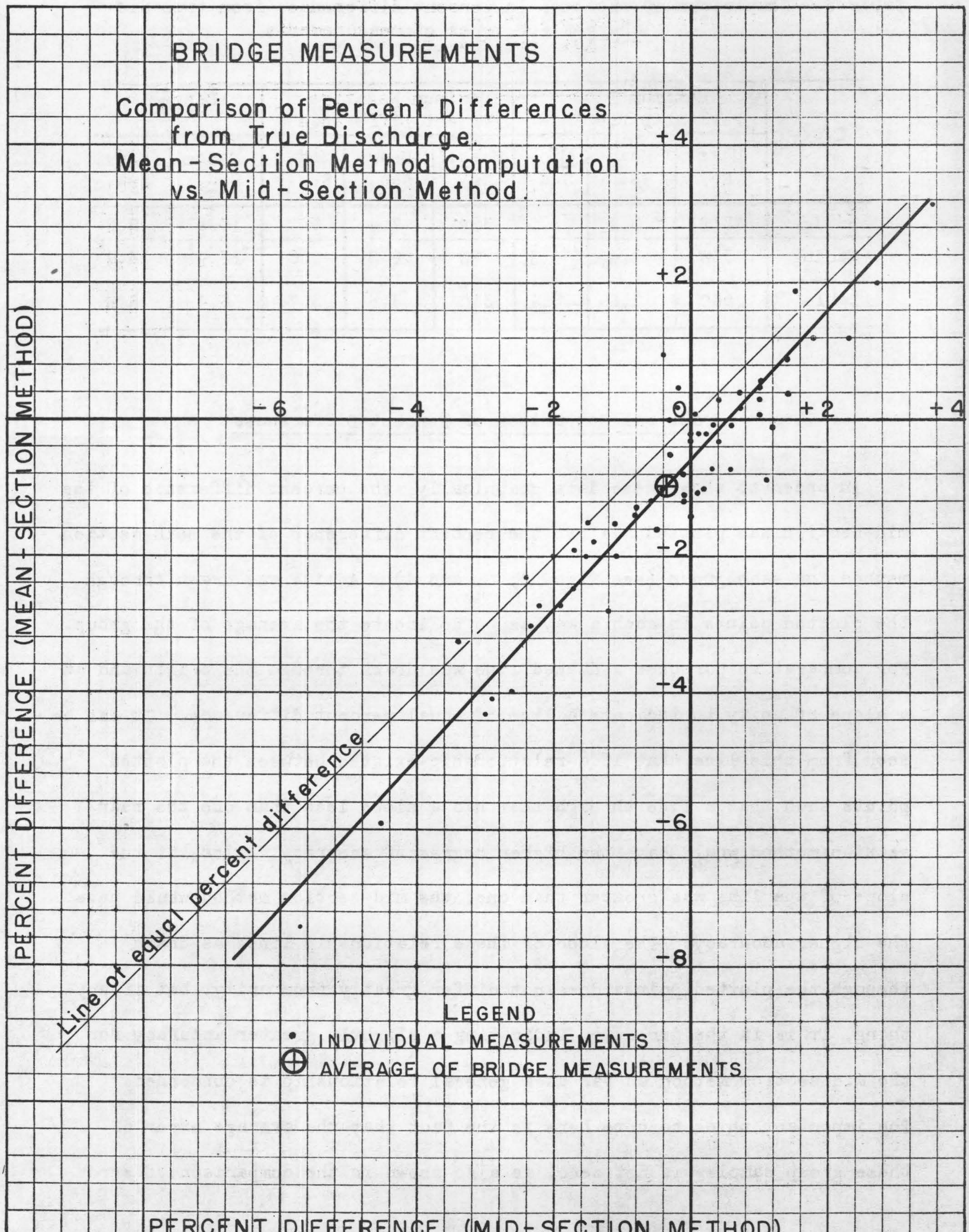

FIGURE 2.—Comparison of percent differences for bridge measurements.

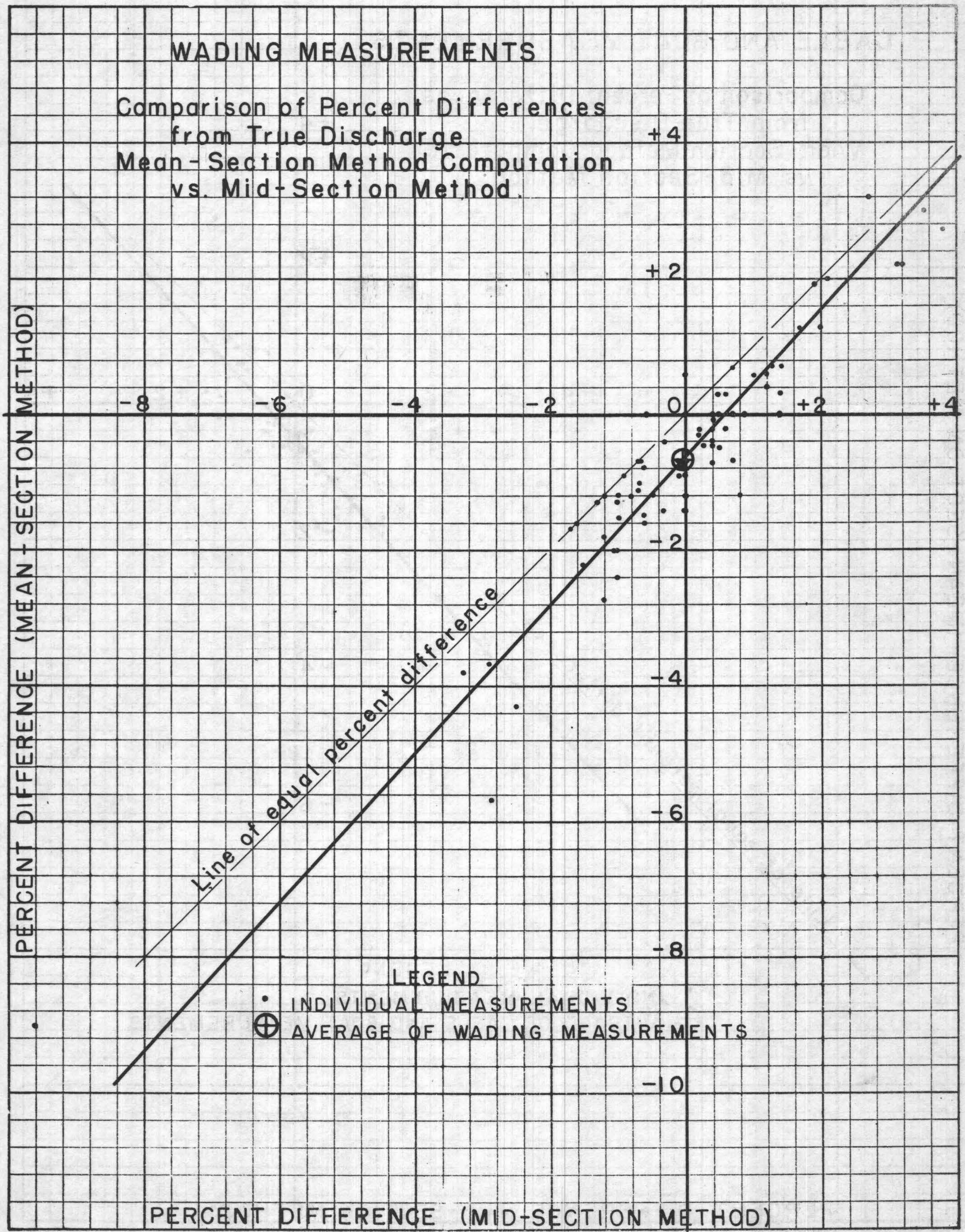

FIGURE 3. — Comparison of percent differences for wading measurements.

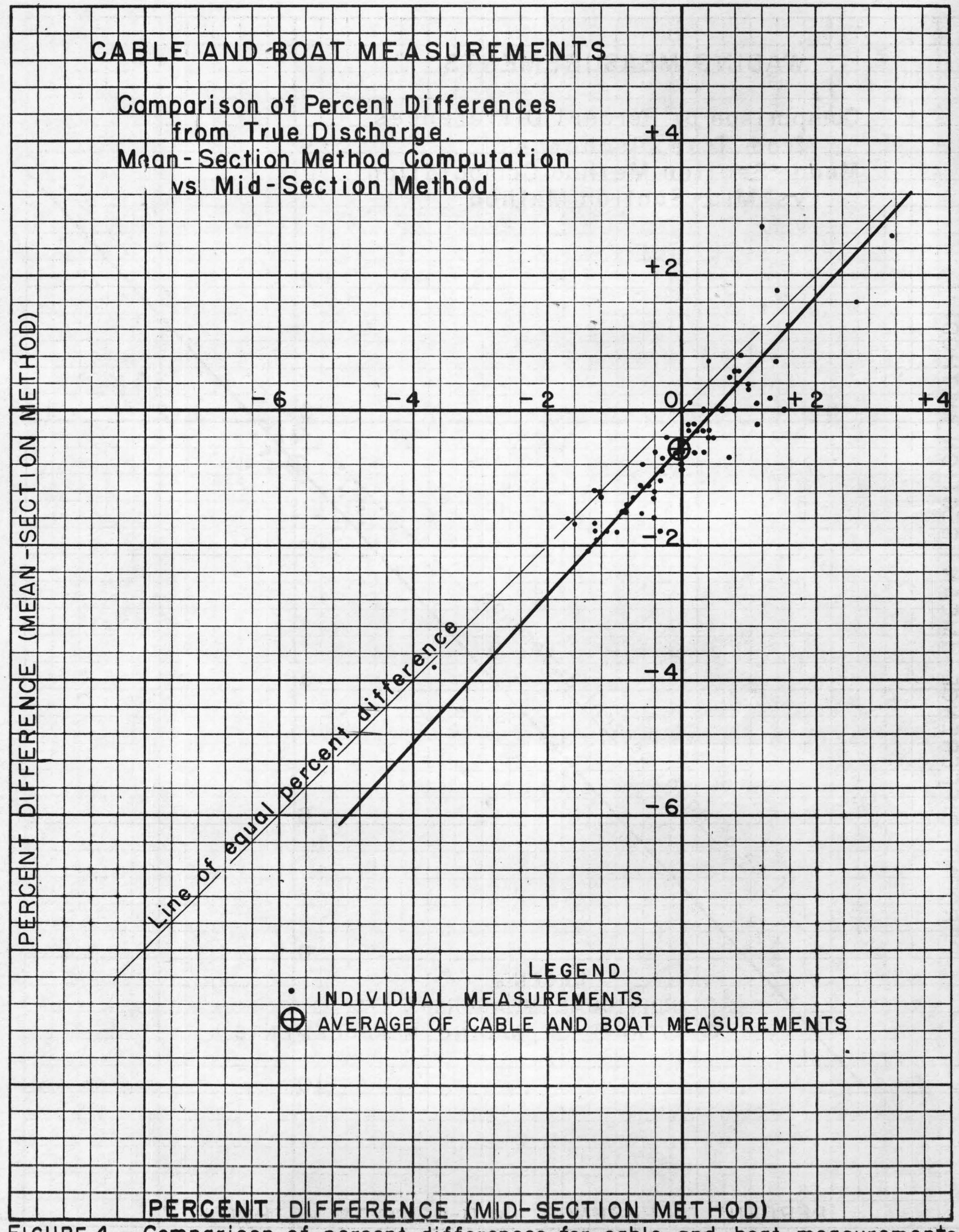

FIGURE 4.— Comparison of percent differences for cable and boat measurements.

table, but in the negative quadrant and closer to zero for the mid-section method in all cases. From the distribution of the points on these graphs it is apparent that the results in the majority of the normal measurements used in this sampling are smaller than the assumed true discharge of the special measurements. Because of this the average error for the mid-section method is smaller and nearer zero than that for the mean-section method.

Statistical Analysis of Data

In all comparative studies which have to do with intrepreting of experimental data as based on a sample, there are always so-called experimental errors involved. To judge the soundness and value of the results from any such work, these results should be compared with an estimate of its error. A statistician calls this process a "test of significance". This test enables one to decide whether the results are based on adequate evidence and whether the effects are real and not due to accidental or chance sampling.

Without going too far into the science of statistics, the first test of significance made with the accuracy element of this study was to determine whether or not the difference in the percent error of the mid-section and mean-section methods is significantly different from zero. We might expect that if there is no inherent difference between these methods of computation, the difference in error would average zero. Arithmetically, this average of the percent differences is about minus 0.6 percent. To test whether this difference is significantly real and not a result of poor or inadequate sampling, a test known as "student's t" was applied.

This test showed that the difference in percent error between the two methods was significantly different from zero and that the chances are less than one in one hundred that the apparent difference in results is due to chance. Considering Figs. 2, 3, and 4, we have shown that a line having an average intercept on the Y-axis of minus 0.6 percent agrees with the data significantly better than would a line through the origin.

The second test conducted was to compare the spreads or variabilities of the mean-section percent differences and the mid-section percent differences. This test shows that there is no significant difference in the variabilities of the two methods, that is, when a measurement is "off" by one method of computation it is also "off" by the other method. In other words, for all practical purposes the slope of the relationship lines in Figs. 2, 3, and 4 is not significantly different from unity.

Comparison of Area Variation

As far as area is concerned there was not as wide a variation in percent difference as there is in discharge when the number of observations is reduced to a normal measurement. The average percent difference amounted to only about 0.3 percent with the smallest figure being for the cable group (see Table 4). The range in difference for area was considerably less than that for discharge, being about one-half the range which occurred in the discharge errors. The percent difference for area is the same for both the mean-section and mid-section methods of computation because both methods result in identical figures for area using the same data.

Table 4.--Comparison of percent differences in area owing to reduced number of observations

Type of Meas.	No. of Meas. in Group	Ave. Per. Diff.	Max. Plus Percent Diff.	Max. Neg. Percent Diff.	Range
Bridge	63	-.42	+2.3	-3.4	5.7
Wading	80	-.32	+2.9	-4.0	6.9
Cable	70	-.29	+1.6	-2.4	4.0
Ave.	213	-.34			5.5

Effect of Velocity Component in Measurement

Having the percent difference for area computed for all measurements, it is possible to derive a comparable figure for velocity by using this average percent difference for area (Table 4) and the average percent difference with regard to sign for discharge (Table 2). Using the average for all types of measurements, the velocity component of the mean-section method of computation has an indicated percent difference of -.38 percent, and the mid-section, +.19 percent. These figures give an indication of the effect of the velocity component of a measurement, particularly as to the weighting of velocity values with corresponding sub-area values in the two methods. It would appear that for the mean-section method, on the average, the velocity is under-weighted and for the mid-section method, over-weighted. The mid-section method has a positive indicated percent difference for the velocity component and a negative percent difference for area, while the mean-section has negative percent differences for both velocity and area. Consequently, when combined, the components tend to compensate in the mid-section method, but increase negatively in the mean-section. This brief analysis deals with an indefinite part of a discharge computation and one whose magnitude has been derived indirectly. The net result which shows the overall comparison of these two methods of computation is shown in Table 2.

Study of Measurements With Over Four Percent Difference

There were 10 normal measurements out of a total of 213 in which discharge varied 4 percent or more from the special measurement. As stated previously, these measurements were picked out for further analysis by comparing discharges obtained in using other combinations of observation stations. They are listed in Table 5, showing the special measurement data, results from the original selection for a normal measurement, and subsequent selections. The original selection of observation stations for measurement 27W was different for the mean-section than for the mid-section method as previously described, the only measurement out of the group of 213 that was treated in this way. As can be seen, the mid-section selection gave much better results. For this analysis, a mean-section method computation was made using data for the original mid-section selections, and a mid-section method computation made using data for the original mean-section selection. Comparing the methods for the same station selections, the mid-section gave more accurate results. Then a more or less random selection of observation stations was made by picking out those between the stations already used in the two previous attempts. This choice gave the best results for measurement 27W both as to discharge and area, with the mid-section method comparing more favorably with the special measurement.

Measurement 38W gave poor results for discharge in the original

Table 5.--Analysis of normal measurements off over 4% in original selection

Meas. (File No.)	Disch.	Per. Diff.	Area	Per. Diff.	No. Obs.	Remarks
27W	281	--	130	--	100	Special Measurement
27W Mean	265	-5.7	127	-2.3	29	Orig. selec. for mean.
27W 2 Mid	272	-2.9	127	-2.3	30	Compt. using stations of 27W mean
27W 2 Mean	275	-2.1	128	-1.5	31	Compt, using stations of 27W mid
27W Mid	276	-1.8	128	-1.5	32	Original selection for mid
27W 3 Mean	283	+0.7	131	+0.7	30	Selected stations between those used above
27W 3 Mid	282	+0.3	131	+0.7	30	
38W	201.5	--	201	--	134	Special Measurement
38W Mean	188	-6.9	197	-2.0	28	Original selection
38W Mid	190	-6.0	197	-2.0	28	
38W 2 Mean	220	+9.2	203	+1.0	31	Changed stations to try to get more accurate disch.
38W 2 Mid	217	+7.7	203	+1.0	31	
38W 3 Mean	217	+7.7	211	+5.0	29	In most cases stations are 1 ft. or 1 sta. beyond original.
38W 3 Mid	215	+6.7	211	+5.0	29	
38W 4 Mean	197	-2.2	198	-1.5	29	In general, stations are 1 or 2 stations behind original
38W 4 Mid	199	-1 2	198	-1.5	29	
42W	162	--	112	--	92	Special Measurement
42W Mean	155	-4.3	110	-2.0	26	Original Selection
42W Mid	158	-2.5	110	-2.0	26	
42W 2 Mean	155	-4.3	110	-2.0	26	Changed only a few stations
42W 2 Mid	157	-3.1	110	-2.0	26	

Table 5.--Analysis of normal measurements off over 4% in original selection--Con.

Meas. (File No.)	Disch.	Per. Diff.	Area	Per. Diff.	No. Obs.	Remarks
42W 3 Mean 42W 3 Mid	162 163	0 +0.6	110 110	-2.0 -2.0	25 25	In general, stations are one station beyond original
42W 4 Mean 42W 4 Mid	162 164	0 +1.2	111 111	-0.9 -0.9	26 26	In general, stations are one station behind original
53W	115	--	49.7	--	101	Special measurement
53W Mean 53W Mid	119 120	+3.4 +4.3	49.7 49.7	0 0	28 28	Original selection
53W 2 Mean 53W 2 Mid	113 114	-1.7 -0.9	49.6 49.6	-0.2 -0.2	27 27	In general, stations are one foot behind original
53W 3 Mean 53W 3 Mid	116 117	+0.9 +1.7	48.4 48.4	-2.6 -2.6	28 28	In general stations are one foot beyond original
77W	177	--	93.4	--	126	Special measurement
77W Mean 77W Mid	161 160	-9.0 -9.6	91.2 91.2	-2.4 -2.4	31 31	Original selection
77W 2 Mean 77W 2 Mid	194 195	+9.6 +10.2	93.6 93.6	+0.2 +0.2	32 32	In general stations are one or two beyond original
77W 3 Mean 77W 3 Mid	167 174	-5.6 -1.7	88.6 88.6	-5.1 -5.1	31 31	In general stations are one station behind original
3B	72,590	--	22,146	--	168	Special measurement
3B Mean 3B Mid	69,650 70,680	-4.0 -2.6	21,864 21,864	-1.3 -1.3	54 54	Original selection
3B 2 Mean 3B 2 Mid	67,830 68,250	-6.6 -6.0	21,598 21,598	-2.5 -2.5	60 60	In general stations are one station beyond original

Table 5.-- Analysis of normal measurements off over 4% in original selection--Con.

Meas. (File No.)	Disch.	Per. Diff.	Area	Per. Diff.	No. Obs.	Remarks
3B 3 Mean 3B 3 Mid	70,418 71,668	-3.0 -1.3	21,750 21,750	-1.8 -1.8	57 57	In general stations are one station behind original
15B	15,483	--	4,972	--	120	Special measurement
15B Mean 15B Mid	14,848 15,031	-4.1 -2.9	4,894 4,894	-1.6 -1.6	46 46	Original selection
15B 2 Mean 15B 2 Mid	14,936 15,131	-3.5 -2.3	4,896 4,896	-1.5 -1.5	39 39	In general stations are one station beyond original
15B 3 Mean 15B 3 Mid	15,320 15,460	-1.1 -0.1	4,990 4,990	+0.4 +0.4	46 46	In general stations are one station behind original
17B	14,982	--	4,135	--	65	Special measurement
17B Mean 17B Mid	14,103 14,313	-5.9 -4.5	4,032 4,032	-2.5 -2.5	33 33	Original selection
17B 2 Mean 17B 2 Mid	14,630 14,853	-2.3 -0.9	4,034 4,034	-2.4 -2.4	34 34	In general stations are one sta. beyond original
17B 3 Mean 17B 3 Mid	14,325 14,369	-4.4 -4.1	4,017 4,017	-2.8 -2.8	33 33	In general stations are one station behind original
38B	2,750	--	1,115	--	126	Special measurement
38B Mean 38B Mid	2,546 2,594	-7.4 -5.7	1,100 1,100	-1.4 -1.4	44 44	Original selection
38B 2 Mean 38B 2 Mid	2,735 2,838	-0.5 +3.2	1,136 1,136	+1.9 +1.9	43 43	In general stations are one station behind original
38B 3 Mean 38B 3 Mid	2,671 2,727	-2.9 -0.8	1,084 1,084	-2.8 -2.8	46 46	In general stations are one station beyond original

Table 5.--Analysis of normal measurements off over 4% in original selection--Con.

Meas. (File No.)	Disch.	Per. Diff.	Area	Per. Diff.	No. Obs.	Remarks
54B	912	--	732	--	77	Special measurement
54B Mean	873	-4.3	717	-2.0	28	Original selection
54B Mid	885	-3.0	717	-2.0	28	
54B 2 Mean	931	+2.1	726	-0.8	29	Selected new stations trying to get in between original ones
54B 2 Mid	940	+3.1	726	-0.8	29	
54B 3 Mean	898	-1.5	723	-1.2	29	In general stations are one station beyond original
54B 3 Mid	909	-0.8	723	-1.2	29	
54B 4 Mean	905	-0.3	732	0	28	In general stations are one station behind orig.
54B 4 Mid	901	-1.2	732	0	28	

selection, but the area was satisfactory. An attempt was made to change the station selection to get a better discharge result. This resulted in even a worse figure, going from about -6.5 percent in the original selection to +8.5 percent in the second selection. The area, however, was more accurate in the second selections. Following this, two other computations were made using observation stations at other points. It was the latter of these two which produced the most satisfactory result for discharge. In all four combinations of stations, the mid-section method gave better results by an average of about one percent.

Only a few of the observation stations in measurement 42W were changed on the second trial. This second selection gave no appreciable difference in either discharge or area. However, two other combinations of observation stations, selected systematically as previously described, gave

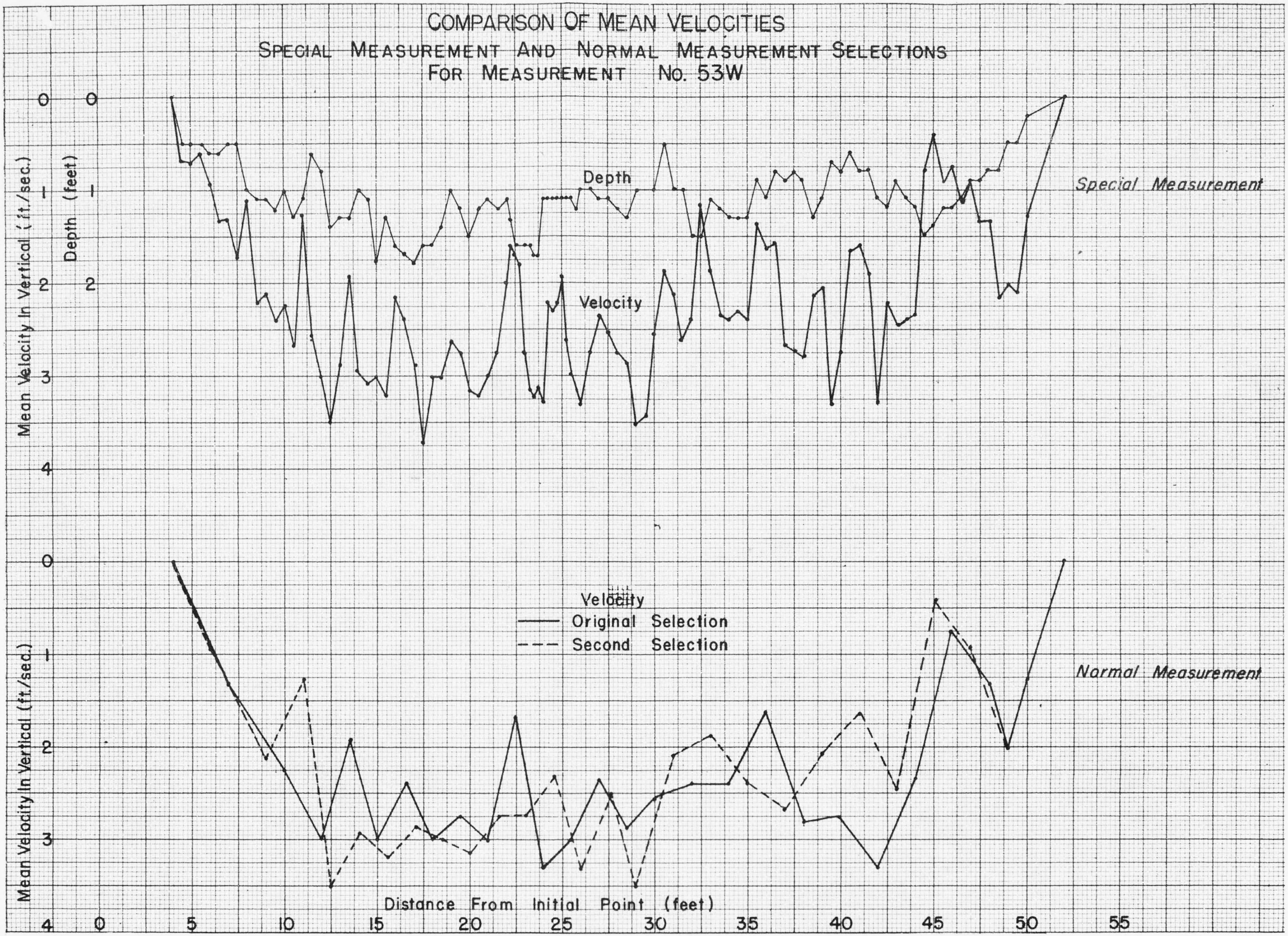

FIGURE 4a. - Comparison of velocities used in selections for normal measurements.

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much better discharge agreement without significant change in area, and with the mean-section computation giving more accurate results.

The remaining seven measurements were treated in a similar manner without any special attempt to improve the results. Observation stations were selected at more or less regular intervals behind and ahead of the original selected observation stations. It is noticeable here that the mid-section method gives better results for measurements with computed discharge smaller than the special measurement, and the mean-section method, better for those with computed discharge larger than the special measurement. Since the computed discharges of a majority of the normal measurements are smaller than the special one, the general picture favors the mid-section method. The variation in velocities which might be used, depending upon the selection of observation stations, is shown in Fig. 4a for a discharge measurement with irregular velocity distribution.

Study of Three Measurements Satisfactory in Original Selections

Measurements 35W, 33C, and 36B are normal measurements for which discharge results were very close to those of the special measurements, but were also studied by varying the selection of stations to see if similar results would be obtained as to variations in discharge and area (see Table 5A). There were not as many measurements in this group as in the group with over 4 percent difference due to the lack of personnel and time for computing and checking measurements. As far as these three measurements are concerned there does not seem to be as wide a range in percent difference as appeared in the previous group. The variations and range of percent differences for both groups analyzed are shown in Table 6.

Table 5A.--Analysis of Normal Measurements Satisfactory in Original Selections

Meas. (File No.)	Disch.	Per. Diff.	Area	Per. Diff.	No. Obs.	Remarks
35W	224	--	105	--	75	Special measurement
35W Mean	224	0	105	0	27	Original selection
35W Mid	224	0	105	0	27	
35W 2 Mean	216	-3.7	102	-2.9	27	In general stations are
35W 2 Mid	216	-3.7	102	-2.9	27	one foot beyond orig.
35W 3 Mean	231	+3.1	107	+1.9	27	In general stations are
35W 3 Mid	231	+3.1	107	+1.9	27	one foot behind orig.
33C	2,928	--	1,473	--	117	Special measurement
33C Mean	2,948	+0.7	1,484	+0.7	34	Original selection
33C Mid	2,940	+0.4	1,484	+0.7	34	
33C 2 Mean	2,880	-1.6	1,440	-2.2	32	In general stations are
33C 2 Mid	2,886	-1.4	1,440	-2.2	32	one station beyond orig.
33C 3 Mean	2,947	+0.6	1,474	+0.1	34	In general stations are
33C 3 Mid	2,941	+0.4	1,474	+0.1	34	one station behind orig.
36B	2,889	--	1,553	--	131	Special measurement
36B Mean	2,896	+0.2	1,559	+0.4	42	Original selection
36B Mid	2,883	-0.2	1,559	+0.4	42	
36B 2 Mean	2,797	-3.2	1,504	-3.1	40	In general stations are
36B 2 Mid	2,841	-1.7	1,504	-3.1	40	one station beyond orig.
36B 3 Mean	2,733	-5.4	1,478	-4.8	41	In general stations are
36B 3 Mid	2,781	-3.7	1,478	-4.8	41	one station behind orig.

Table 6.--Variation in Percent Differences from True Discharge (Due to various combinations of observation stations).

Meas. No.	Discharge Mean-Section			Discharge Mid-Section			Area		
	Max. Disch. % Diff.	Min. Disch. % Diff.	Range In %	Max. Disch. % Diff.	Min. Disch. % Diff.	Range In %	Max. Area %Diff.	Min. Area %Diff.	Range In %
Measurements off 4% and over in original selection									
27W	+0.7	-5.7	6.4	+0.3	-2.9	3.2	+0.7	-2.3	3.0
38W	+9.2	-6.9	16.1	+7.7	-6.9	14.6	+5.0	-2.0	7.0
42W	0	-4.3	4.3	+1.2	-3.1	4.3	-0.9	-2.0	1.1
53W	+3.4	-1.7	5.1	+4.3	-0.9	5.2	0	-2.6	2.6
77W	+9.6	-9.0	18.6	+10.2	-9.6	19.8	+0.2	-5.1	5.3
3B	-1.6	-6.6	5.0	-1.3	-6.0	4.7	-1.3	-2.5	1.2
15B	-1.1	-4.1	3.0	-0.1	-2.9	2.8	+0.4	-1.6	2.0
17B	-2.3	-5.9	3.6	-0.9	-4.5	3.6	-2.4	-2.8	0.4
38B	+3.2	-7.4	10.6	-0.5	-5.7	5.2	+1.9	-2.8	4.7
54B	+2.1	-4.3	6.4	+3.1	-3.0	6.1	0	-2.0	2.0
Ave.			11.3			9.9			4.2
Measurements satisfactory in original selection									
35W	+3.1	-3.7	6.8	+3.1	-3.7	6.8	+1.9	-2.9	4.8
33C	+0.7	-1.6	2.3	+0.4	-1.4	1.8	+0.7	-2.2	2.9
36B	+0.2	-5.4	5.6	-0.2	-3.7	3.5	+0.4	-4.8	5.2
Ave.			4.9			4.0			4.3

ANALYSIS OF TIME SAVINGS

Average Time Savings

The second element to be considered in this comparative study is the matter of time savings. Because the mid-section method of computation has two less arithmetical processes, averaging of velocities and depths, it is evident that ordinarily this method will consume less time. The extent of this time saving is shown in Table 7 for each group of computers and checkers; that is, those experienced in the mean-section only, those experienced in mid-section only, and those experienced in both methods. The average saving in minutes for each group and for the total has been computed. This study shows that about five minutes would be saved in computing each measurement on the average by using the mid-section method, and about three minutes in checking each measurement.

Table 7.--Time Savings in Minutes, Mid-Section Over Mean-Section For Same Measurement

	Personnel Experienced in Mean-Section only		Personnel Experienced in Mid-Section only		Personnel Experienced in Both Methods		All Personnel	
	Comp.	Ch'k.	Comp.	Ch'k.	Comp.	Ch'k.	Comp.	Ch'k.
Total saving in Minutes	587.4	315.8	332.6	207.5	172.9	109.7	1092.9	633.0
No. of Measurements	126	140	45	37	42	36	213	213
Ave. saving per measurement (min.)	4.7	2.3	7.4	5.6	4.1	3.0	5.1	3.0

Graphical Comparison of Time Consumption

In order to show the comparison of time consumed in the computation and checking operations performed in these 213 normal measurements, the time for the mid-section method was plotted against the time for the mean-section method for each experience group (Figs. 5, 6, 7, 8, 9, 10). The slope of the line drawn from the origin through the average of those points is an indication of the relative time consumption as far as the specific operations included in the tests are concerned. It does not show the relation for the computation of a complete measurement as a constant time for the remaining operations common to both methods added to each side will reduce this ratio somewhat. A dashed line at a slope of unity shows equal time for each method. It would be expected that all the points would fall to the left of the line of equal time consumption but due to some particular circumstance the mid-section method took longer to compute in a few cases and the points fall to the right of this line. This is more noticeable in the experienced-in-mean group, where apparently the lack of experience in the mid-section method caused more time consumption in that method in a few cases.

The slopes of these lines varied between groups, as might be expected. That for the experienced-in-mid group was the highest since inexperience in the mean-section method would raise the time for that method and increase the difference between the two methods. The slope for experienced-in-mean group was the lowest due to inexperience in the mid-section method increasing the time consumption for that method and decreasing the difference between the two methods. The slope for experienced-in-both groups was between the previous two as would be expected.

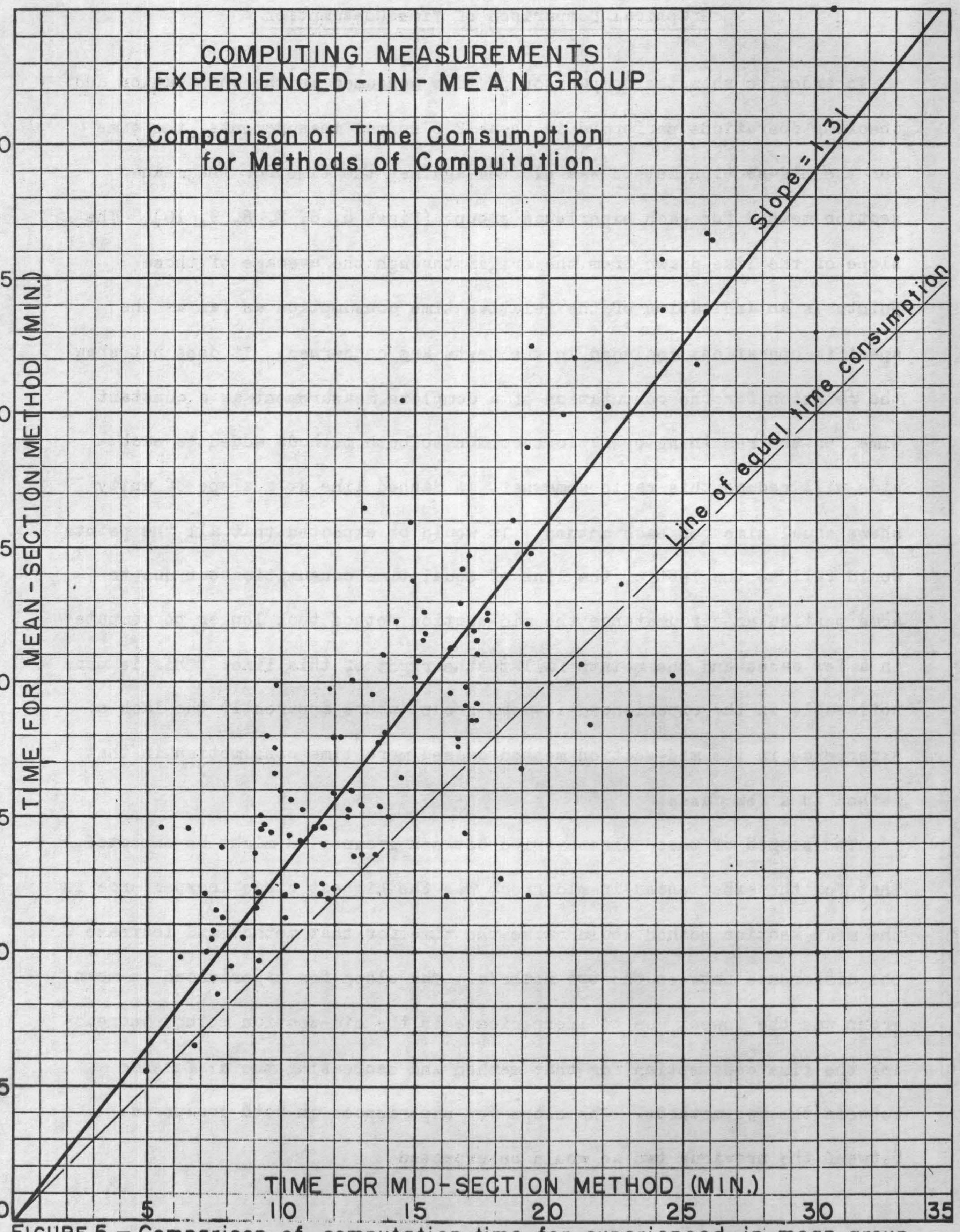

FIGURE 5.— Comparison of computation time for experienced-in-mean group.

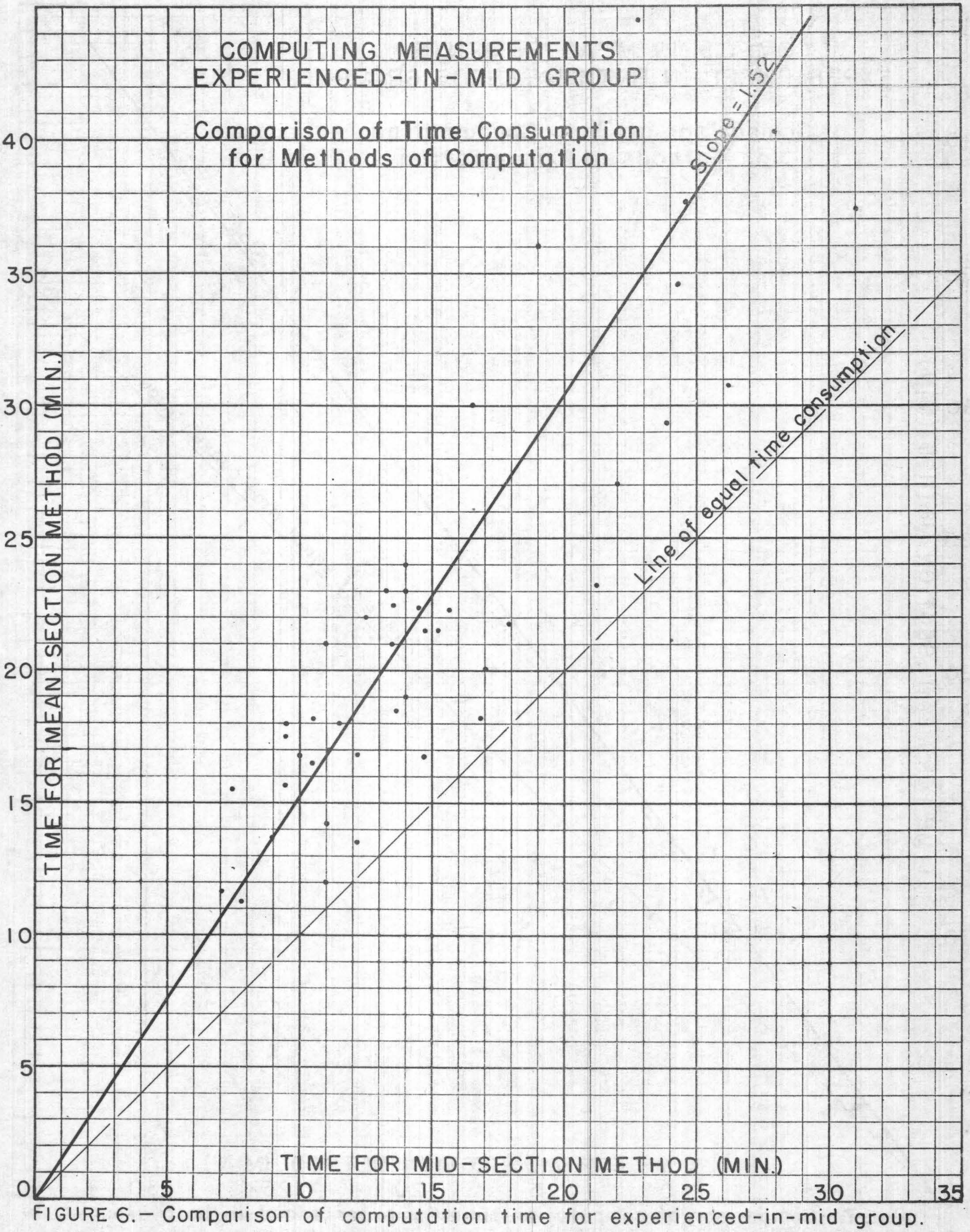

FIGURE 6.— Comparison of computation time for experienced-in-mid group.

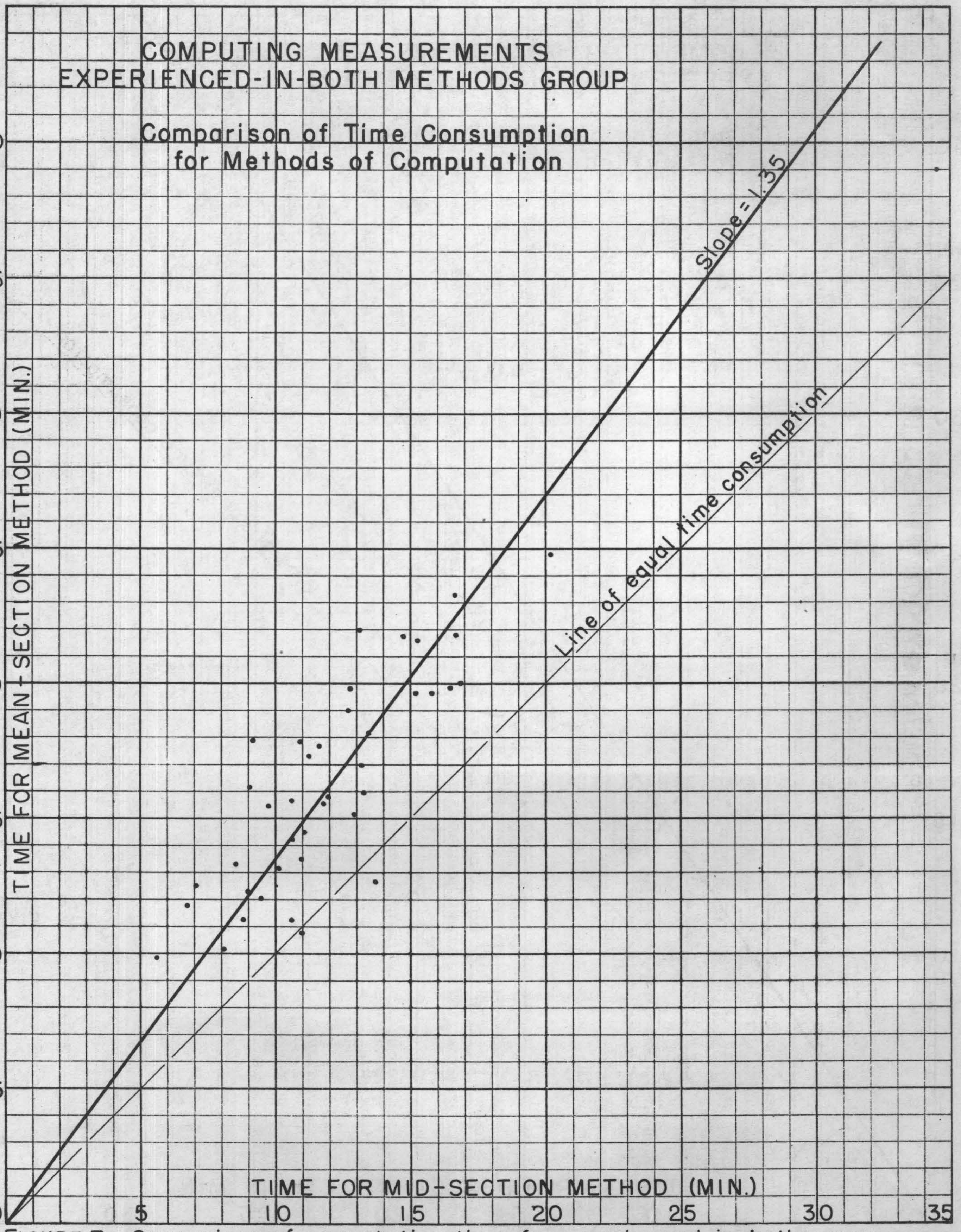

FIGURE 7.- Comparison of computation time for experienced-in-both group.

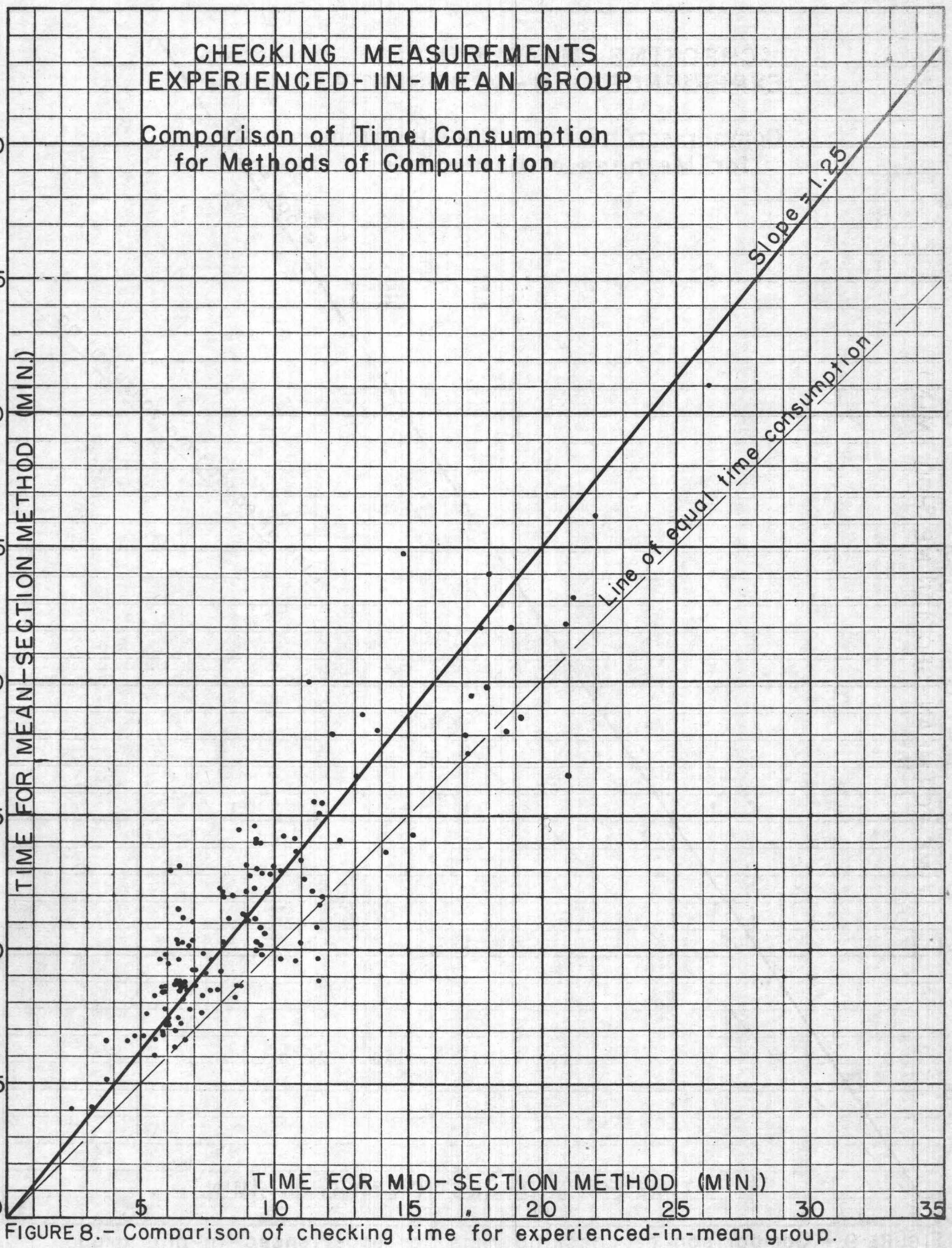

FIGURE 8.- Comparison of checking time for experienced-in-mean group.

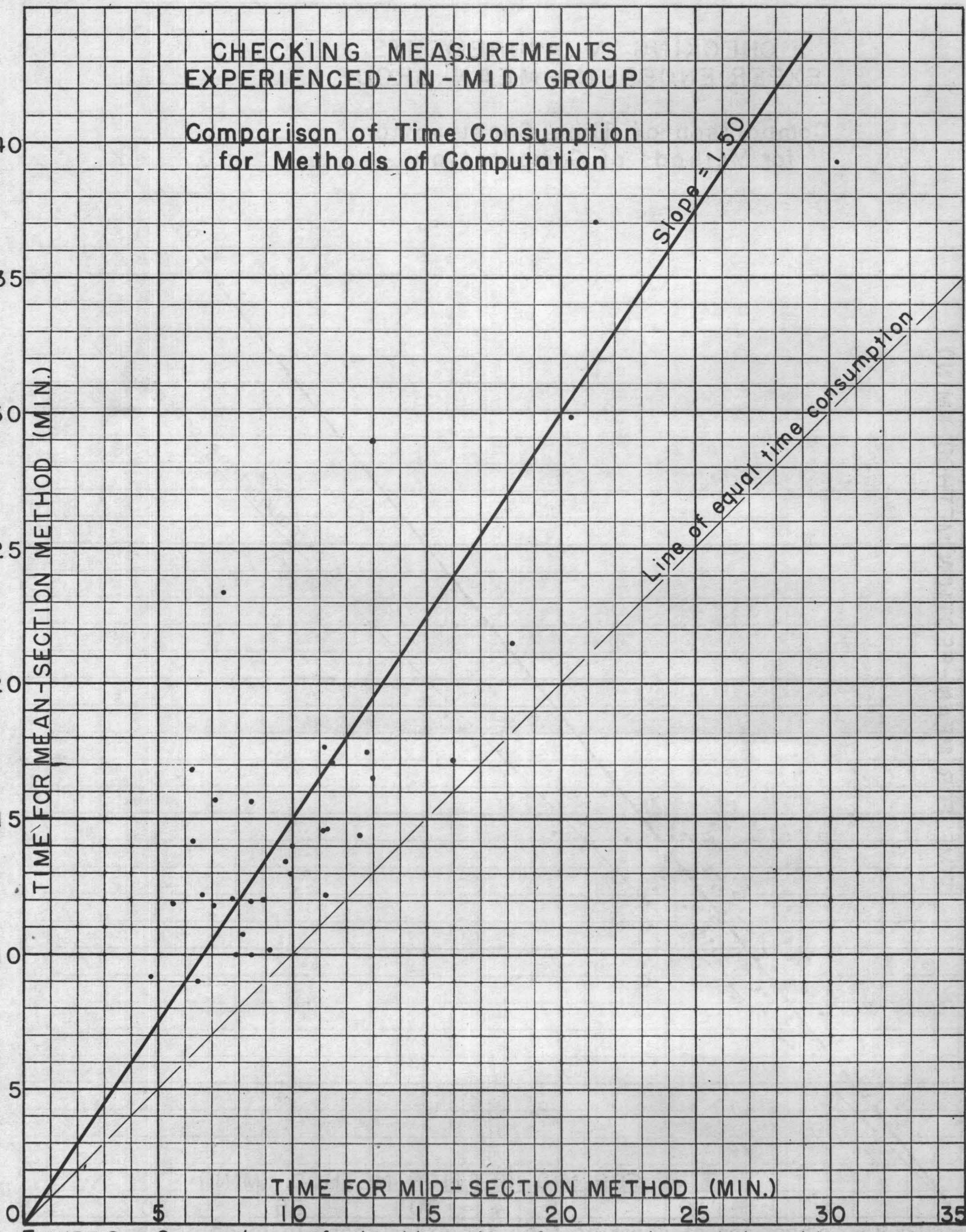

FIGURE 9.— Comparison of checking time for experienced-in-mid group.

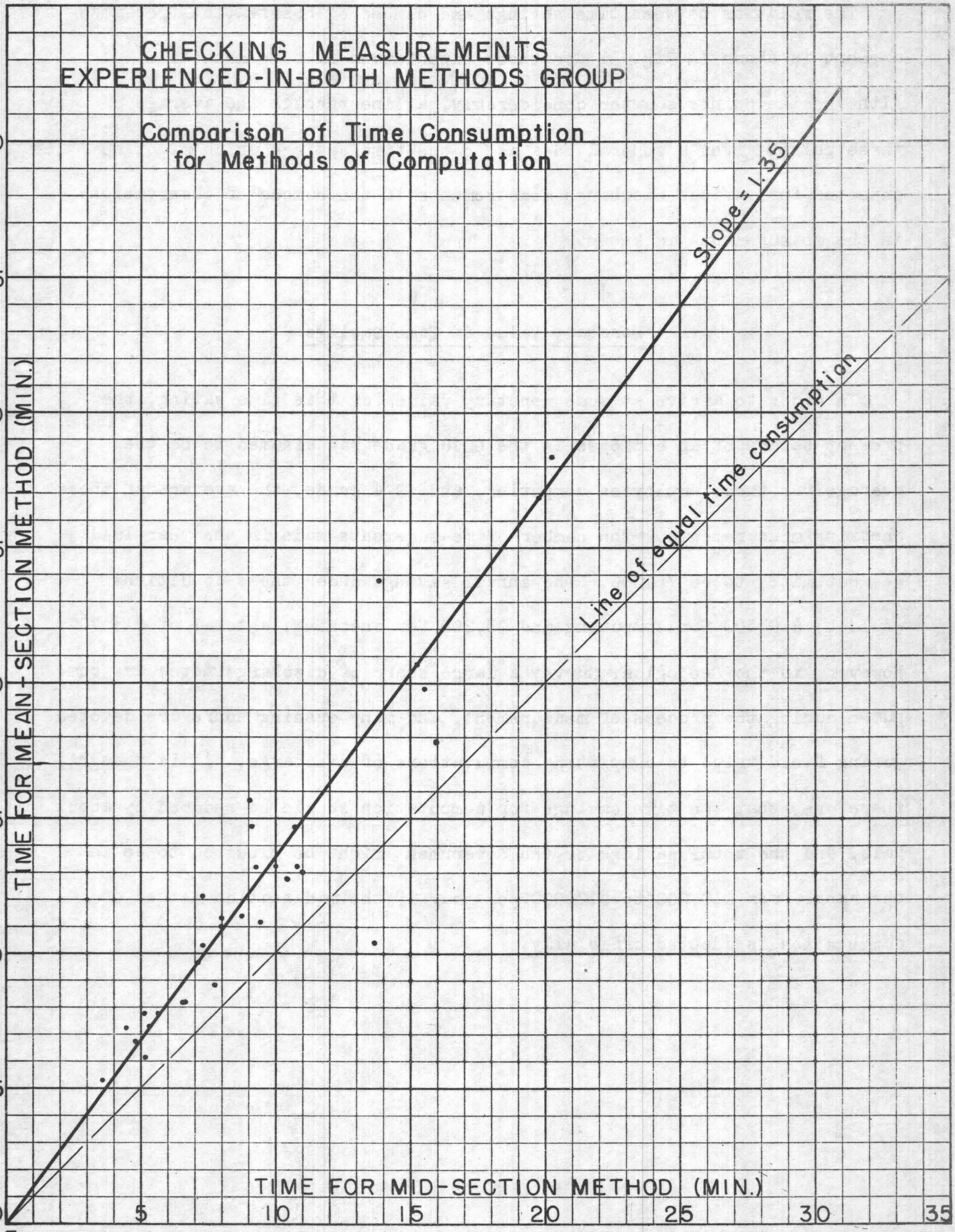

FIGURE 10.– Comparison of checking time for experienced-in-both group.

The relation between time savings and number of observations per measurement is shown in Fig. 11 for those experienced in both methods. Although the points scatter considerably, a line through the average of these points gives a general idea as to the time savings which might be expected for various discharge measurements if the number of observations in the measurements is known.

Monetary Value of Time Savings

In order to arrive at some monetary value for this time saving, the present salary of an employee in the GS 6 grade was assumed to be the average for those employees computing, and GS 4 grade, the average of those checking measurements. The number of measurements made in the year 1949 was estimated to be 75,000. The annual savings under these conditions would be $10,500 for computing and $5,200 for checking, a total of $15,700. However, in the Geological Survey a large share of discharge notes are computed during the process of measurement, and many evening hours are devoted during field trips to completing computations of discharge. It is thought, therefore, that the time savings for computation should be reduced by about half, and the total savings to the Government might be expected to be in the range from $10,000 to $12,000 per year if the mid-section method of computation is adopted officially.

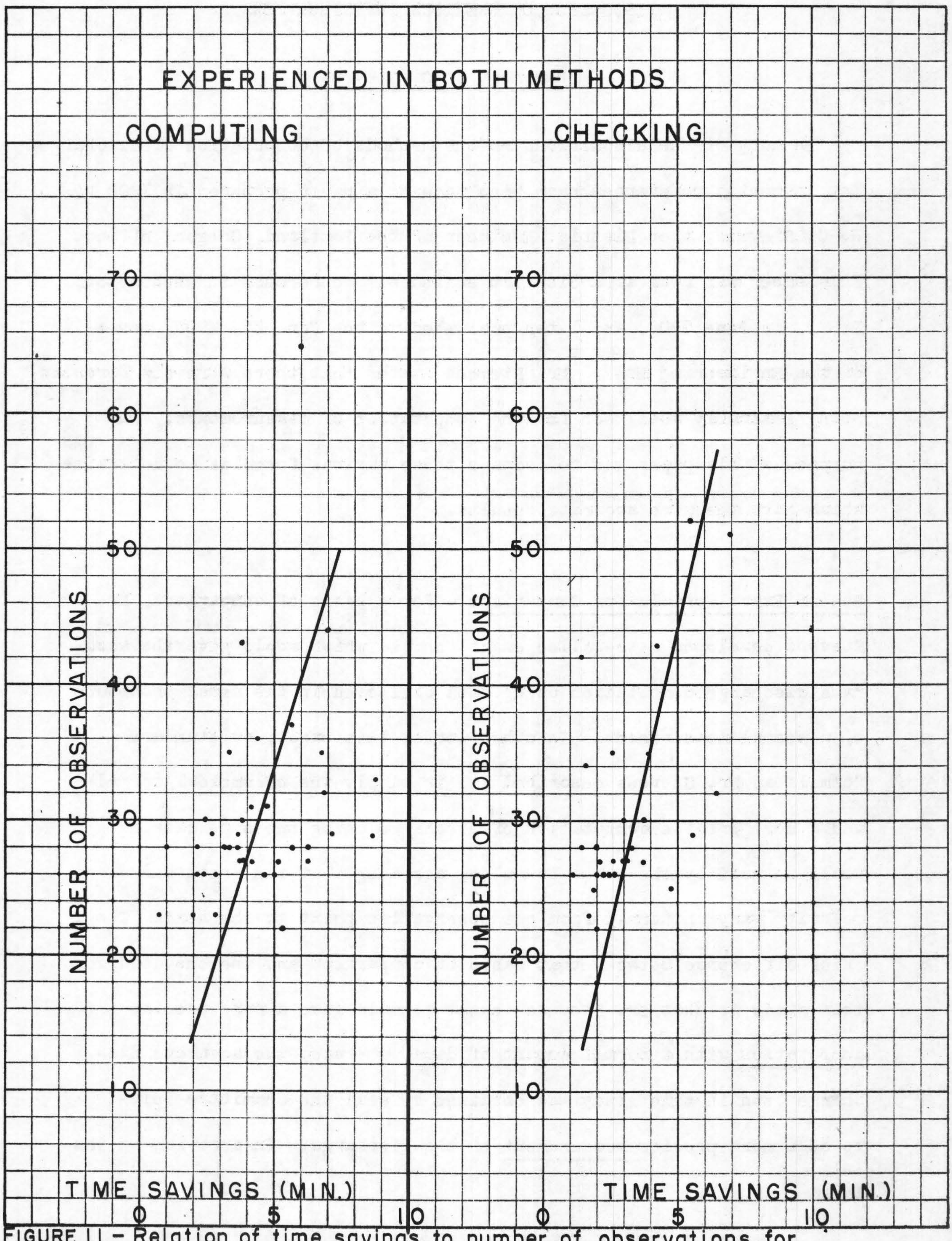

FIGURE 11.- Relation of time savings to number of observations for computation by mid-section method vs. mean-section method.

DISCUSSION OF PREVIOUS INVESTIGATIONS

Paper by J. C. Stevens

In many of the discussions on the methods of computation of discharge measurements, references have been made to a paper prepared in 1908 by J. C. Stevens, then District Engineer of the Portland, Oregon, office. This paper was read at a district engineers' conference in Washington, D. C., in June 1908, and later published in the June 25, 1908, issue of the Engineering News. Mr. Stevens stated that there were six formulas being generally used then for the computation of measurements. The purpose of his paper was to compare those various formulas to determine which gave the more accurate results.

Use of Exact Formula for Comparison.--For a basis of comparison, Mr. Stevens developed a so-called exact formula which would give the accurate discharge computation using data collected in the usual procedure of a normal measurement. In other words, this exact, or standard formula as Mr. Stevens described it, is simply the prismoidal formula and a more precise computation of discharge using the same data as would be used by the other formulas, assuming that the depth and velocity vary uniformly from one observation point to the next. The chief difference between that basis of comparison and the one used in this study is that Mr. Stevens' exact formula gave a more precise computation with a normal amount of data, whereas, the accurate discharge used in this study was obtained by what the committee felt to be a more precise measurement of the discharge. In arriving at the exact formula the author makes the assumption that the depth and velocity vary uniformly from one depth to the next, and from one velocity to the next. This is a logical assumption and is also present in other formulas, but it is a condition that does not always actually exist in the characteristics of rivers and streams. Consequently, even the exact formula may not give the true discharge even though it is more precise as far as making the best use of the observed data is concerned. One way to minimize the effects of this assumption and to take into account varying conditions in depth and velocity is to increase the number of observations of these depths and velocities to be used in the computation of the discharge. For instance, if we assume that the depth and velocity vary uniformly, between two points 10 feet apart, but that it is obvious from inspection that they do not, it is quite logical that more observations taken between these points will measure these variations and make them usable in the computations, thus resulting in a more accurate discharge determination. In other words, as we decrease the distance between the observations of depth and velocity, the higher the probability that these quantities <u>will</u> vary uniformly from one to the next, or that the assumption is true.

<u>Comparison</u> <u>of</u> <u>Formulas</u>.-- In comparing the mean-section and mid-section formulas with his exact one, Mr. Stevens showed that his formula D, or what is now called the mid-section method, and formula B, the mean-section method, gave consistently the smallest errors, that of D being twice and usually of opposite sign than that of B, which in general is negative. He also proved that this relation was due to the difference in the formulas for those two methods, so that it is evident that under normal conditions the mid-section method will give an equal or higher discharge figure than the mean-section method. This was found to be confirmed in this study also, as was shown in the graphs of Figs. 2, 3, and 4. If the true discharge is in general higher than that computed by either method in a normal set of observations, then it is evident that the mid-section computation will give more accurate results most of the time.

Mr. Stevens made the following statements in his conclusions regarding the relative merits of his formulas B and D, or the mean-section and mid-section methods.

> "(8) The extreme simplicity of Formula D recommends it for general use..............It is well adapted to regular or irregular intervals between points of observation."
>
> "(9) Formula B has the least error of any under consideration, but requires two more columns in the notes than the use of D."

The discussion of Mr. Stevens' paper is presented in this report to bring out the differences between his comparisons and the ones of this study, and also to point out that even forty years ago an attempt was made to settle this question of methods of computation. The object of his study was "the examination of several formulas for computing stream discharge, with a view to the adoption of one as a standard which will give reliable results under all conditions." At the beginning of his paper Mr. Stevens also stated that "under certain conditions all the formulas considered will give practically the same results, in which case the one involving a minimum amount of labor should by all means be adopted, and the more so when it is shown that the simplest has the least error under all conditions." It would seem that from statements made by Mr. Stevens, his conclusions seemed to be in favor of formula D, or the mid-section method.

Discussion by C. E. Grunsky

In the Transactions of the American Society of Civil Engineers, March 1910, is published a paper by John C. Hoyt on "The Use and Care of the Current Meter, as Practiced by the United States Geological Survey." One of the engineers who presented a discussion of Mr. Hoyt's paper, Mr. C. E. Grunsky, consulting engineer, brought out the matter of discharge measurement computations. He expressed his preference for a computation method which is now called the mid-section method, and on the basis of his assumptions indicated that it was more accurate than the mean-section method then in use by the Geological Survey. His basis of comparison was a discharge determined by developing a discharge curve by plotting the products of depth and velocity at each observation station as ordinates and connecting the plotted points by a curved line.

Discussions in Water Resources Bulletin

At various times there have been discussions on computation methods published in the Water Resources Bulletin, an administrative memorandum issued quarterly in the Water Resources Division, Geological Survey. Several engineers of the Water Resources Division have expressed their ideas and opinions on this subject. The following are references to these discussions found in Water Resources Bulletins: Slack, 1224, p. 20; Slack, 325, p. 23; Dalrymple, 542, p. 74; Colby, 842, p. 114; Veatch, 1142, p. 164; Gambrell, 243, p. 14; Colby, 543, p. 63; Eagle, 543, p. 65; Twichell, 543, p. 68; Lord, 1144, p. 180; Pierce, 245, p. 9.

The above discussions by Mr. Stevens, Mr. Grunsky, and others would be of interest to anyone desiring to do any reviewing on this subject.

CONCLUSIONS

After viewing the comparisons made in this study, there is no large difference as far as accuracy is concerned. As has been pointed out, the mid-section method gives slightly more accurate results when compared to the true or integrated discharge. Assuming that the true discharge is one obtained by taking a large number of observations, results from the mid-section method, on the average, do not vary as much from this true figure as those from the mean-section method when the observations are reduced to a normal number.

As a matter of emphasis it should be pointed out that this study deals with the accuracy of discharge measurements only in relation to the method of computation. Investigations and experiments have shown that current meters give an accurate determination of the mean velocity by observations taken at the .2 and .8 depths, or .6 depths. It must be assumed that proper care was taken in the measurements of water depths and velocities. In other words, this accuracy study is concerned chiefly with the computations of the discharge measurement, and not with that portion of making the measurement which involves equipment and personal influences.

The measurements used in this study were made under a wide variety of field conditions covering all those normally experienced except extremely narrow channels. It is conceivable that some conditions might exist such that the mean-section method would consistently give more satisfactory results than the mid-section method. If the mid-section method is eventually adopted as the "official" method and any field office finds conditions whereby this method does not consistently give satisfactory results, a study should be made by that office to determine the reasons for the inconsistency. The Washington office should be kept informed of and review all studies made in this connection.

The matter of a sufficient number of observations to give satisfactory discharge results is a subject for a study in itself and no attempt was made to do that here. It is noted that, with reasonably good measuring conditions, the usual practice of selecting the number and location of observation stations as used in this study appears satisfactory. This study also shows indirectly that in general more accuracy in discharge measurements can be gained by changing or improving measuring sections and increasing the number of or varying the observations than by improving the method of computation.

The one point these two methods of computation have in common is that the computed areas are the same. This statement can be proved mathematically, and is shown to be true in actual practice if the figures for partial areas are not rounded. The reason for any difference in discharge is due to weighting the partial areas with different values of velocity. At one time in the past when the mid-section method was proposed to be adopted as the official method, the statement was made that this method was "for computing field notes, and not for taking field notes." This statement is quoted here to emphasize that for practical purposes the use of the mid-section method requires no radical change in the procedure of making discharge measurements, and no revisions in any published or unpublished figures of discharge.

With regard to time savings, the mid-section method of computation consumes less time than the mean-section method. If all the personnel involved in computing and checking discharge measurements were familiar with the mid-section method, it has been shown that there would be a saving of from $10,000 to $12,000 annually under present day conditions.

In summing up the results found in this comparative study, the following points are brought out:

(1) The mid-section method of computation results in a slightly more nearly accurate figure of discharge, being an average of 0.6 percent closer to the true discharge.

(2) The mid-section method results in a considerable savings in time as compared to the mean-section method.

(3) There is no appreciable difference in the field procedure of making a discharge measurement for either method of computation.

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