CHARACTERISTICS OF U.S. GEOLOGICAL SURVEY DISCHARGE MEASUREMENTS FOR WATER YEAR 1990

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Multiply	By	To obtain
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)

CHARACTERISTICS OF U.S. GEOLOGICAL SURVEY DISCHARGE MEASUREMENTS FOR WATER YEAR 1990

by Janice M. Fulford

ABSTRACT

The U.S. Geological Survey (USGS) Water Resources Division (WRD) makes tens of thousands of stream discharge measurements each year throughout the United States and Puerto Rico. Most of the measurements require the use of point velocity instrumentation. A survey of current-meter usage and discharge-measurement data for water year 1990 was undertaken to help evaluate the performance of existing instrumentation. The velocity, discharge, and depth ranges measured; the types of meters used; and the measurement problems encountered were surveyed. Survey respondents indicated vegetation as the most frequent cause of significant measurement error. Information from the survey quantifies the range of several common flow characteristics and measurement conditions for streams throughout the United States.

INTRODUCTION

Tens of thousands of discharge measurements are made by personnel of the U.S. Geological Survey (USGS) each year. These discharge measurements of a river or open channel flow are made with a variety of techniques that may or may not require the use of point-velocity instruments. However, the majority of discharge measurements made by the USGS use point-velocity instruments (current meters) to determine the discharge. The accuracy and performance of these current meters have a major effect on the quality of the discharge measurements made by the USGS.

The development of new instrumentation technology such as the acoustic and electromagnetic current meters, and renewed interest in the performance of older instrumentation prompted the creation of a committee by the USGS in 1990 to investigate current meters. As part of the initial investigations the committee performed two tasks: a review of literature from previous meter studies and a survey of the characteristics of discharge measurements made by the USGS. This paper presents the results of the second task--the characteristics of discharge measurements as determined from the survey of water year 1990 (October 1, 1989 to September 30, 1990) discharge measurements.

The survey was undertaken to determine the characteristics of discharge measurements made by the USGS: the velocity, discharge, and depth ranges measured; the types of meters used; and the measurement problems encountered. This knowledge will be used in evaluations of the performance characteristics of current meters used by the USGS.

The survey for water year 1990 has two parts: a questionnaire and a computer data-base retrieval. The questionnaire has questions on which meters were used, on the conditions under which meters were used, and on the quantity and quality of discharge measurements. The computer data-base retrievals contain information summarizing each discharge measurement made in the 1990 water year.

The paper is divided into a short summary of current-meter measurement of discharge and two major sections (1) survey of meter usage and (2) discharge measurements. The first major section contains the results and discussion of the questionnaire. The second section contains the compilation and discussion of the computer data-base retrieval.

CURRENT-METER MEASUREMENT OF DISCHARGE

Because the survey data is either discharge-measurement data or related to discharge measurements, a general knowledge of discharge measurement techniques and terminology is helpful in understanding the data and data analysis. Discharge is measured with a current meter by measuring velocity in various locations across a stream and multiplying the velocity by the product of the contributing depth and width of the stream.

The USGS uses the midsection method to determine discharge. A cross section that spans the stream width is divided into several vertical strips. Velocity is measured in each strip at either 0.6 of the depth or 0.2 and 0.8 of the depth depending on the depth of flow. The discharge in each strip is determined by multiplying the area of the strip by its mean velocity, either the 0.6 measurement or the average of the 0.2 and the 0.8 measurements. The discharges for all strips are summed to yield the total discharge.

Discharge measurements are classified into measurement types by the technique used to cross the stream, such as wading, boat, bridge, cableway, or ice. The measurement type used depends on the depth of flow, velocity, and the location of the measurement section.

Rantz (1982) gives a detailed description of streamgaging techniques used by the USGS in "Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge." Descriptions of streamgaging techniques can also be found in Herschy (1985).

SURVEY OF METER USAGE

The questionnaire surveyed USGS data-section personnel on their current-meter use during water year 1990. Data section chiefs in District offices of the USGS were asked to respond to the questionnaire and (or) to have personnel of their choosing respond. Districts were asked to return at least one completed questionnaire. (A "District" is usually a state, except for a few districts that have more than one state.) The questionnaire is one page and requires either an estimated percentage or a count for answers. Figure 1 is a copy of the distributed questionnaire.

Ninety-two completed questionnaires were returned. Questionnaires were received from all Districts except two. Many Districts sent multiple responses. California sent the most (10) and 30 Districts sent the minimum requested (one each). Table 1 lists the number of questionnaires returned by state and the responses to the first four questions on the questionnaire. States in the same District are listed together except for Delaware and Maryland. Delaware and Maryland are listed separately because a separate response was received from each. The total number of continuous-record sites (sites at which stage is continuously recorded) reported on the questionnaire is 6,098. The average number of measurements made per continuous-record site as reported on the questionnaire is 8.7. The total number of partial-record sites (measurement sites at which stage is not continuously recorded) reported on the questionnaire is 2,872.

Because each questionnaire does not represent the same number of discharge measurements, averages of the responses were computed unweighted and weighted for questions 5 through 14 (see figure 1). The unweighted average is the sum of the responses for a question divided by the number of questionnaires, 92. It is indicative of what the responding field personnel experience and may not be a good estimate of the average 1990 water year measurement. It is an estimate of a typical District's response to a question.

Questionnaire for field personnel for water year '90

District:__ Name:_____Phone:_____

1.How many continuous record sw sites did you serve from your office _____
2. For an average site, number of discharge measurements made in WY '90 _____

3.How many other discharge measurement sites do you serve from your office_____
4. For an average site, number of discharge measurements made in WY '90 _____

5.For wading measurements, what percentage are made with: Price___% Pygmy___%

6.For wading measurements, what percentage are rated:
Excellent ____% Good ____% Fair ____% Poor ____% NA __

7.For cable-way measurements, what percentage are rated:
Excellent ____% Good ____% Fair ____% Poor ____% NA __

8.For bridge measurements, what percentage are rated:
Excellent ____% Good ____% Fair ____% Poor ____% NA __

9.For boat measurements, what percentage are rated:
Excellent ____% Good ____% Fair ____% Poor ____% NA __

10.For ice measurements, what percentage are rated:
Excellent ____% Good ____% Fair ____% Poor ____% NA __

For the following questions(11-14), show estimated percentages for use of meters of the measurement conditions. Note, the sum of percentages for any question may exceed 100 percent.

11. how often your office uses the following meters in discharge measurements,
__Price __pygmy __electromagnetic __acoustic
__Ott type _____ice(specify) _____other(specify)

12. how often your field personnel have fouling of Price and pygmy meters from,
__aquatic vegetation __ice/slush __silt/sediment __misc. debris

13. how often your discharge measurements are rated fair or poor because of,

__ vegetation	__ air line/wet line	__ rapid stage changes
__ high turbulence	__ submerged debris	__ high sediment load
__ surface waves	__ floating debris	__ extreme horizontal angles
__ sand bed channel	__ ice problems	__ irregular cross-sections
__ low velocities	__ shallow depths	__ other_____(specify)

14. how often your discharge measurements are made in sections with;
__velocities <.2fps __depths <1.5 ft __large eddies __boils, whitewater
__beds of boulders __beds of cobbles __beds of gravel __ice cover or slush

15. Please enter any additional comments on field use of meters.

Figure 1.--Current-meter use questionnaire sent to District offices of the U.S. Geological Survey.

Table 1.--*Number of responses to questionnaire, number of continuous-record sites, number of partial-record sites and number of measurements per site by state*

STATE	Number of responses	Continuous-record sites		Partial-record sites	
		Number of sites	Measurements per site	Number of sites	Measurements per site
Alabama	1	92	9.0	30	0.0
Alaska	1	80	6.0	65	2.0
Arkansas	1	51	8.0	255	1.0
Arizona	3	122	8.0	10	1.6
California	10	445	10.4	224	4.8
Colorado	5	269	12.2	50	2.0
Connecticut	1	42	7.0	20	6.0
Delaware	1	22	10.0	46	3.0
Florida	3	276	7.0	106	4.0
Georgia	1	128	9.0	141	1.0
Hawaii	1	105	7.0	160	2.0
Iowa	3	122	12.0	51	1.2
Idaho	1	202	9.0	74	5.0
Illinois	3	144	9.5	38	1.5
Indiana	1	176	8.0	0	.0
Kentucky	1	110	9.0	23	2.0
Louisiana	1	61	8.0	30	2.0
Massachusetts & Rhode Island	1	85	6.0	70	3.0
Maine	1	48	4.0	0	.0
Maryland	1	67	9.0	0	.0
Mississippi	1	80	10.0	30	8.0
Minnesota	3	83	9.0	62	.1.7
Missouri	3	122	10.0	33	.7
Montana	1	210	10.0	180	2.0
North Carolina	4	169	7.5	78	3.8
North Dakota	1	73	12.0	29	10.0
Nebraska	1	143	13.0	6	2.0
New Hampshire & Vermont	1	63	8.0	20	3.0
New Jersey	1	92	9.0	150	2.0
New Mexico	3	149	10.7	31	5.3
Nevada	1	120	8.0	135	3.0
New York	2	97	7.5	110	2.5
Ohio	1	132	6.0	4	3.0
Oklahoma	1	113	9.0	60	2.0
Oregon	2	180	6.0	8	1.0
Pennsylvania	2	177	9.5	155	3.0
South Carolina	1	119	8.0	4	6.0
South Dakota	3	147	10.6	22	3.0
Tennessee	3	82	8.7	102	.3
Texas	5	274	7.6	53	3.6
Utah	1	157	10.0	6	4.0
Virginia	3	84	7.0	59	1.0
Washington	3	210	6.7	55	5.0
Wisconsin	1	112	8.0	29	6.0
West Virginia	1	77	6.0	8	2.0
Wyoming	1	125	10.0	50	4.0

The weighted average is the average adjusted or weighted by the number of discharge measurements (the number of continuous-record sites times the number of measurements per site plus the number of partial sites times the number of measurements per partial site) that each response represents. The weighted average is computed by summing the products of the individual responses with its respective number of measurements and dividing it by the total number of measurements. It is an estimate of the response that would have been given for a typical discharge measurement for the United States or the average that would have been computed from questionnaires answered for each 1990 discharge measurement.

Differences between the unweighted and weighted average result if the typical District response is different than the response for the typical discharge measurement. The numbers presented for each question are the weighted average except where differences between the weighted and unweighted averages are significant. In those cases both averages are presented (and noted as to whether they are the weighted or unweighted average). Numbers not noted in the report text are weighted averages of the responses. Because the numbers given by the respondents are estimates, the unweighted and weighted averages of the responses for a given question may not sum to 100 percent.

For questions 12 through 14, the percentages of non-zero responses are listed. This percentage is an estimate of the significance of the average or averages. An average response with a large percent of non-zero values is more significant than a similar average with a smaller percent of non-zero values.

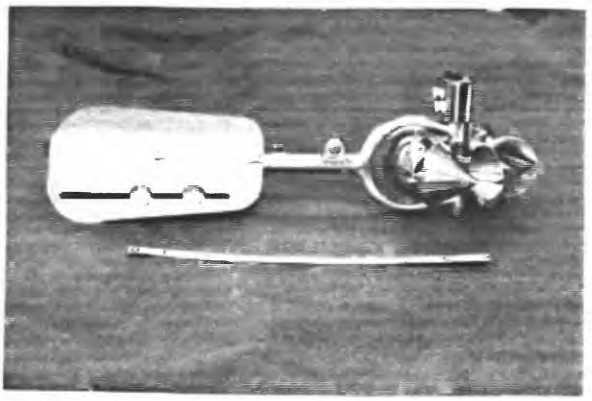
Current Meters used by the U.S. Geological Survey

The USGS primarily uses two current meters, the Price type-AA and the Price pygmy. Both of these meters are mechanical, vertical-axis meters that use six conical cups that rotate about the meter shaft to translate the horizontal flow velocity into rotational velocity. Revolutions of the meter are signaled by a switching mechanism, either optical or cat whisker, and are counted by an electronic counter (current meter digitizer) or by an operator listening with a headset for the sound generated by each switch closure. The type-AA meter is the larger meter, with a 5-inch-diameter rotor that is 2 inches high. The pygmy is two-fifths as large as the type-AA.

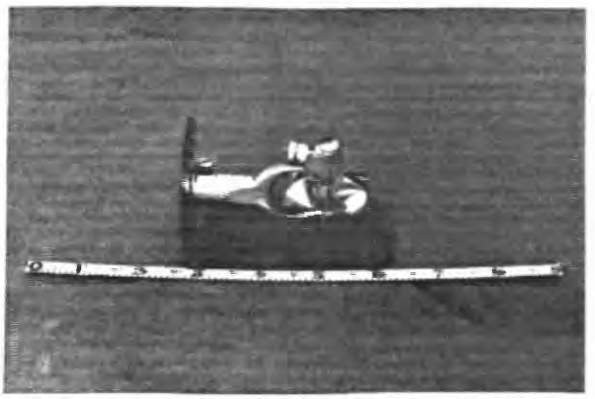
In addition to these two meters, ice, electromagnetic, Ott-type[1], and acoustic meters are occasionally used. The electromagnetic and acoustic meters are not standardized and differ by manufacturer. The Ott-type meter referred to in this report is a USGS designed meter that uses a special Ott designed component propeller on a horizontal-axis meter for moving-boat measurements. Ice meters are various meters used for discharge measurements under ice and are usually a type-AA, pygmy, or Canadian-type yoke meter. Occasionally a vane meter is used for under-ice measurements. In figure 2 are photographs of the various meters listed on the questionnaire.

All questionnaire respondents use both the type-AA and pygmy current meters. For wading measurements (question 5), the type-AA is used for more measurements than the pygmy, 54 percent and 46 percent, respectively. For all types of measurements, the type-AA meter is the most commonly used, about 60 percent of the time. The pygmy is used about 39 percent of the time. However, 35 percent of the respondents indicated that they used the pygmy more frequently than the type-AA. Nine percent of the respondents indicated equal use of the type-AA and pygmy.

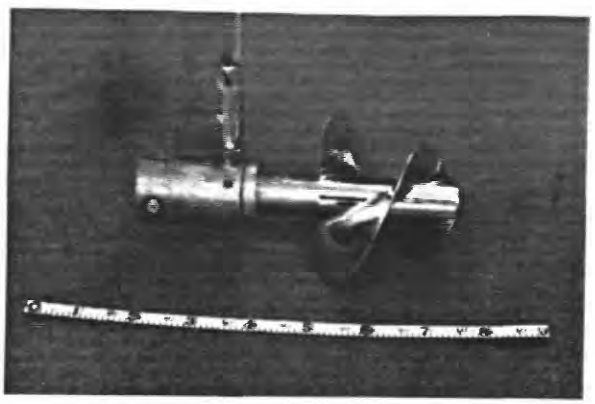
[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.



Price type -AA meter

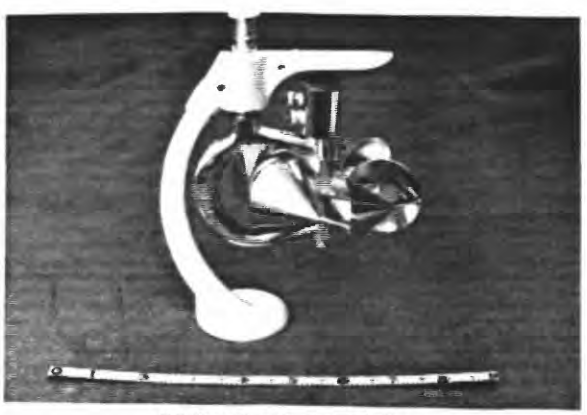


Price pygmy meter

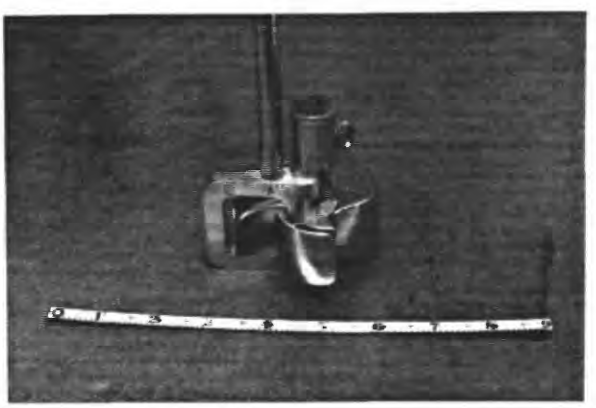


Ott-type moving boat meter

example of electromagnetic meter (Marsh McBirney)



U.S. Geological Survey winter yoke meter



vane winter meter

Figure 2.-- Current meters listed on questionnaire except for acoustic meter. (Tape in pictures is 0.9 feet long. Ruler in electromagnetic meter photo is 0.5 feet long.)

Table 2. *Frequency of use by U.S. Geological Survey personnel of various types of current meters*

Meter type	Percent using	Percent of time used (weighted average)
Price type-AA	100.0	60.1
Price Pygmy	100.0	39.2
Electro-magnetic	7.6	.2
Acoustic	6.5	.1
Ott-type	3.3	.1
Ice	13.0	2.2

Most respondents did not indicate use of the other current meters listed on the questionnaire. For respondents who use meters other than the type-AA and pygmy, they used an ice meter 9 percent of the time and electromagnetic-, acoustic-, and Ott-type meters 2 to 3 percent of the time. The frequency of use of various current meters by USGS personnel is listed in table 2 and is shown in figure 3.

Rating of Discharge Measurements by U.S. Geological Survey Personnel

Discharge measurements are rated by USGS personnel as to their accuracy or total error (the difference between the measured and actual discharge). They are rated as either excellent, good, fair, or poor. For each measurement rating the error ranges in percent are: less than or equal to 2 percent, excellent; more than 2 and less than 5 percent, good; greater than or equal to 5 and less than 8 percent, fair; and equal to or more than 8 percent, poor.

Characteristics of the measurement section (the number of verticals at which the velocity is measured; the degree of turbulence; the steadiness of the stage; and the presence of ice, vegetation, or wind) affect the accuracy of discharge measurements and, consequently, the rating given to a particular discharge measurement. This rating is subjective and may not reflect the true accuracy of the discharge measurement.

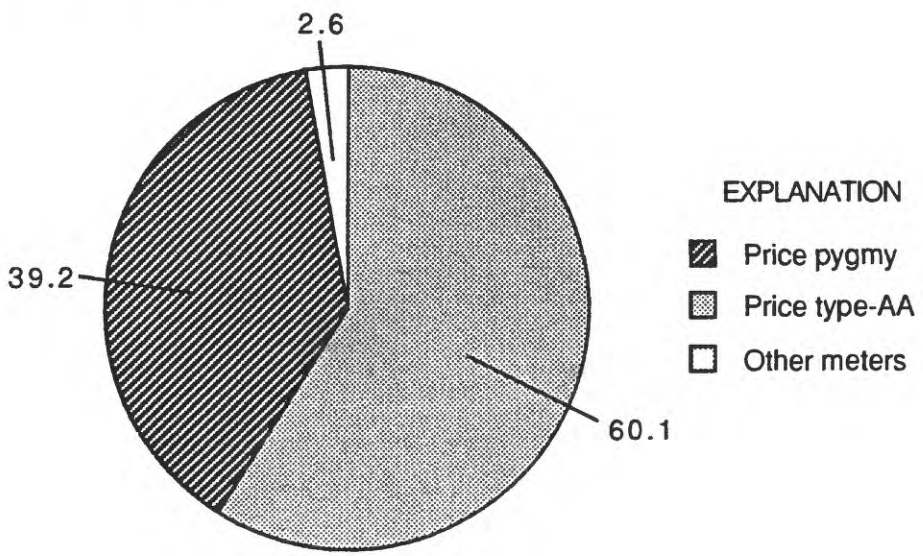


Figure 3.--Frequency of use of various meter types in percent.

Table 3.--*Percentage of wading, cableway, bridge, boat, and ice measurements rated excellent, good, fair, or poor by respondents performing measurement type and percentage of respondents that performed each measurement type,*

Rating	Wading	Cableway	Bridge	Boat	Ice
Excellent	1.0	1.3	.4	.2	.8
Good	61.0	71.4	58.6	87.2	13.4
Fair	28.9	26.9	31.8	24.4	39.7
Poor	8.9	4.7	7.9	5.8	47.9
Performed	100.0	75.0	95.7	44.6	47.8

A summary of the responses to the questions on measurement rating (questions 6 to 10) is listed in table 3. Included in the table are the percentage of respondents that performed each measurement type. Other percentages shown in table 3 are the weighted averages of the responses from those personnel that indicated performance of the measurement type.

All respondents performed wading measurements. Bridge measurements were performed by about 96 percent and cableway measurements by 75 percent of the respondents. Boat and ice measurements were each performed by less than half.

Measurement personnel rated the majority of discharge measurements as good. The next most common ratings were fair and poor. Few measurements are rated excellent. Ice measurements were usually rated poor or fair with about 13 percent of ice measurements rated good and less than a percent rated excellent. Boat and cableway measurements have slightly better average ratings than do wading and bridge measurements.

Meter Fouling

All current meters are subject to fouling. In particular, mechanical meters, such as the type-AA and the pygmy, are sensitive to fouling by debris and other agents. For type-AA and pygmy meters, respondents indicated that aquatic vegetation is the primary source of meter fouling. Miscellaneous debris was the next most likely source of fouling, followed by ice/slush and silt/sediments. Table 4 summarizes the responses to the question on type-AA and pygmy-meter fouling and the percentage of non-zero responses.

Measurement Characteristics that Contribute to Error

There are many measurement section characteristics or conditions that result in fair or poor discharge measurement ratings. An ideal measurement section is a straight reach with a stable smooth streambed that is free of eddies and converging or diverging currents. Turbulence, rapidly varying flow (spatially and/or temporally), and debris are examples of measurement section conditions that cause significant errors in discharge measurements. Normally stream gagers avoid sections with these conditions, but sections with poor measurement conditions are sometimes used

Table 4.--*Percent time that type-AA and pygmy meters are fouled by various agents*

Fouling agent	Percentage of time fouled (weighted average)	Percentage of non-zero responses
Aquatic vegetation	12.4	92.4
Ice/slush	4.9	48.9
Silt/sediment	2.5	28.3
Miscellaneous debris	9.2	73.9

Table 5.--*Frequency with which adverse measurement conditions cause discharge measurements to be rated poor or fair*

Adverse condition	Frequency of occurrence (average)	Frequency of occurrence (weighted average)	Percent of non-zero responses
Vegetation	13.6	15.3	92.4
Low velocities	9.7	10.5	82.6
Rapid stage changes	8.6	8.0	85.9
Shallow depths	10.9	13.6	77.2
Irregular cross-sections	12.0	13.8	70.7
High turbulence	7.2	7.5	75.0
Floating debris	5.4	4.8	67.4
Sand-bed channels	9.3	6.1	48.9
Ice problems	5.7	7.1	51.1
Submerged debris	4.1	3.5	55.4
Extreme horizontal angles	2.9	2.7	56.5
Surface waves	3.4	3.0	48.9
Air line/wet line	1.5	1.3	31.5
High sediment load	1.5	1.4	14.1

out of necessity. Respondents answered two questions that pertained to measurement-section conditions, one on how conditions adversely affect measurement ratings and one on how frequently less than ideal measurement conditions are encountered.

A summary of the responses to the questions concerning causes of poor or fair measurement ratings is presented in table 5. Both the weighted and unweighted averages are presented in the table because of the noticeable differences between them. Based on the percent frequency of occurrence and the percent of non-zero responses, respondents most often indicated vegetation as causing measurements to be rated fair or poor. Also conditions ranking high as causing fair or poor ratings are irregular cross-sections, low velocities, rapid-stage changes, and shallow depths.

A few noticeable differences between the unweighted average and weighted average for sand-bed channels, ice problems, shallow depths, vegetation, and irregular cross sections exist. For sand-bed channels, the weighted average is smaller (6.1 percent) than the average (9.3 percent) and in contrast to the average, is less important than high turbulence, rapid-stage changes, and ice problems as a cause of fair or poor measurement rating. This may be because sand-bed channels do not occur in every District, but are a significant cause of fair or poor ratings where they occur. The weighted average for ice problems (7.1) is larger than the average (5.7) and in contrast to the average values, ice problems are more significant than sand-bed channels as a cause of fair or poor ratings. This may be because fewer questionnaires were returned by Districts that have icy weather. Shallow depths, vegetation, and irregular cross sections have weighted averages larger than the average. However, this difference does not significantly change their ranking relative to the other causes of fair or poor measurement rating.

Respondents also indicated how frequently they measured in sections with various conditions that may adversely affect the accuracy of discharge measurements. The frequency with which measurements are made in these less than ideal conditions is presented in table 6. Based on the percent frequency of occurrence and the percent of non-zero responses, depths of less than 1.5 ft, cobbled streambeds, and gravel streambeds are the most frequently encountered of these

6.--*Frequency of occurrence of measurement conditions that may adversely affect measurement accuracy*
[ft/s, feet per second; ft, feet]

Adverse condition	Frequency of occurrence (weighed average)	Percentage of non-zero responses
Velocities <0.2 ft/s	8.4	88.0
Depths <1.5 ft	38.9	96.7
Large eddies	2.7	55.4
Boils, whitewater	4.3	55.4
Streambeds of boulders	5.5	53.3
Streambeds of cobbles	24.0	71.7
Streambeds of gravel	32.5	82.6
Ice cover or slush	8.3	51.1

conditions. About one quarter of all discharge measurements are made in sections affected by one of these conditions. The other conditions listed on the questionnaire are experienced less than 9 percent of the time.

CHARACTERISTICS OF DISCHARGE MEASUREMENTS FOR WATER YEAR 1990

Discharge-measurement data for water year 1990 were retrieved from each USGS district. Districts having discharge measurements stored in computer files retrieved and sent an Automated Data Processing System (ADAPS) computer file through the USGS computer network. Four Districts (Alaska, Maine, Ohio, and Virginia) that did not have discharge data stored in computer files, sent photocopies of forms (USGS form 9-207) containing discharge-measurement data for water year 1990 for their continuous-record gaging sites. The photocopied data from those Districts were manually entered into computer files and included in the analysis.

Unfortunately, some data available from the computer retrievals are not available on the photocopied forms. The computer retrievals contain data for mean velocity, discharge, width, area, measurement type, and measurement rating. The photocopied forms do not have data for measurement type and the computer retrievals have missing data for some measurements.

All data were checked for errors. The files for the photocopied data were carefully checked for typographical errors and preliminary data analyses for all files were checked for suspicious results.

Preliminary processing of the retrieved ADAPS files revealed unexpected problems with the retrievals and data. Because of these problems, each state's ADAPS computer files were processed and verified by a computer program. The program checked for and removed repeated station retrievals, retrievals of stations with no 1990 measurements, and data outside the 1990 water year. Additionally, the program removed ADAPS header text and checked for unusual depths (very small, very large) and other differences between discharge and the product of mean velocity and area that were greater than 10 percent.

These suspicious measurement data were flagged by the program, examined individually for errors, and corrected. Obvious typographical errors in data, such as transposed numbers and misplaced decimal points, were corrected. Data that had inconsistencies other than obvious typographical errors were deleted. Most computer files received contained errors, the most common being the retrieval of data outside the desired water year. The verified, processed computer files and the manually entered measurement files were then analyzed.

A statistical analysis computer program was used to analyze the resulting files. The discharge data were analyzed for each District (or state) separately and for the combined data. Additionally, several common flow characteristics (squared Froude number, wetted perimeter, and conveyance times roughness) were computed from the data and analyzed.

The data analysis is presented here in three sections: analysis of the entire (National) data set, analysis by state (or WRD District), and analysis of computed flow parameters. Summary statistics for mean velocity, width, area, discharge, measurement rating, measurement type, and mean depth are presented in the first two sections. Summary statistics for the computed flow characteristics are presented in the third section by state (or WRD District) and for the combined data. Parts of data associated with some discharge measurements are missing or inconsistent and consequently not included in the computation of summary statistics. As a result of these omissions, the number or count of each data type summarized are different.

Analysis of National Data Set

The combined District files of discharge measurements for water year 1990 contain data from 6,199 continuous-record sites and 53,799 measurements. The average number of discharge measurements per site is 8.7 with a standard deviation of 2.3 measurements. These measurements include a small fraction of discharge measurements made by flumes or estimated, but the overwhelming majority of the measurements are made with current meters. Table 7 lists the summary statistics for discharge, mean velocity, width, mean flow depth, and area. The count of discharges in table 7 does not equal the total number of discharge measurements because of missing and deleted measurement data. Negative discharges in table 7 are from tidally affected sites that have reverse flows.

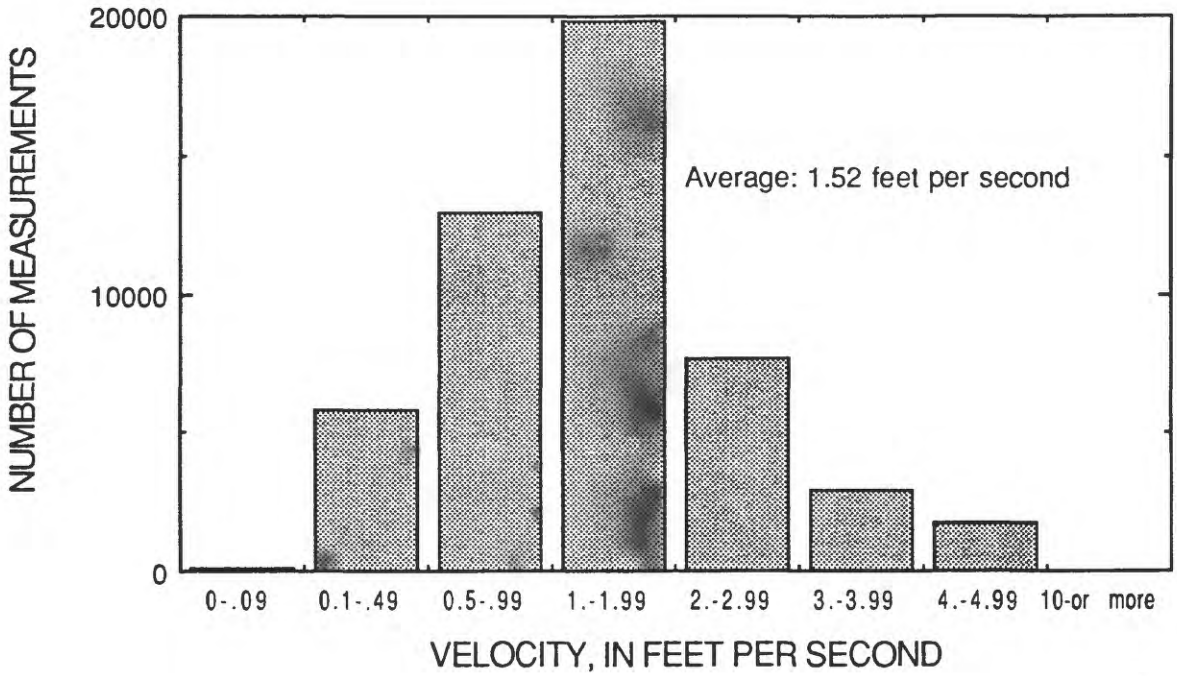
Because this survey was motivated by interest in current-meter performance, depth and velocity were analyzed more extensively than were the other data types. Frequency distributions for mean velocity and mean flow depth are shown in figure 4. For most discharge measurements mean velocities are less than 2.0 ft/s. Almost half of the discharge measurements are made in mean flow depths of less than 1.25 ft. Using the mean values, the average 1990 discharge measurement has a discharge of 1,960 ft^3/s, and a mean velocity of 1.52 ft/s.

Measurement Type

The combined data were grouped by measurement type and analyzed. Illustrated in figure 5 is the percentage of measurements attributed to each measurement type: bridge, wading, cableway, ice, and boat. For the combined data that had measurement type entered, approximately three quarters are wading measurements. Bridge measurements are the second most common type, making up nearly 16 percent of the measurements.

Table 7.--*Summary statistics for discharge measurements made in water year 1990*
[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	105.4	234	0.1	13,675	51,543
Area (ft^2)	663.2	3,328	0	149,000	51,117
Velocity (ft/s)	1.52	1.09	0	12.66	51,076
Discharge (ft^3/s)	1,960	13,557	-836	679,800	53,188
Depth (ft)	2.3	3.4	0	51.5	51,069



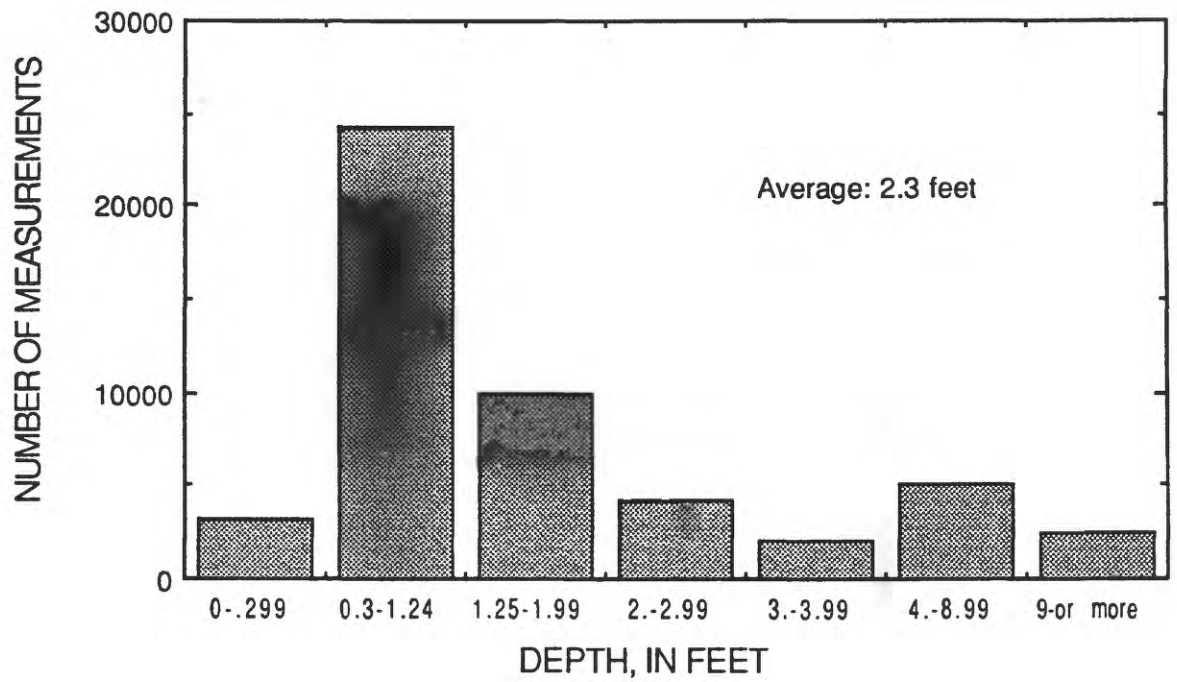


Figure 4.--Frequency distributions of mean velocity and mean flow depths for all discharge measurements made in water year 1990.

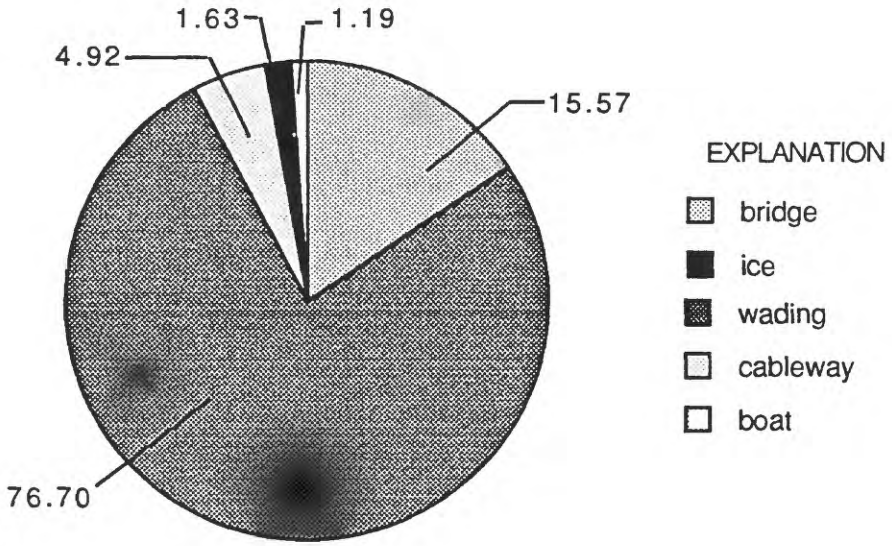


Figure 5.--Percentage of water year 1990 measurements by measurement type.

Summary statistics for measurement data with measurement type available are shown grouped by measurement type in tables 8a through 8e. Measurement type data were not available for Maine, Virginia, Ohio, or Alaska.

The lowest mean velocities are for ice measurements and the highest mean velocities are for cableway measurements. Average discharges are highest for bridge measurements and lowest for wading measurements. Boat measurements have the largest average area and wading measurements have the smallest area. Wading and ice measurements have the smallest average flow depth and bridge measurements have the largest.

Velocity frequency distributions plotted for the four most frequently used measurement types, wading, bridge, cableway, and ice, are shown in figure 6. The distribution for wading measurements is very similar in shape to the velocity distribution for all measurements (figure 4) because wading measurements make up about three quarters of all measurements. The velocity frequency distribution shape for ice measurements looks similar to the distribution for wading measurements except for the lower mean velocity. Velocity frequency distributions for bridge and cableway measurements are skewed to the higher velocities, because high velocity discharges and large depths cannot be waded.

Table 8a.--*Summary statistics for wading discharge measurements made in water year 1990 (data for Alaska, Maine, Ohio, and Virginia not available)*
[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	50.5	78.9	0.15	8,209	36,962
Area (ft^2)	68.4	234.9	0	25,400	36,708
Velocity (ft/s)	1.23	0.73	0	12.66	36,690
Discharge (ft^3/s)	108	642	-0.79	87,900	37,050
Depth (ft)	1.0	0.7	0	21.0	36,683

Table 8b.--*Summary statistics for bridge discharge measurements made in water year 1990 (data for Alaska, Maine, Ohio, and Virginia not available)*

[ft, feet; ft^2, square feet; ft/s, feet per second; ft3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	299.3	427.7	1.7	9,540	7,479
Area (ft^2)	2,703	5,707	1.8	100,000	7,389
Velocity (ft/s)	2.38	1.41	0.02	10.31	7,375
Discharge (ft^3/s)	8,515	25,290	-836	660,000	7,487
Depth (ft)	6.7	4.6	0.14	51.5	7,381

Table 8c.--*Summary statistics for cableway discharge measurement made in water year 1990 (data for Alaska, Maine, Ohio, and Virginia not available)*

[ft, feet; ft^2, square feet; ft/s, feet per second; ft3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	214.2	235.8	16	2,768	2,770
Area (ft^2)	1,871	5,969	34.1	98,800	2,760
Velocity (ft/s)	3.01	1.54	0.24	10.04	2,758
Discharge (ft^3/s)	6,755	28,887	17.9	631,000	2,805
Depth (ft)	5.4	5.2	0.29	45.0	2,758

Table 8d.--*Summary statistics for ice discharge measurements made in water year 1990 (data for Alaska, Maine, Ohio, and Virginia not available)*

[ft, feet; ft^2, square feet; ft/s, feet per second; ft3/s, cubic feet per second,]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	82.1	120.7	0.7	1,415	776
Area (ft^2)	124	270	0.1	2,650	763
Velocity (ft/s)	0.92	0.50	0.01	2.97	760
Discharge (ft^3/s)	143	393	0	4,820	779
Depth (ft)	1.0	0.8	0.04	6.5	763

Table 8e.--*Summary statistics for boat discharge measurements made in water year 1990 (data for Alaska, Maine, Ohio, and Virginia not available)*

[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	468.3	844.9	36.8	13,675	572
Area (ft^2)	6,932	15,160	115	149,000	567
Velocity (ft/s)	1.74	1.03	0.14	4.94	566
Discharge (ft^3/s)	15,593	41,144	-218	337,000	571
Depth (ft)	10.5	8.2	2	50.4	566

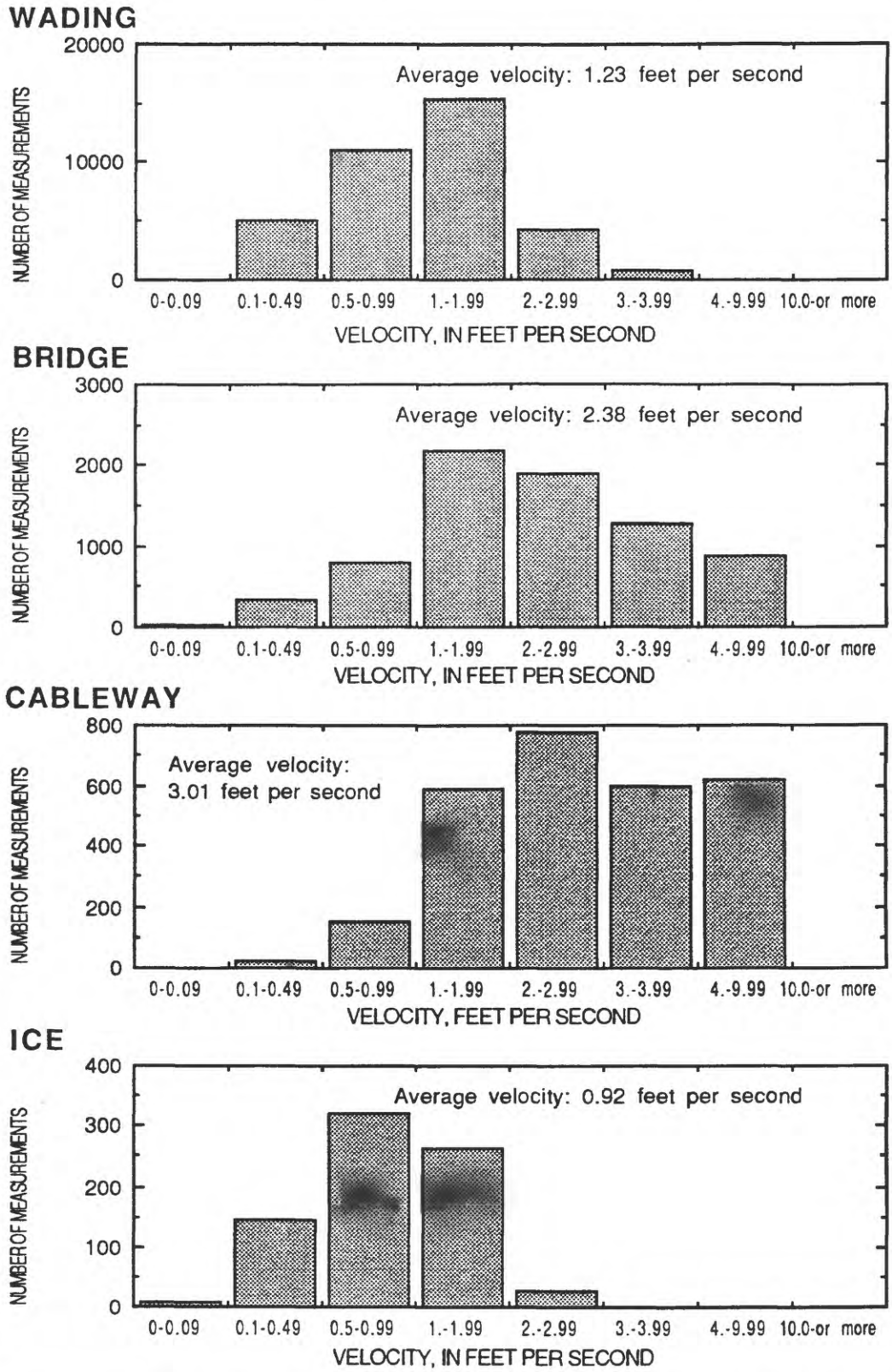


Figure 6.--Frequency distribution of velocity for wading, bridge, cableway, and ice measurement types.

Measurement Rating

The combined data were grouped by measurement rating and analyzed. Those measurements without measurement-rating data and Ohio measurements rated good/fair on the photocopied forms were excluded from the statistical analysis. Because Ohio measurements rated good/fair are a small proportion of the total measurement data, they were excluded from the measurement-rating analysis instead of arbitrarily picking good or fair. The percentage of measurements attributed to each measurement rating--excellent, good, fair, and poor--is shown in figure 7. For any 12 measurements, approximately 7 are rated good and 4 are rated fair. The remaining measurement is usually rated poor. Less than 1 percent of measurements are rated excellent. Summary statistics for the combined data grouped by measurement rating are shown in tables 9a through 9d.

Velocity frequency distributions for the excellent, good, fair, and poor ratings are shown in figure 8. Velocity frequency distributions for each rating type, except for the poor ratings, look similar to the distribution for the entire data set. The velocity frequency distribution for poor ratings is skewed to velocities of less than 2 ft/s.

Analysis of State Data

This section presents the analysis of the discharge measurement data by state (or WRD District). In most cases, the statistics are reported separately for each state. Not all states are reported separately because some Districts span state boundaries. Those states reported together are Vermont and New Hampshire and Massachusetts and Rhode Island. Delaware, even though it is part of a District with Maryland, is reported separately.

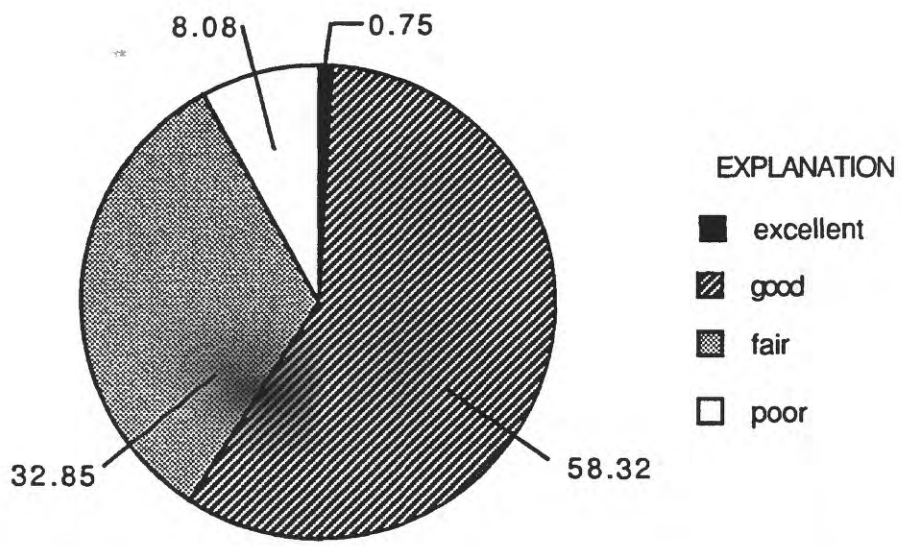


Figure 7.--Percentage of water year 1990 measurements by measurement rating (Ohio measurements rated good/fair are excluded.)

Table 9a.--*Summary statistics for discharge measurements rated excellent in water year 1990*
[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	108.2	135.0	1.0	1,020	253
Area (ft^2)	513	1,653	0.7	15,800	252
Velocity (ft/s)	1.67	1.12	0.23	7.67	253
Discharge (ft^3/s)	1,264	8,923	0	121,000	379
Depth (ft)	2.3	2.8	0.2	21.2	252

Table 9b.--*Summary statistics for discharge measurements rated good in water year 1990 (Ohio cases rated good/fair are not included)*
[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	117.0	241.8	0.3	9,540	29,397
Area (ft^2)	761	3,611	0.01	100,000	29,203
Velocity (ft/s)	1.67	1.04	0.06	9.32	29,189
Discharge (ft^3/s)	2,242	14,715	-568	660,000	29,776
Depth (ft)	2.5	3.5	0.01	50.4	29,186

Table 9c.--*Summary statistics for discharge measurements rated fair in water year 1990 (Ohio cases rated good/fair are not included)*
[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	92.0	229.9	0.1	13,675	16,398
Area (ft^2)	550	3,024	0	149,000	16,257
Velocity (ft/s)	1.43	1.11	0.02	12.66	16,244
Discharge (ft^3/s)	1,673	11,470	-0.79	508,000	16,606
Depth (ft)	2.0	3.1	0	51.5	16,237

Table 9d.--*Summary statistics for discharge measurements rated poor in water year 1990*
[ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Characteristic	Mean	Standard deviation	Low	High	Count
Width (ft)	70.8	172.3	0.2	2,875	3,985
Area (ft^2)	321	1,341	0	25,900	3,916
Velocity (ft/s)	1.18	1.24	0	10.71	3,905
Discharge (ft^3/s)	1,099	12,175	-218	679,800	4,081
Depth (ft)	1.6	2.9	0	41.9	3,907

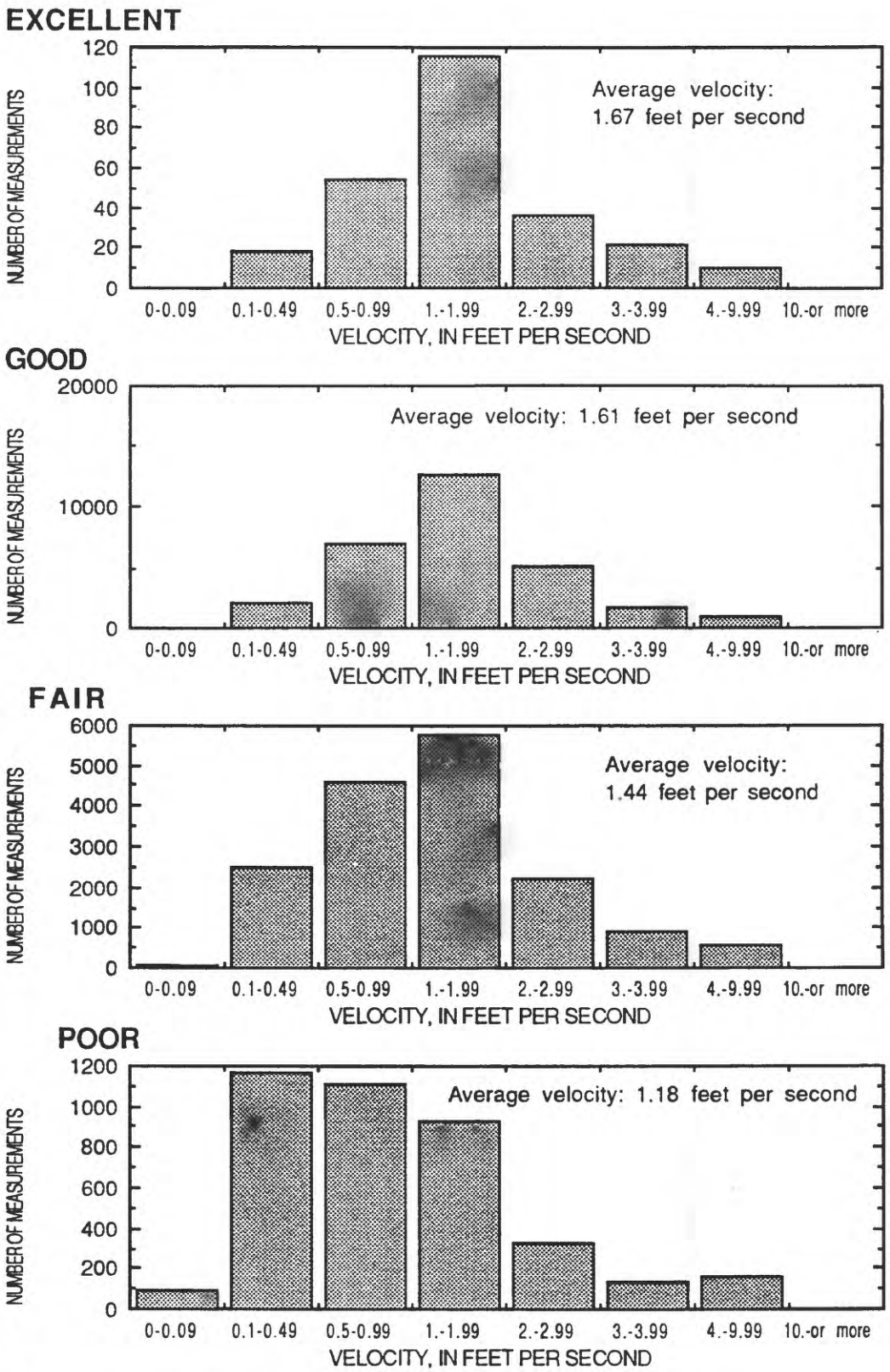


Figure 8.--Frequency distributions of velocity for excellent, good, fair, and poor measurement rating.

Table 10.--*Number of discharge measurement sites and average measurements per site listed by state*

State	No. of sites	Average measurements per site	State	No. of sites	Average measurements per site
Alaska	81	6.2	Montana	228	7.8
Alabama	76	9.3	North Carolina	169	8.3
Arkansas	49	7.6	North Dakota	73	11.7
Arizona	102	11.4	Nebraska	116	13.8
California	393	9.5	New Jersey	90	7.1
Connecticut	42	6.9	New Mexico	130	10.4
Colorado	237	12.5	Nevada	110	8.9
Delaware	13	12.6	New York	208	7.2
Florida	211	7.0	Ohio	128	6.5
Georgia	111	10.3	Oklahoma	143	7.6
Hawaii	79	7.2	Oregon	159	5.8
Iowa	115	14.6	Pennsylvania	232	8.3
Idaho	243	7.6	Puerto Rico	61	11.8
Illinois	150	10.1	South Carolina	107	5.8
Indiana	174	7.9	South Dakota	73	10.2
Kansas	133	9.0	Tennessee	80	8.5
Kentucky	100	9.0	Texas	280	7.6
Louisiana	61	9.0	Utah	157	10.7
Massachusetts & Rhode Island	83	6.4	Vermont & New Hampshire	62	6.2
Maryland	75	7.9	Virginia	95	6.5
Maine	47	4.5	Washington	241	6.4
Michigan	140	8.5	Wisconsin	103	8.6
Minnesota	62	9.4	West Virginia	76	5.6
Missouri	104	11.5	Wyoming	125	11.7
Mississippi	72	9.3			

Summary Statistics

The total number of measurement sites and the average number of measurements made per site were computed from the data. The number of measurement sites per state ranges from 13 to 393 with 127 being the average. The median number of sites is 107. The average number of measurements made per site for the water year ranged from a low of 4.5 for Maine to a high of 14.6 for Iowa. The average value is 9 measurements per site, and the median is 8.5 measurements per site. Table 10 lists by state the number of measurement sites and the average number of measurements per site.

Summary statistics for width, area, mean velocity, discharge, and mean flow depth data are listed by state in table 11. Included in the summary statistics are the mean, standard deviation, and number of values for each data type.

Table 11.--*Statistics by state for width, area, mean velocity, discharge, and mean flow depth for water year 1990*

[S.D., standard deviation; No., number of measurements; ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

STATE	WIDTH (ft)		AREA (ft^2)		VELOCITY (ft/s)		DISCHARGE (ft^3/s)		DEPTH (ft)	
	Mean		Mean		Mean		Mean		Mean	
	S.D.	No.	S.D.	No.	S.D.	No.	S.D.	No.	S.D.	No.
Alaska	194.3		1,604		2.27		8,021		2.7	
	376.4	485	5,160	479	1.57	477	40,161	500	3.9	477
Alabama	106.9				1.42		1,635		2.6	
	243.9	698	1,856	693	1.00	693	7,206	696	3.1	692
Arkansas	194.1		2,941		1.73		12,566		6.0	
	295.5	322	7,779	320	1.61	320	44,655	369	7.7	320
Arizona	73.1		482		1.32		1,033		2.2	
	114.1	753	1,428	746	0.92	746	3,576	820	4.2	744
California	54.6		179		1.35		357		1.4	
	88.6	3,400	596	3,365	1.04	3,366	1,501	3,713	1.8	3,364
Colorado	48.8		76		1.71		209		1.0	
	54.3	2,886	155	2,871	1.11	2,871	633	2,953	0.9	2,869
Connecticut	79.5		335		1.53		911		2.0	
	144.4	289	1,261	289	1.11	289	3,899	289	2.0	289
Delaware	37.8		103		1.05		135		1.7	
	29.7	164	191	164	0.70	164	407	164	1.9	164
Florida	103.3		798		0.74		1,151		2.5	
	464.5	1,396	5,389	1,375	0.50	1,376	9,110	1,418	3.5	1,361
Georgia	161.2		1,165		1.55		3,104		4.1	
	279.2	1,124	2,947	1,122	1.10	1,122	10,189	1,145	4.2	1,122
Hawaii	12.1		16		0.97		31		1.0	
	13.1	566	33	563	0.62	562	278	566	0.6	563
Iowa	241.0		2,113		2.05		6,720		4.7	
	332.0	1,664	4,187	1,656	1.44	1,654	12,413	1,673	4.9	1,656
Idaho	113.0		612		2.08		1,566		2.6	
	146.0	1,730	1,827	1,722	1.33	1,720	4,810	1,818	3.6	1,721
Illinois	106.0		617		1.37		1,330		2.7	
	214.0	1,495	1,832	1,485	0.88	1,482	4,553	1,495	3.3	1,485
Indiana	95.0		412		1.43		947		2.3	
	126.0	1,364	1,102	1,361	0.83	1,359	3,151	1,361	2.4	1,361

Table 11.--*Statistics by state for width, area, mean velocity, discharge, and mean flow depth for water year 1990*

[continued; S.D., standard deviation; No., number of measurements; ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

STATE	WIDTH (ft)		AREA (ft^2)		VELOCITY (ft/s)		DISCHARGE (ft^3/s)		DEPTH (ft)	
	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.
Kansas	96.5		339		1.35		788		1.8	
	171.1	1,159	974	1,153	0.81	1,152	2,999	1,185	2.5	1,153
Kentucky	101.3		763		1.48		1,741		3.3	
	138.2	898	4,256	888	0.96	889	11,280	892	4.9	888
Louisiana	210.8		4,211		1.23		9,330		7.8	
	346.9	370	12,515	363	3.77	359	34,494	416	12.7	362
Massachusetts &	50.3		129		1.53		280		1.8	
Rhode Island	41.6	525	392	515	0.80	514	1,251	520	1.8	515
Maryland	54.1		115		1.24		209		1.3	
	75.6	591	375	591	0.75	591	952	591	1.3	591
Maine	205.0		892		1.72		2,060		3.1	
	183.0	206	1,482	206	1.00	206	4,923	210	2.7	206
Michigan	84.3		266		1.45		497		2.1	
	82.4	1,184	624	1,183	0.80	1,183	1,569	1,183	1.8	1,183
Minnesota	70.7		257		1.14		449		1.8	
	81.0	557	777	545	0.96	545	1,752	555	2.3	545
Missouri	384.0		5,569		2.12		21,931		5.9	
	618.2	1,179	13,106	1,171	1.34	1,169	61,658	1,183	7.0	1,171
Mississippi	167.4		1,283		1.54		3,077		4.2	
	349.5	661	3,561	657	0.95	656	9,388	662	4.7	657
Montana	90.8		322		1.91		910		1.8	
	113.6	1,716	800	1,711	1.20	1,713	2,946	1,768	1.9	1,709
North Carolina	60.4		189		1.20		319		1.9	
	61.1	1,048	374	1,045	0.84	1,045	837	1,052	2.0	1,045
North Dakota	50.7		174		0.89		182		1.2	
	115.4	617	725	606	0.57	604	1,473	845	1.7	599
Nebraska	133.8		232		1.60		636		1.3	
	313.9	1,596	653	1,588	0.85	1,586	2,969	1,595	1.6	1,587
New Jersey	64.1		217		1.13		292		1.8	
	107.0	640	677	627	0.70	627	1,133	630	1.7	627

Table 11.--*Statistics by state for width, area, mean velocity, discharge, and mean flow depth for water year 1990*

[continued; S.D., standard deviation; No., number of measurements; ft, feet; ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

STATE	WIDTH (ft)		AREA (ft^2)		VELOCITY (ft/s)		DISCHARGE (ft^3/s)		DEPTH (ft)	
	Mean		Mean		Mean		Mean		Mean	
	S.D.	No.	S.D.	No.	S.D.	No.	S.D.	No.	S.D.	No.
New Mexico	50.5		77		1.54		193		1.1	
	58.0	1,318	121	1,303	0.91	1,303	588	1,366	0.9	1,302
Nevada	27.7		42		1.29		100		1.0	
	32.0	964	75	959	1.01	956	360	977	1.0	958
New York	98.8		291		1.55		738		1.8	
	117.3	1,499	812	1,486	1.04	1,486	2,976	1,487	1.7	1,486
Ohio	110.0		420		1.72		1,087		2.4	
	108.0	827	870	827	1.05	827	3,079	827	2.4	827
Oklahoma	169.0		1,083		1.69		4,830		3.2	
	337.0	1,030	3,230	984	1.29	978	19,257	1,070	4.4	981
Oregon	98.5		439		1.83		1,049		2.6	
	101.0	888	1,641	885	1.29	885	3,868	912	3.0	912
Pennsylvania	135.0		554		1.43		1,071		1.9	
	208.0	1,918	2,040	1,890	0.80	1,889	4,179	1,895	2.2	1,890
Puerto Rico	37.3		38		0.89		48		0.8	
	27.9	704	63	703	0.64	704	137	722	0.8	703
South Carolina	151.0		1,017		1.20		1,814		3.0	
	413.0	614	3,729	608	0.74	609	6,788	619	3.6	608
South Dakota	39.0		137		1.12		227		0.9	
	91.0	1,168	1,019	1,159	0.66	1,157	2,112	1,417	1.3	1,159
Tennessee	121.0		751		1.55		1,902		2.9	
	205.0	642	2,747	637	1.04	638	10,804	676	4.0	637
Texas	144.8		1,057		1.39		3,149		2.8	
	428.0	2,112	3,648	2,103	1.06	2,099	13,188	2,106	4.3	2,099
Utah	43.2		82		1.43		152		1.1	
	57.2	1,573	206	1,555	1.05	1,556	456	1,651	1.0	1,555
Virginia	144.0		575		1.44		1,079		2.8	
	149.0	612	927	612	0.86	612	2,378	615	2.6	612
Vermont &	88.9		337		1.72		893		2.4	
New Hampshire	85.4	380	789	372	1.16	372	2,879	374	2.7	372

Table 11.--*Statistics by state for width, area, mean velocity, discharge, and mean flow depth for water year 1990*

[continued; S.D., standard deviation; No., number of measurements; ft, feet: ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second]

STATE	WIDTH (ft)		AREA (ft^2)		VELOCITY (ft/s)		DISCHARGE (ft^3/s)		DEPTH (ft)	
	Mean		Mean		Mean		Mean		Mean	
	S.D.	No.	S.D.	No.	S.D.	No.	S.D.	No.	S.D.	No.
Washington	107.3		1,055		2.24		4,535		3.1	
	155.0	1,479	4,831	1,465	1.61	1,457	21,980	1,508	5.2	1,463
Wisconsin	109.9		460		1.45		1,014		2.2	
	147.2	878	1,170	876	0.91	876	3,649	877	2.5	876
West Virginia	154.4		938		1.62		2,101		3.3	
	162.3	421	2,198	419	1.01	419	7,309	419	3.5	418
Wyoming	65.1		118		1.65		379		1.2	
	73.6	1,243	217	1,240	1.11	1,239	803	1,430	1.1	1,239

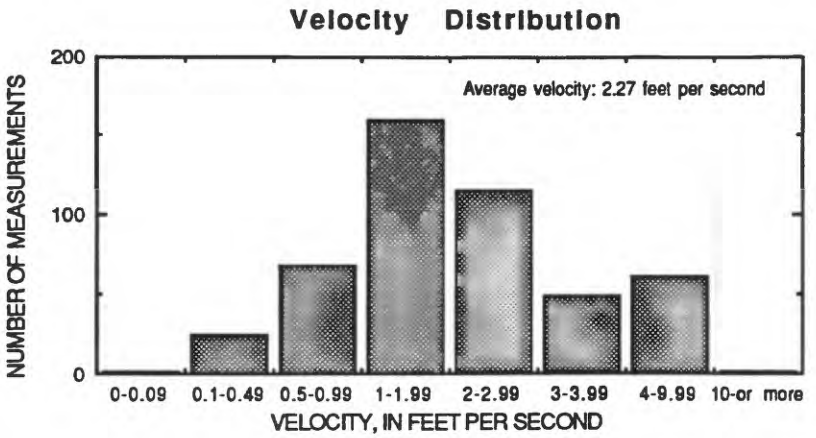
Mean velocities in all Districts ranged from 0.74 ft/s to 2.27 ft/s. The lowest mean velocity was in Florida. The three next lowest mean velocities were in North Dakota, Puerto Rico, and Hawaii. The highest mean velocity was in Alaska. The next three highest mean velocities were in Washington, Missouri, and Idaho. The median mean velocity for the Districts was 1.45 ft/s.

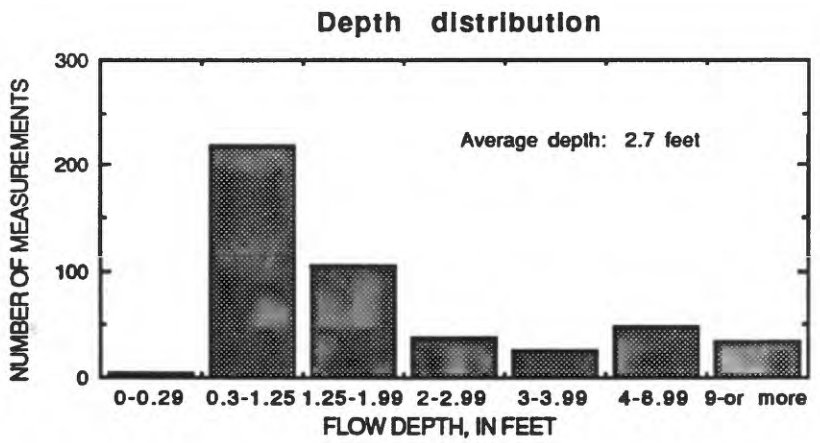
Mean discharges by state ranged from a low of 30.9 ft^3/s to a high of 21,931 ft^3/s. The highest mean discharge was in Missouri and the next three highest discharges were in Arkansas, Louisiana, and Alaska. The median mean discharge was 1,014 ft^3/s.

Mean district measurement depths ranged from 0.8 ft to 7.8 ft. The shallowest mean depth was computed for Puerto Rico and the deepest for Louisiana. The median depth was 2.2 ft for the Districts (or states).

Frequency Analysis of Velocity, Depth, Rating Type and Measurement type

Distributions for mean velocities and mean depths and percentages of measurements grouped by measurement rating and by measurement type were computed for each state or pair of states. Data for each state(s) are shown in two bar charts and one or two pie charts. The bar charts show the velocity and depth frequency distributions. One pie chart shows the proportion of discharge measurements rated excellent, good, fair, or poor. The other pie chart depicts the proportion of discharge measurements made using the various measurement types: wading, bridge, cableway, boat, or ice. This last pie chart is not available for states in districts that had photocopied data (Alaska, Maine, Ohio, and Virginia). Figures 9 through 57 are the District figures arranged alphabetically by state.





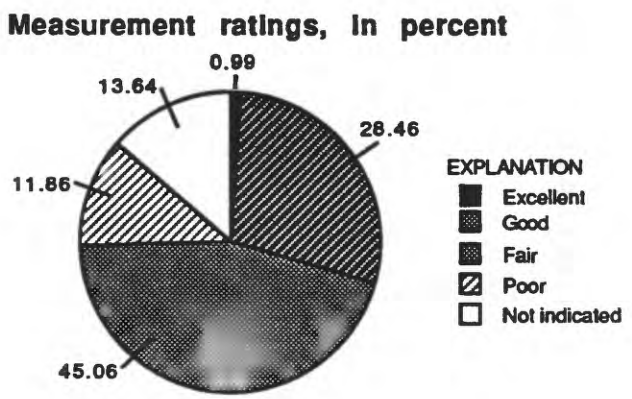
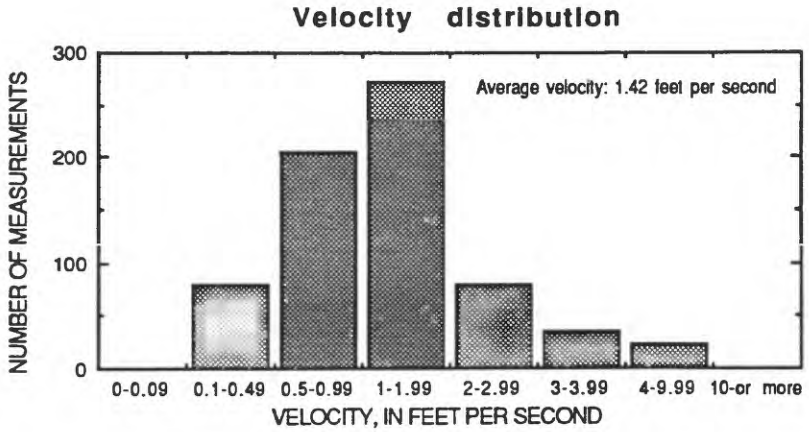
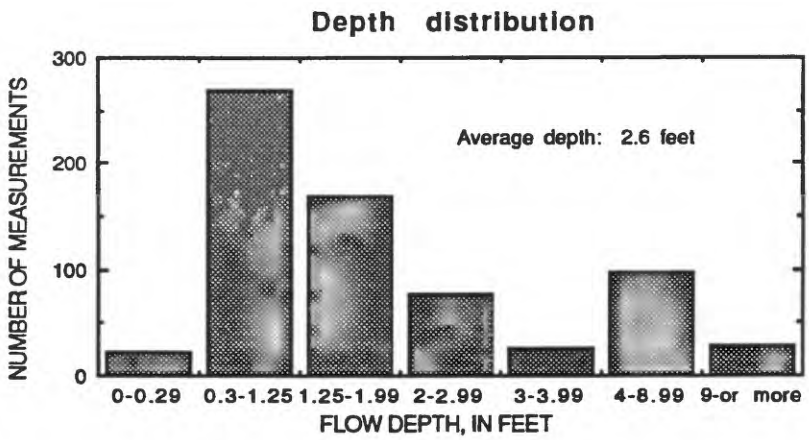


Figure 9.--Alaska's velocity and depth frequency distributions and percentage of measurements by measurement rating for water year 1990.





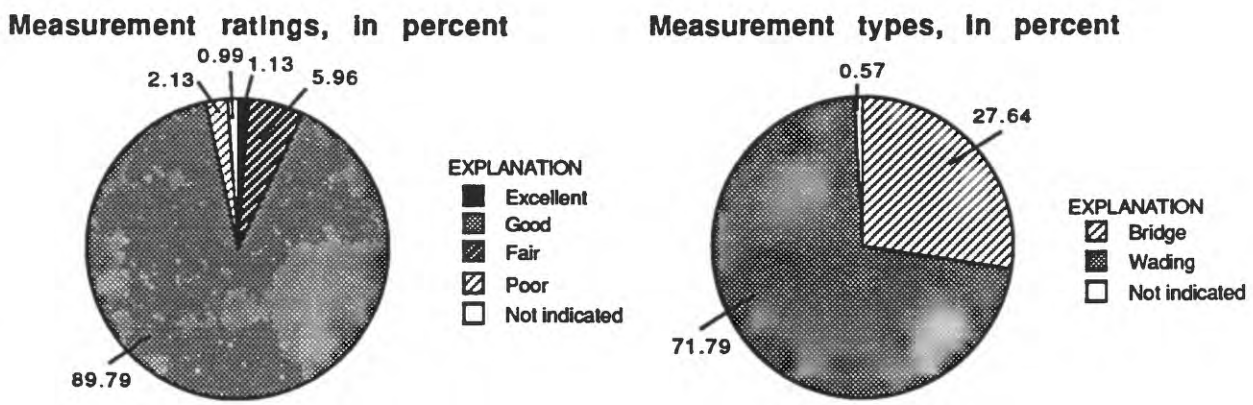
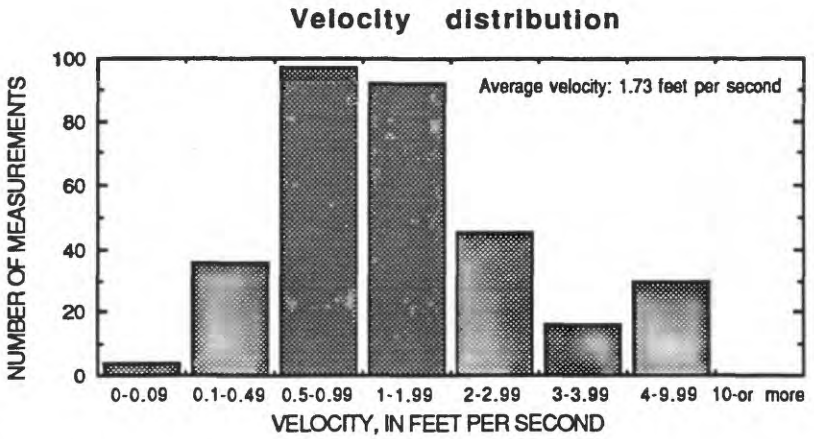
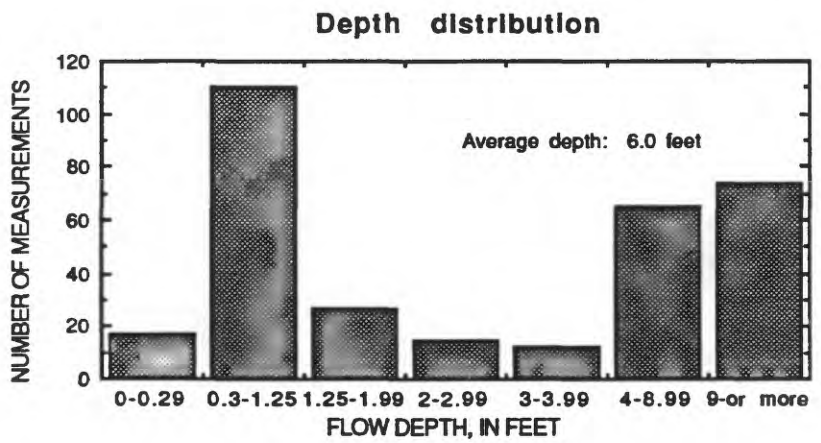


Figure 10.--Alabama's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





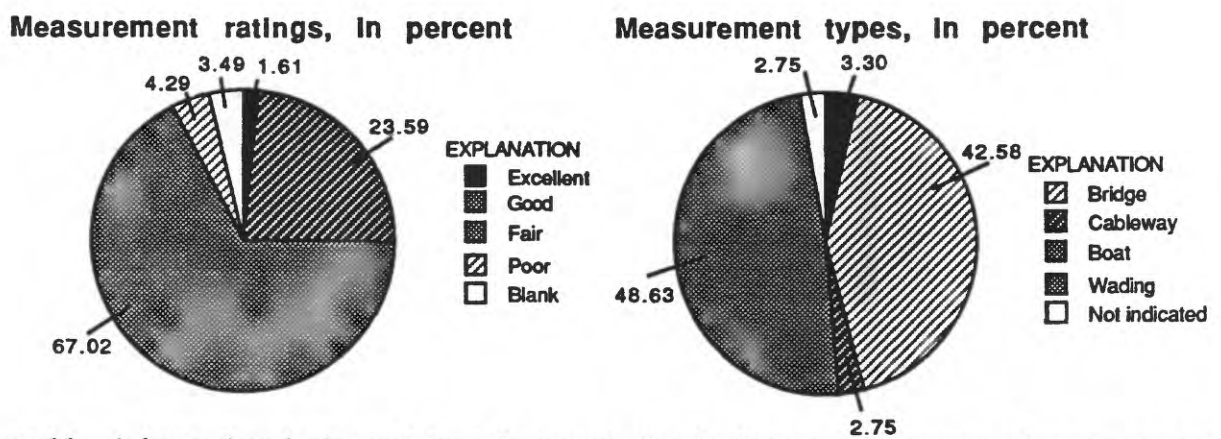
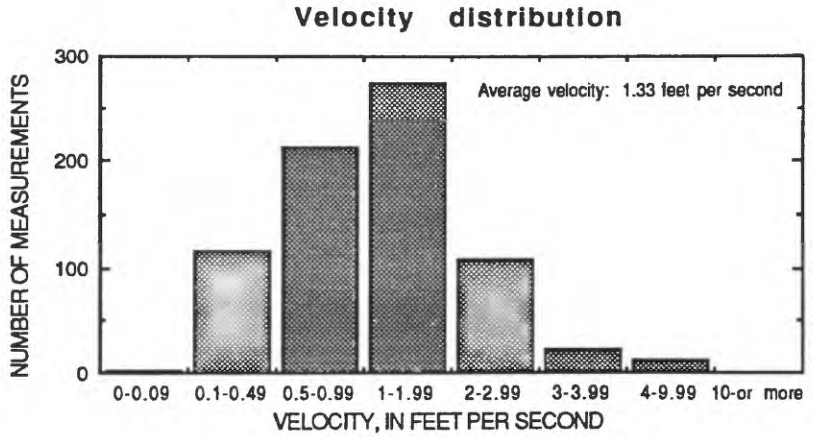
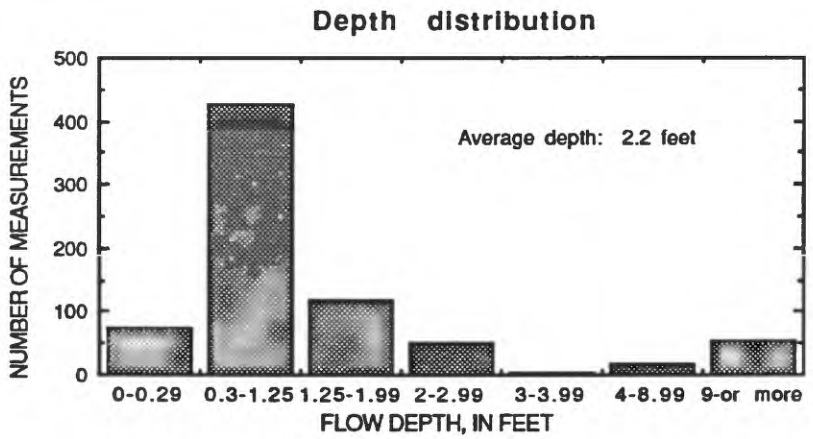
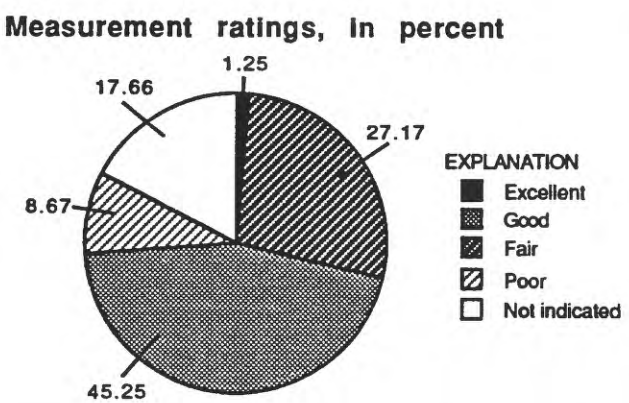


Figure 11.--Arkansas's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







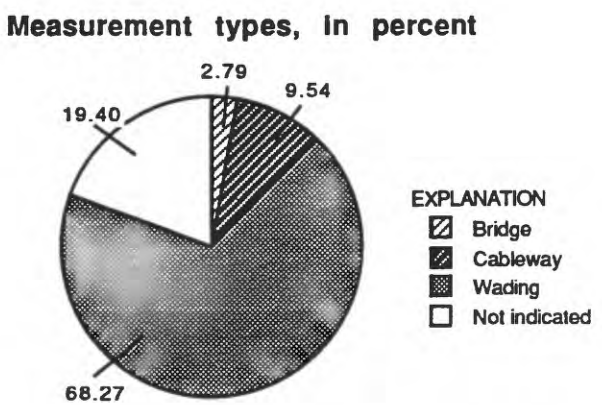
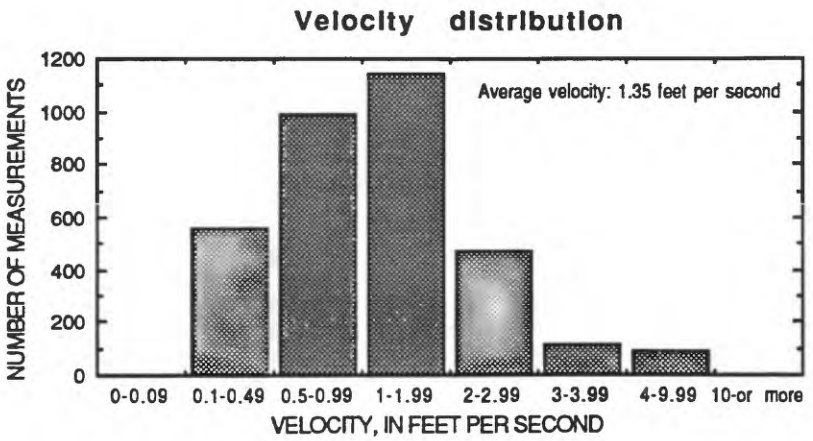
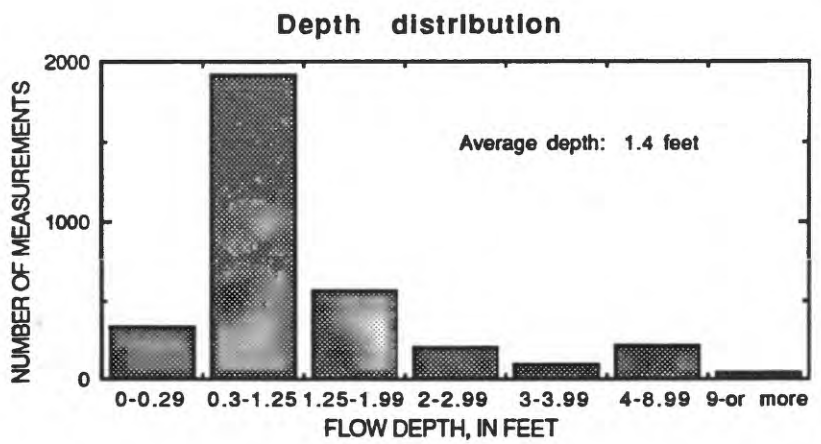


Figure 12.--Arizona's velocity and depth distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





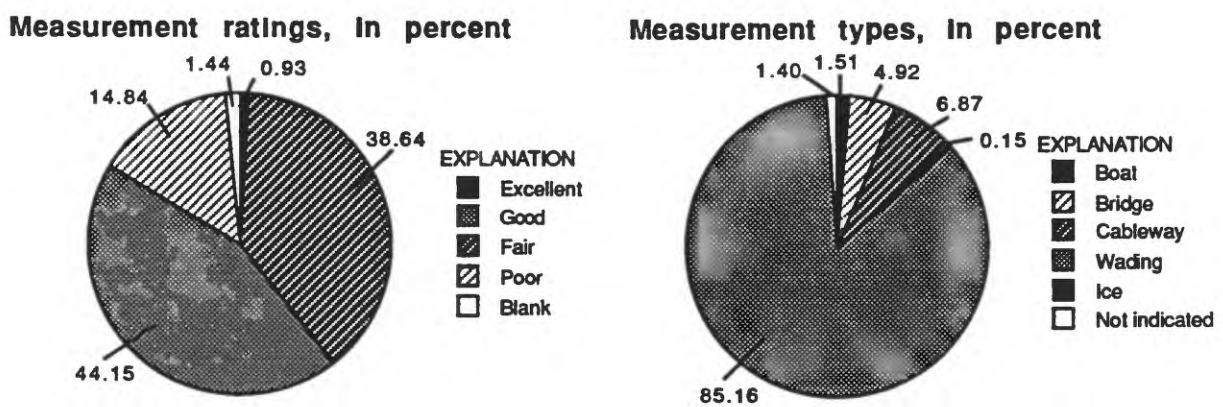
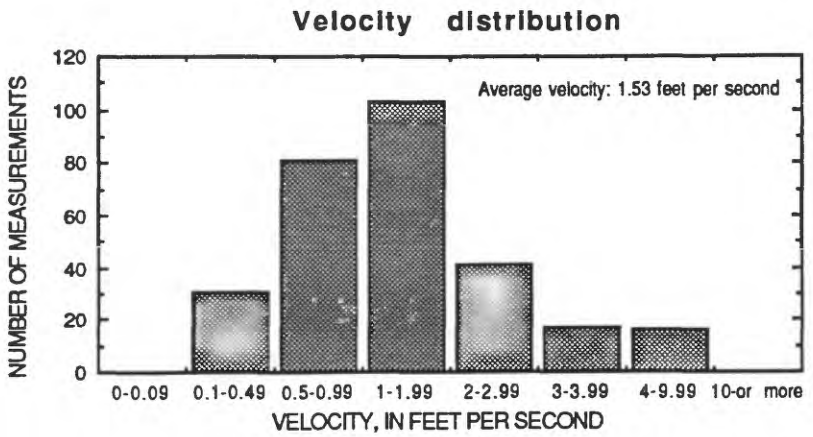
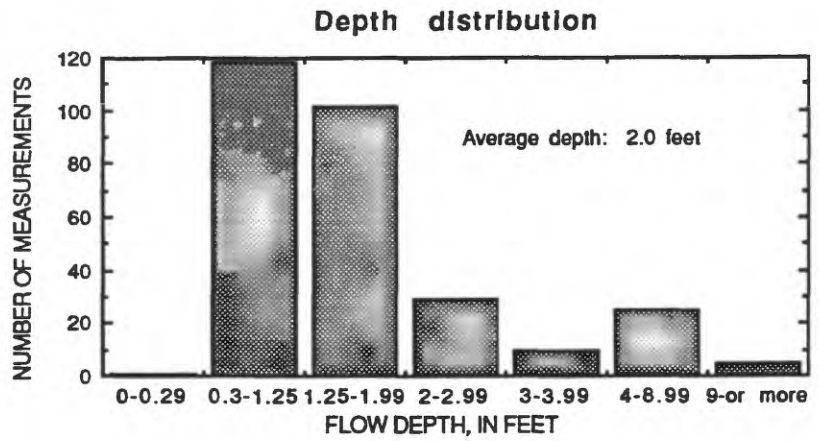


Figure 13.--California's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





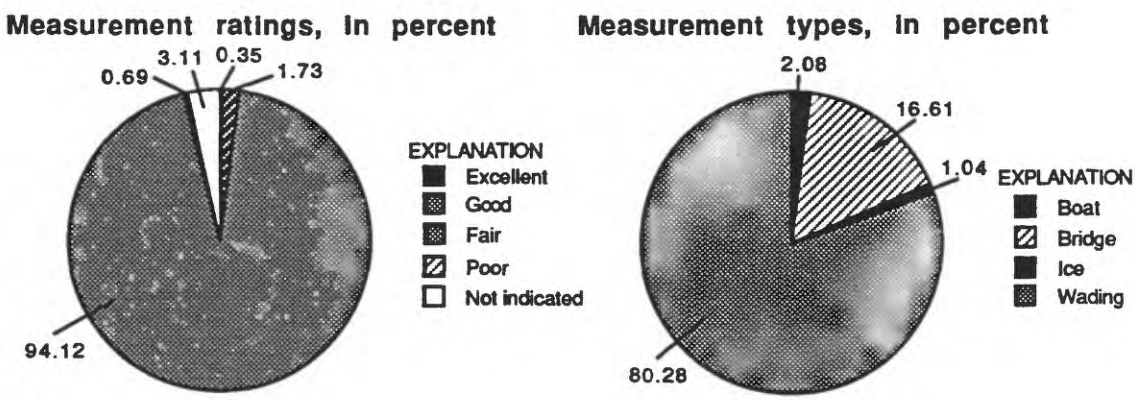
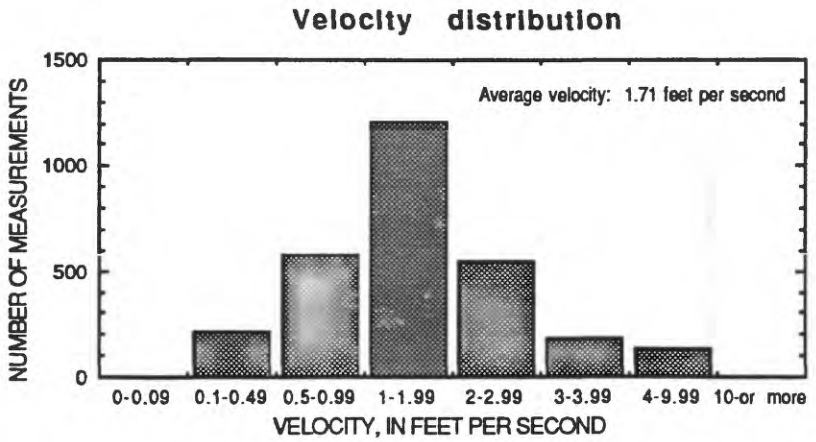
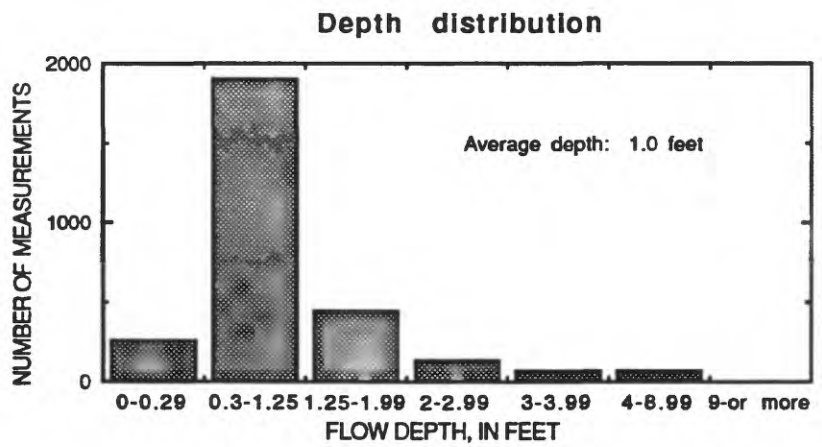


Figure 14.--Connecticut's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





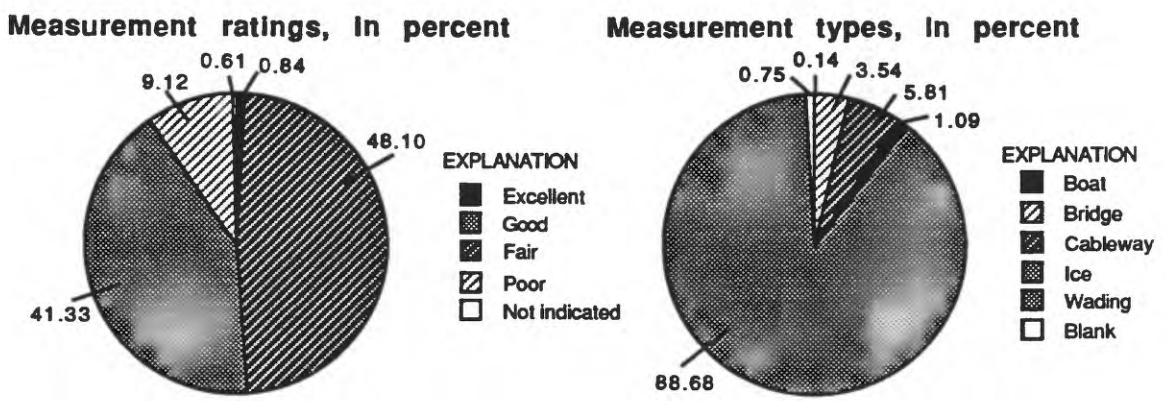
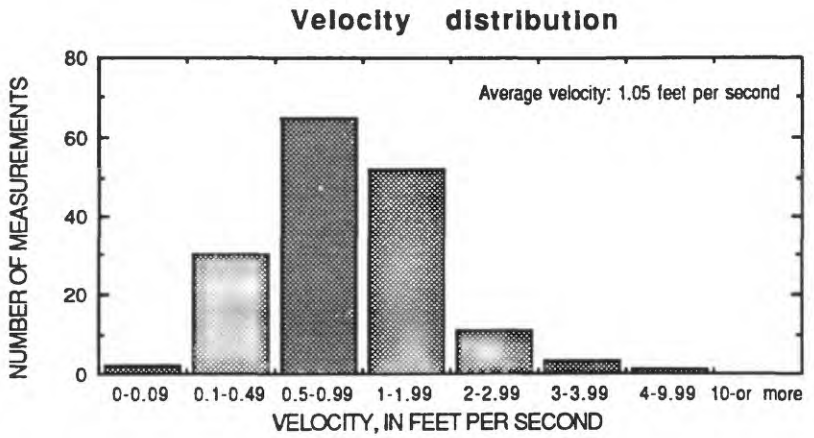
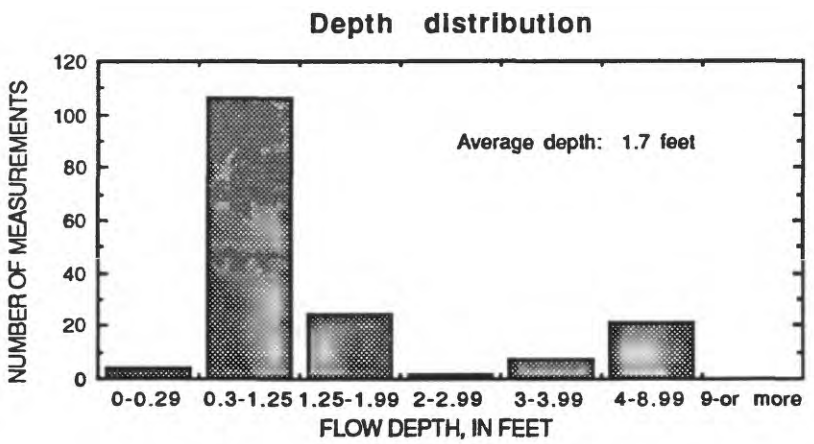
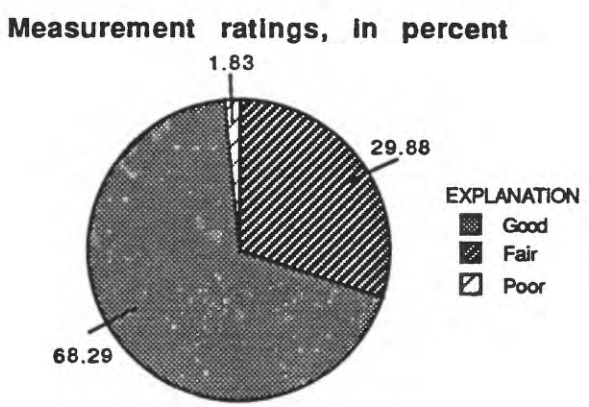


Figure 15.--Colorado's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







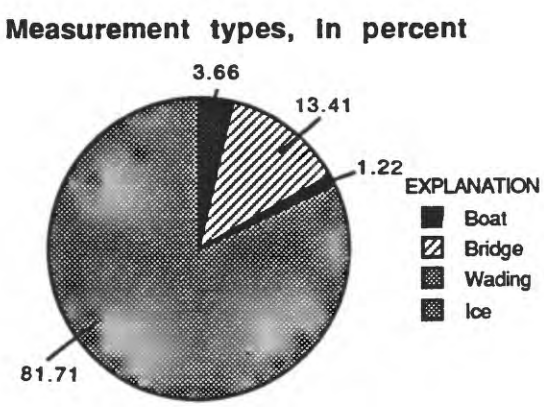
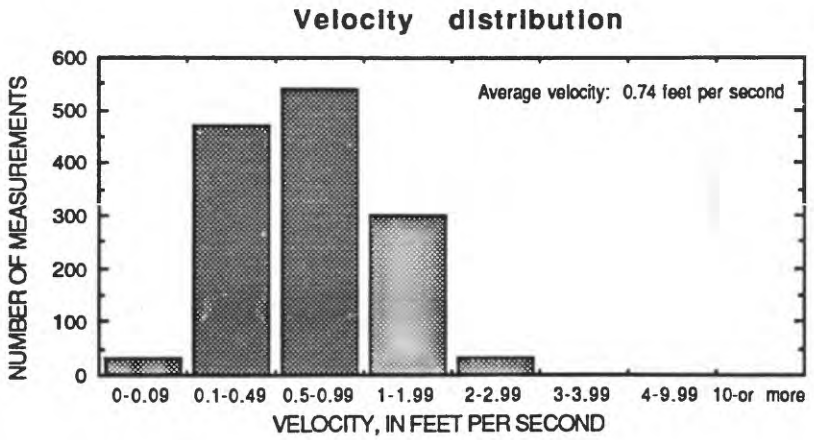
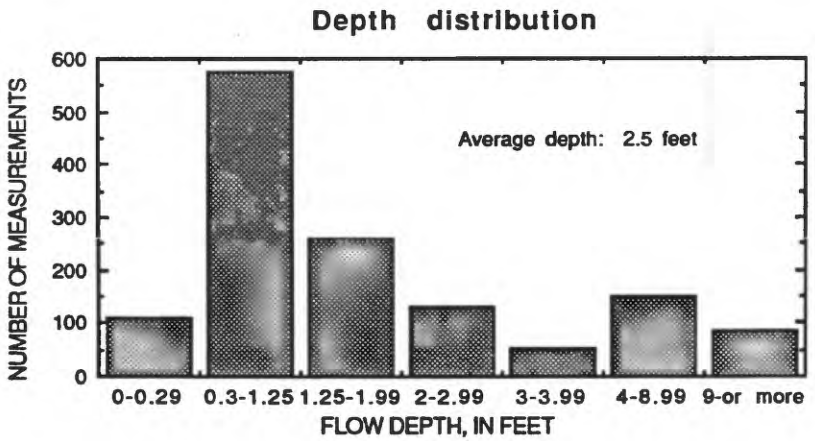


Figure 16.--Delaware's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





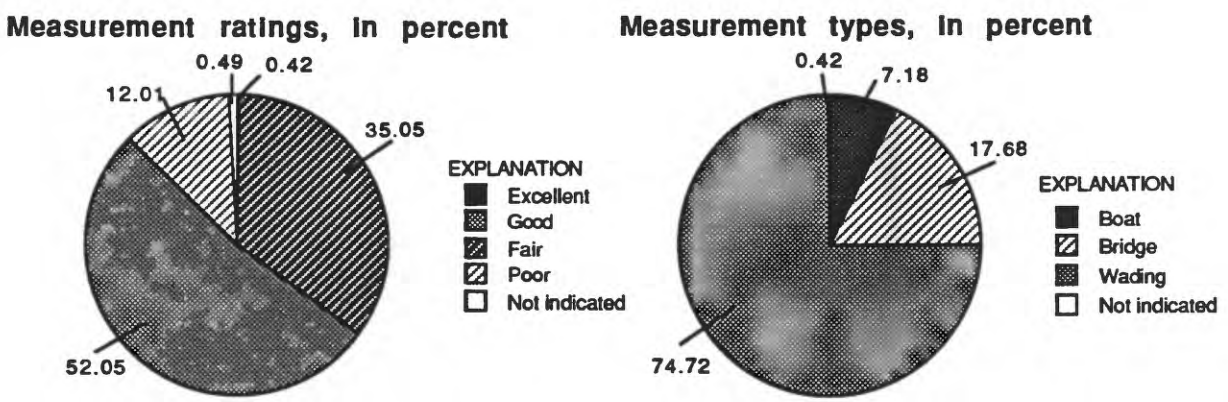
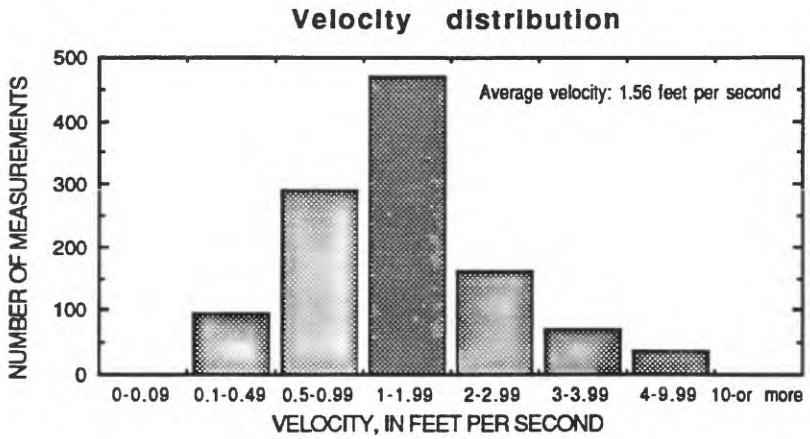
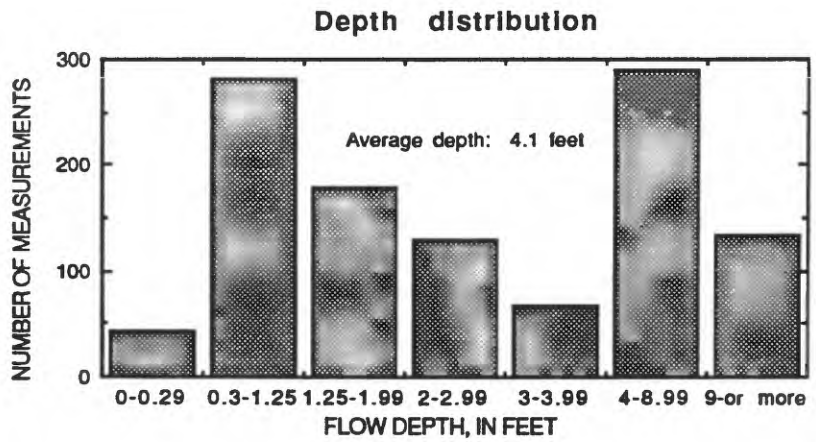


Figure 17.--Florida's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





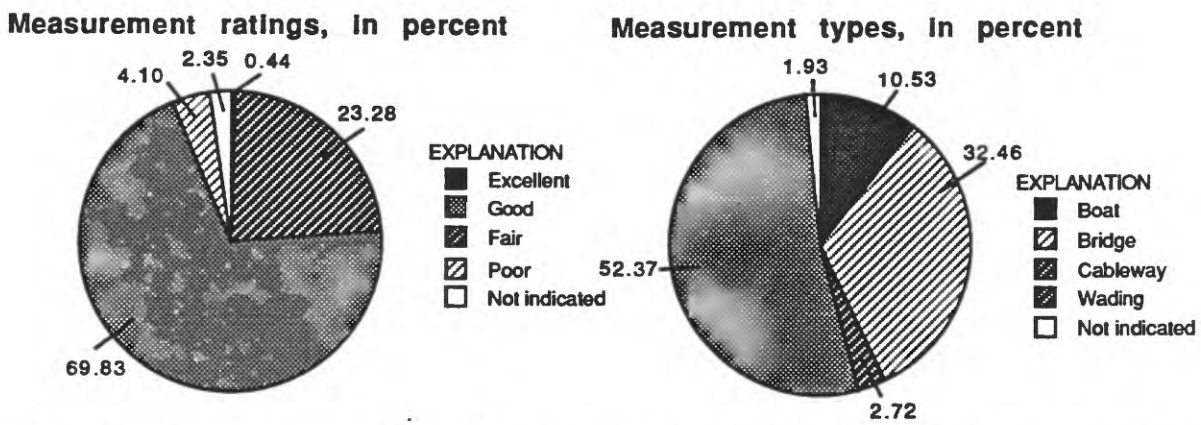
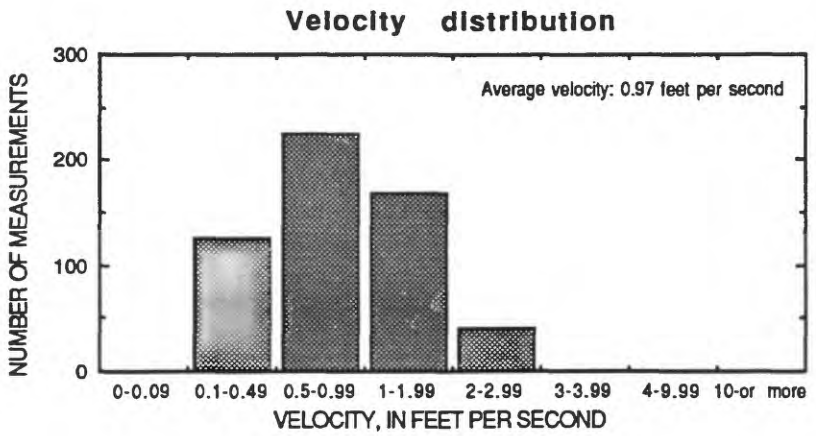
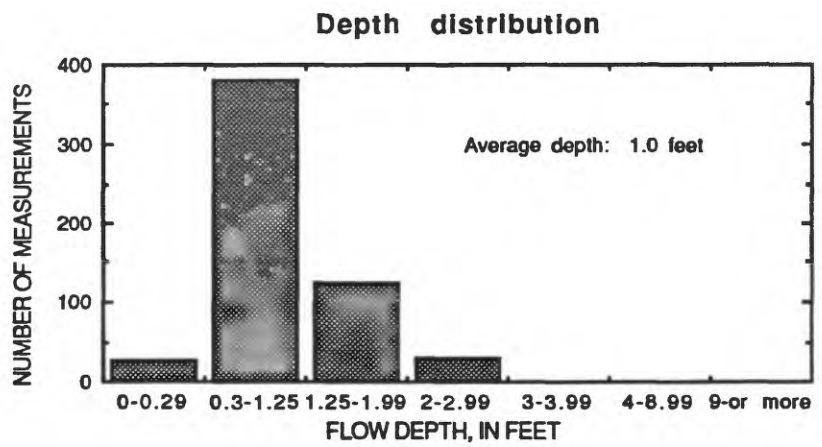


Figure 18.--Georgia's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





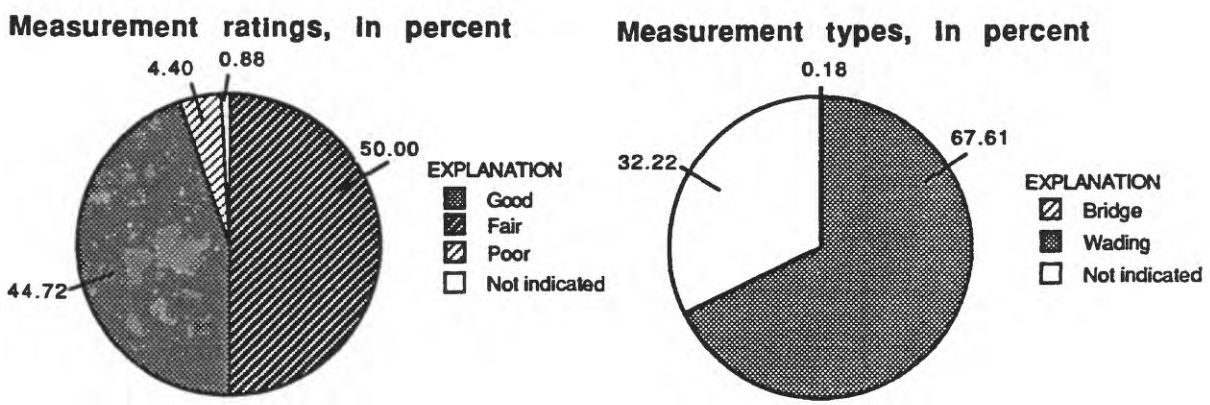
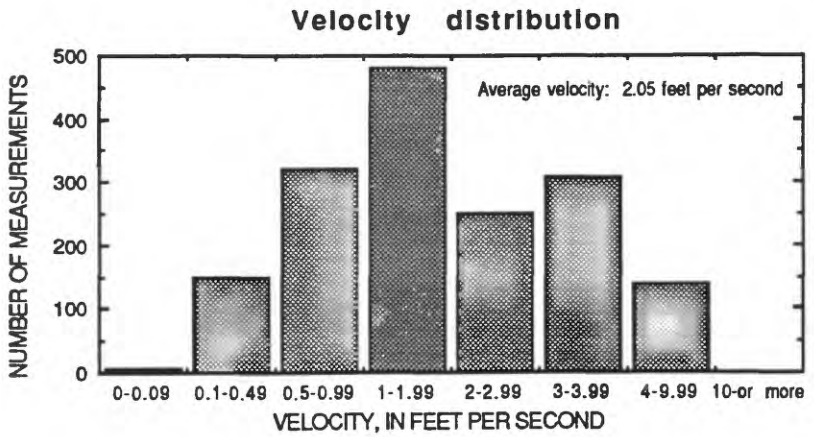
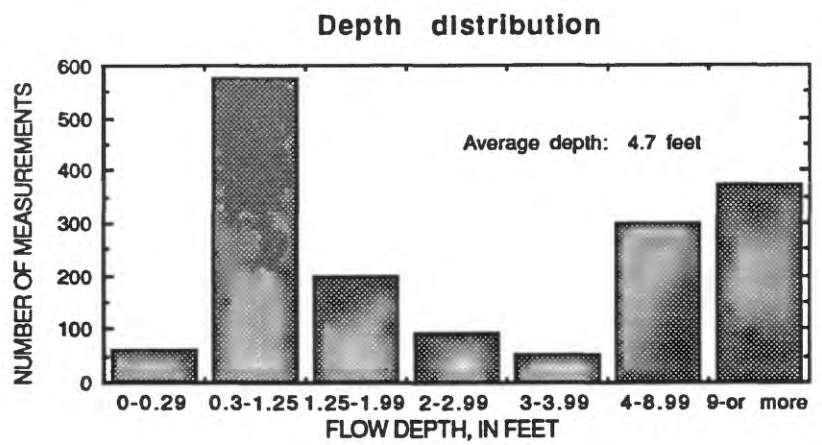


Figure 19.--Hawaii's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





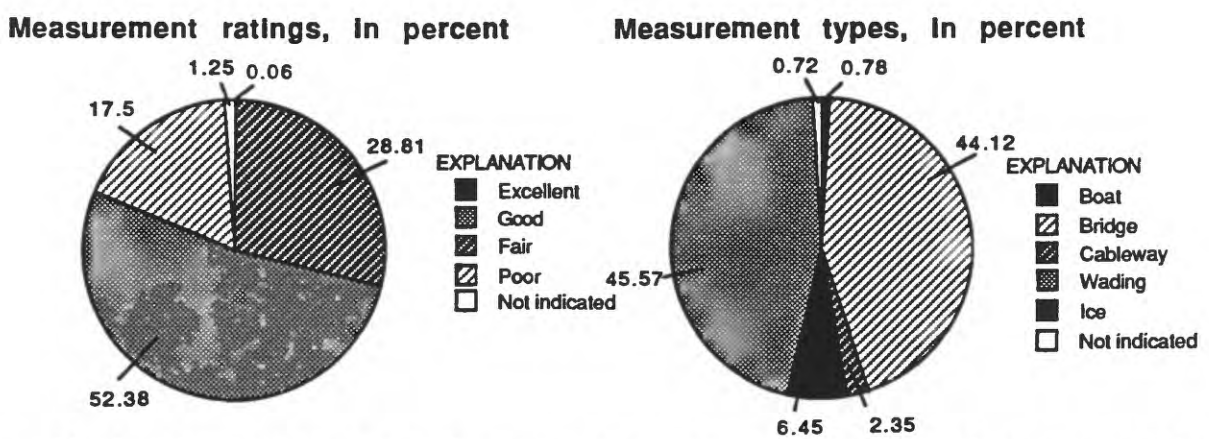
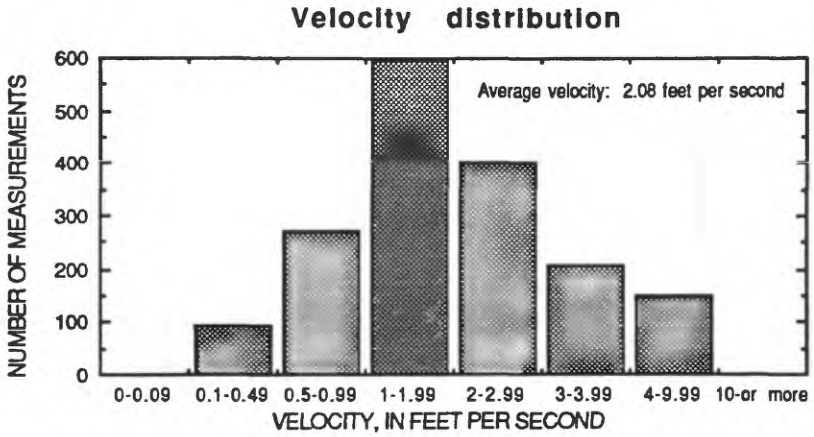
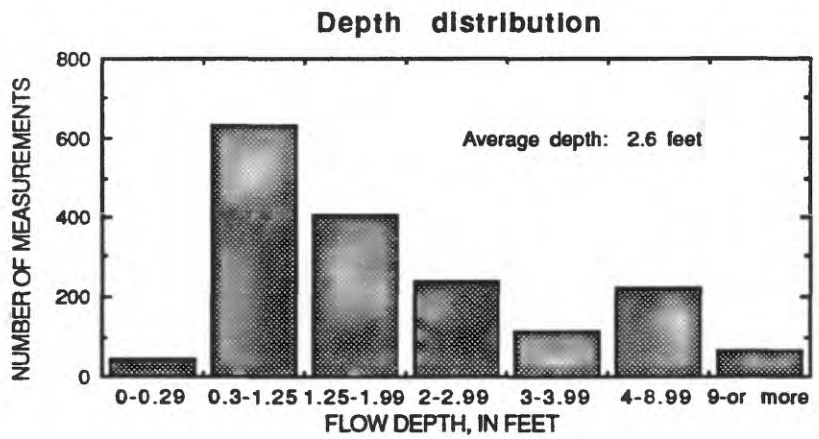


Figure 20.--Iowa's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





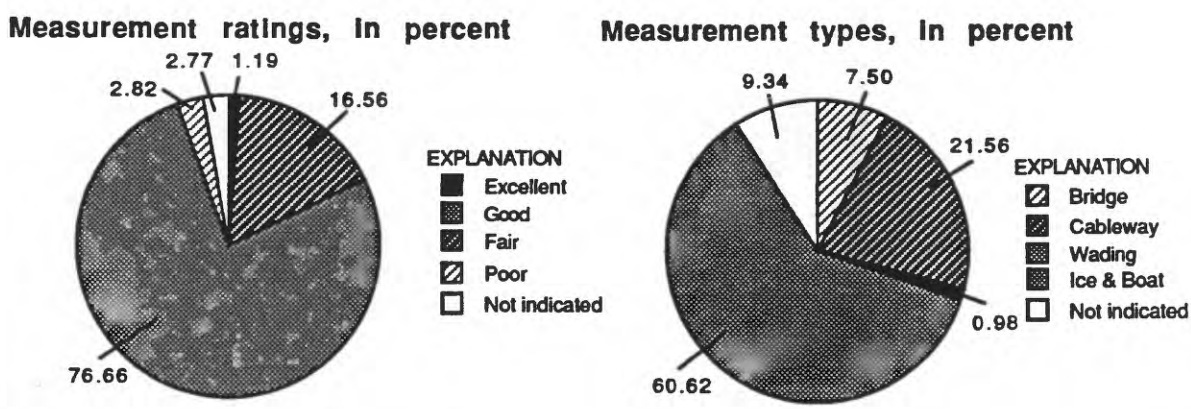
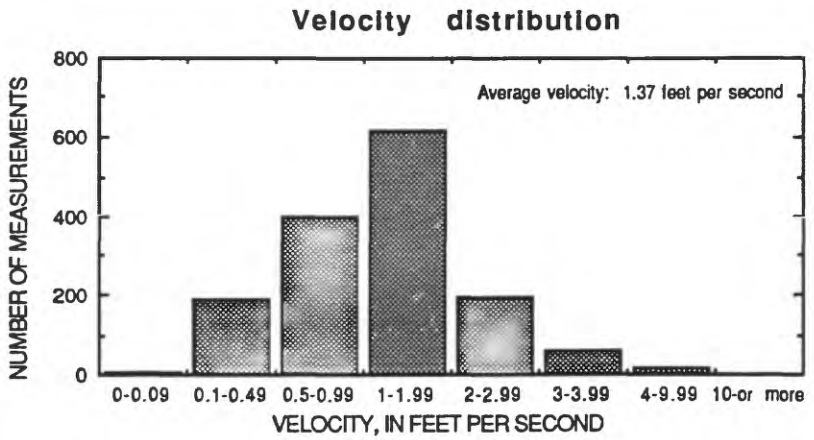
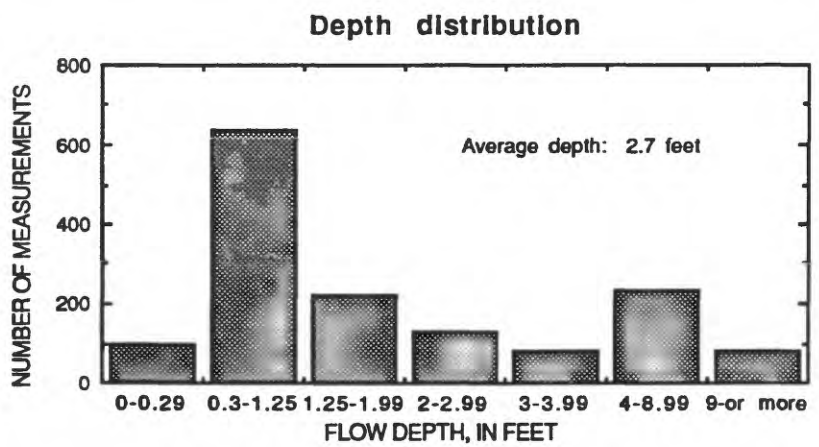


Figure 21.--Idaho's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





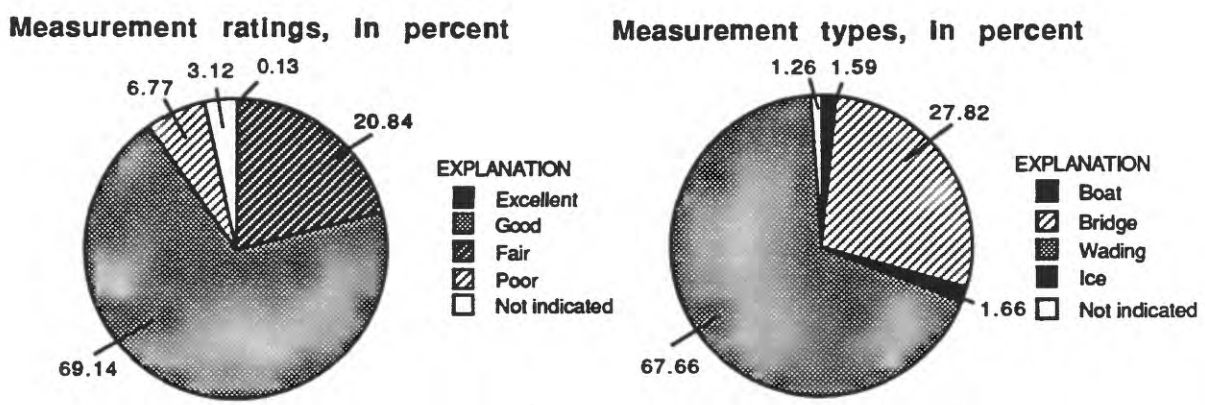
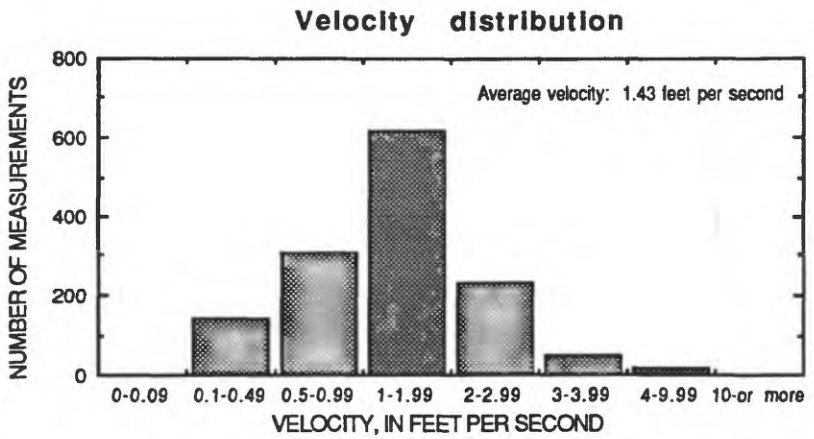
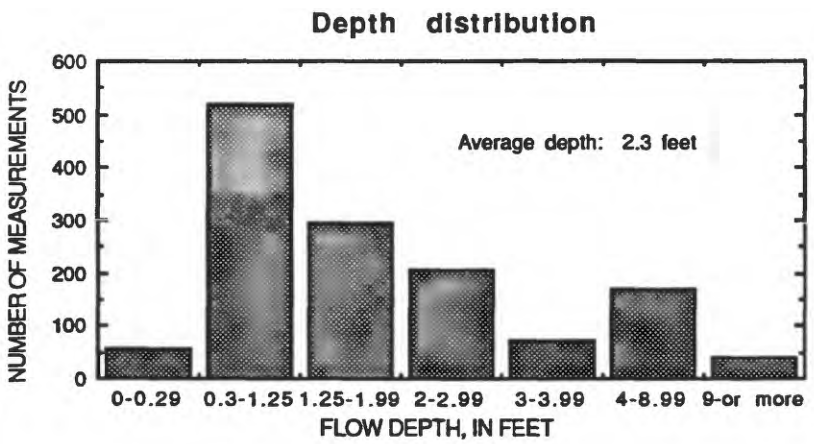
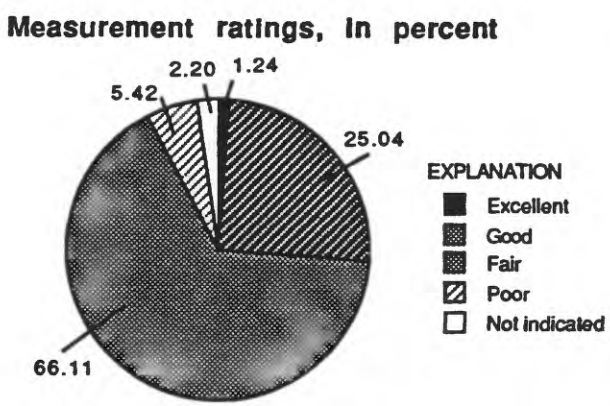


Figure 22.--Illinois's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







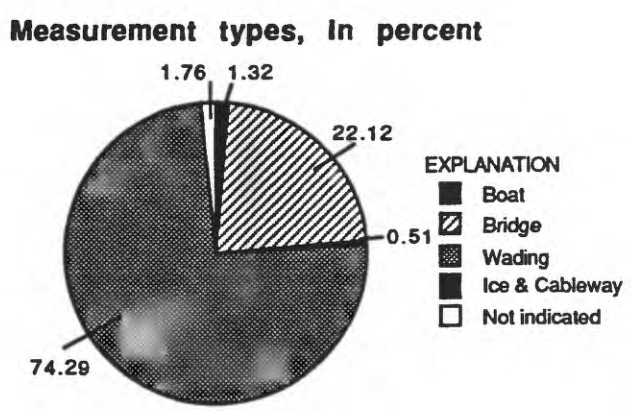
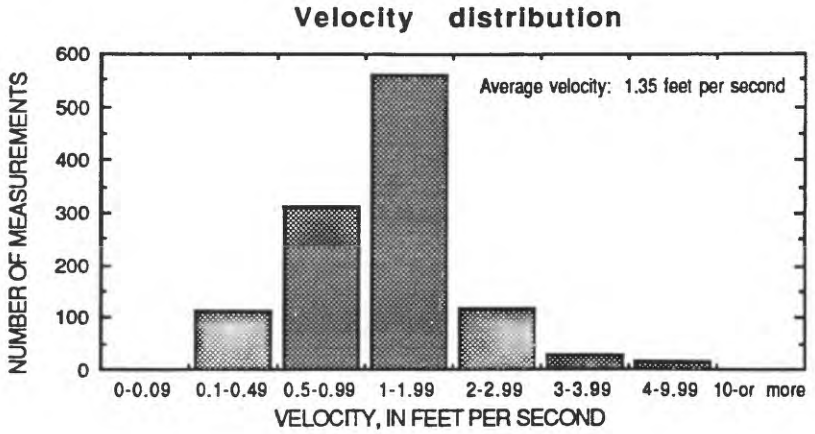
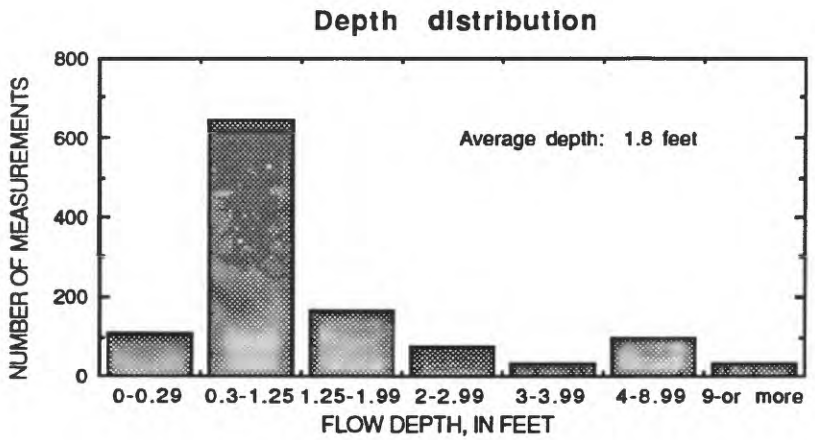
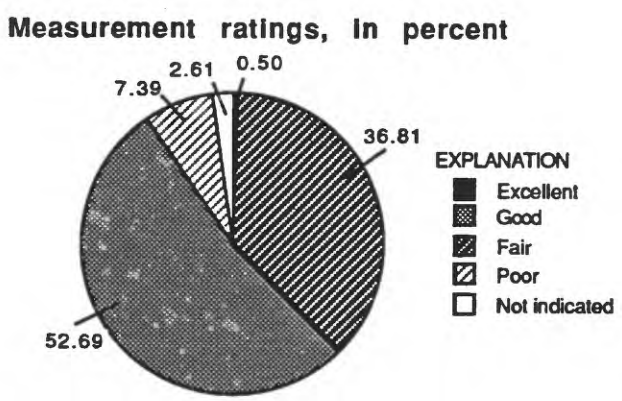


Figure 23.--Indiana's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







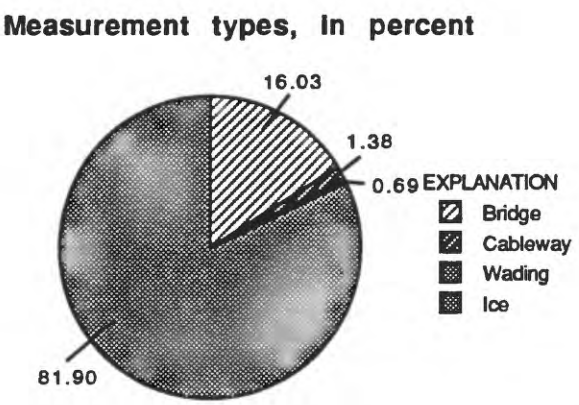
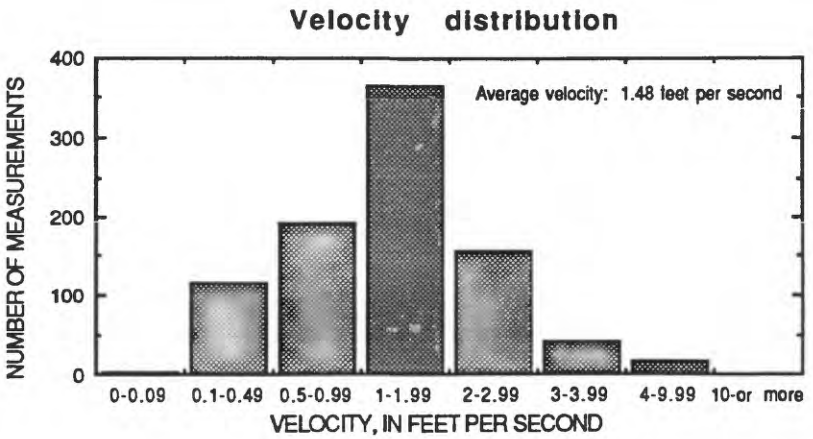
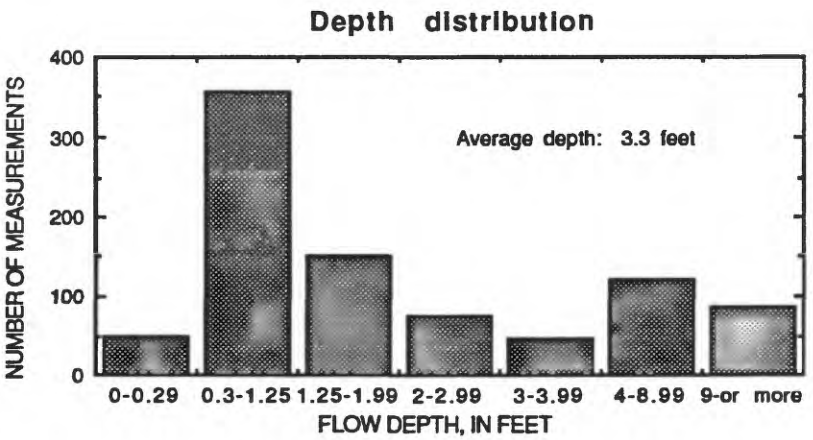
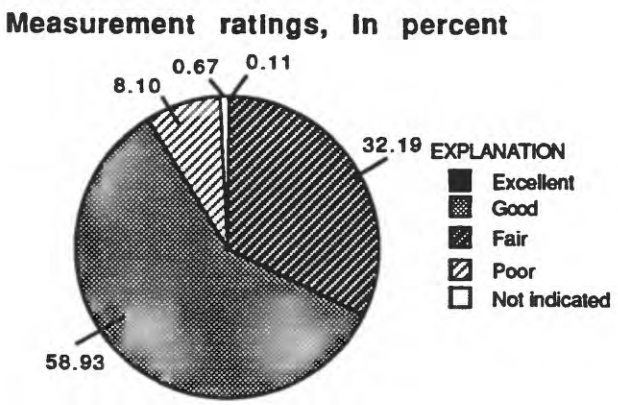


Figure 24.--Kansas's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







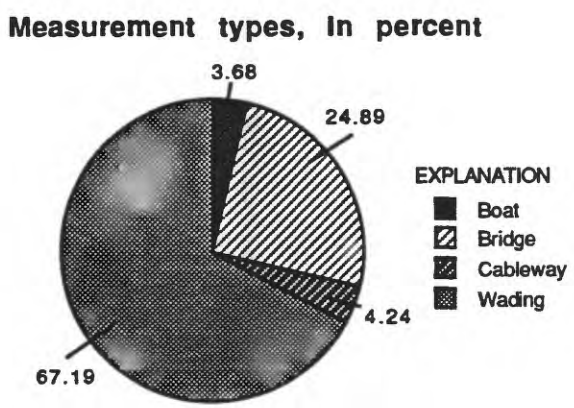
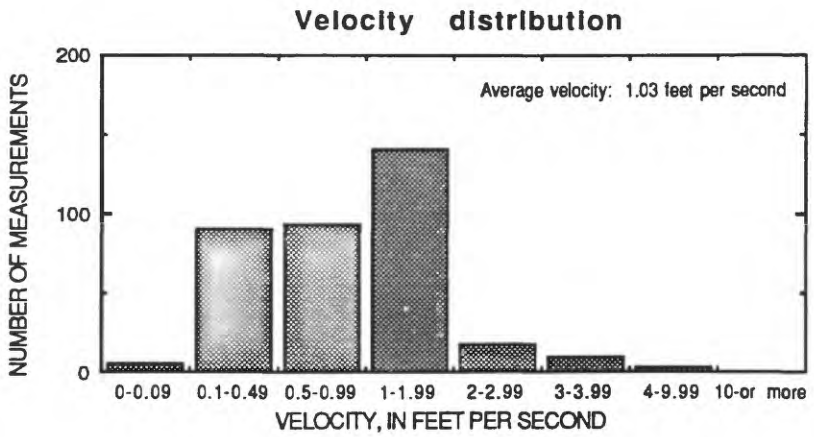
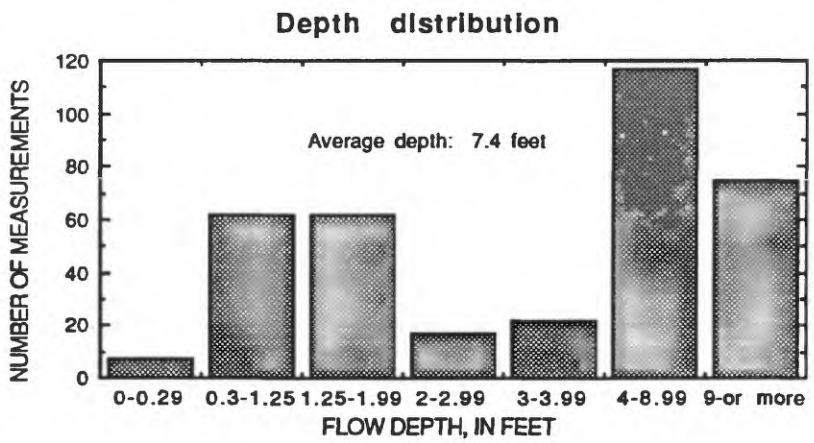
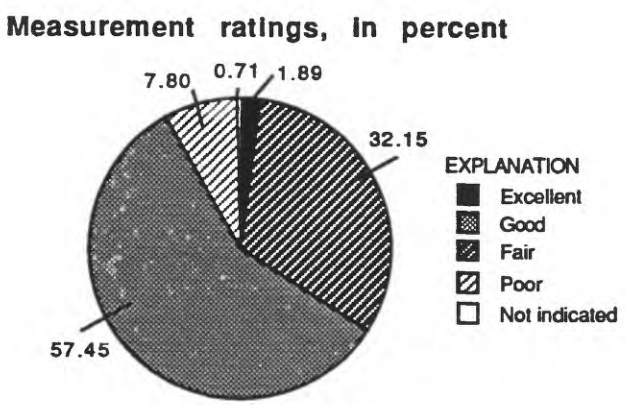


Figure 25.--Kentucky's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







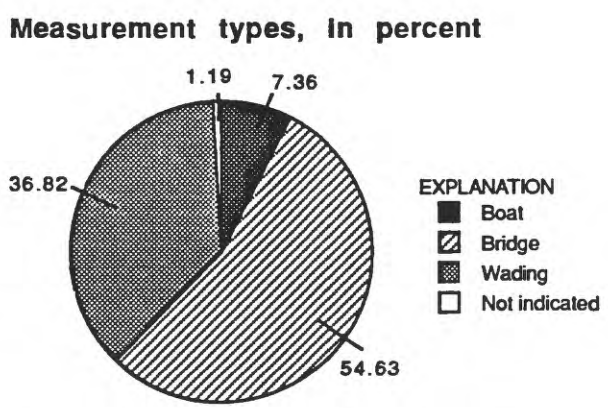
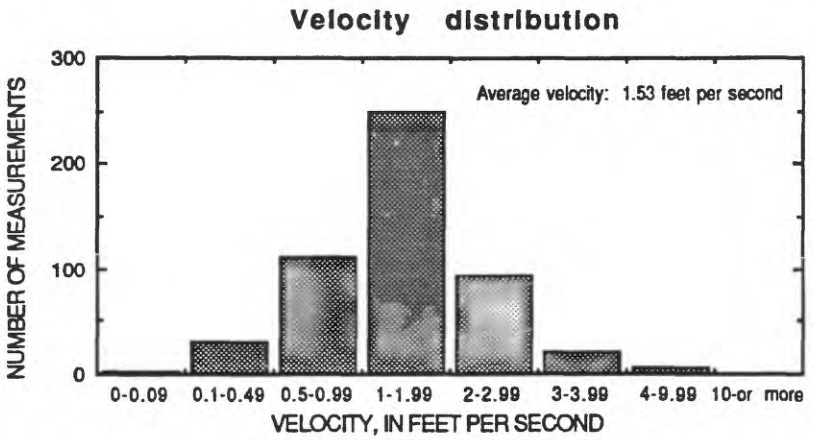
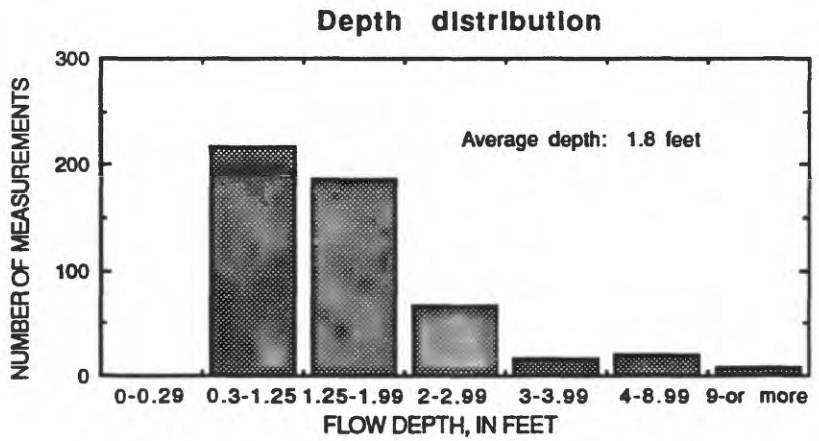


Figure 26.--Louisiana's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





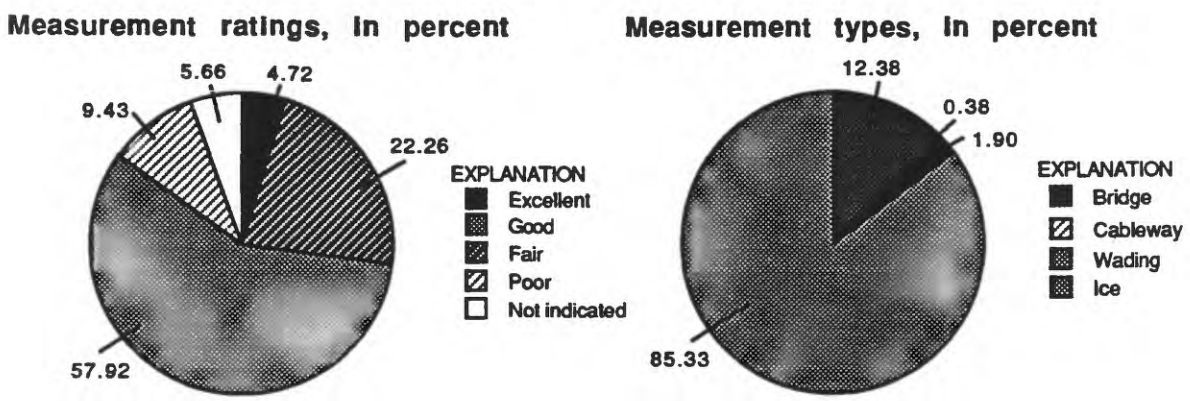
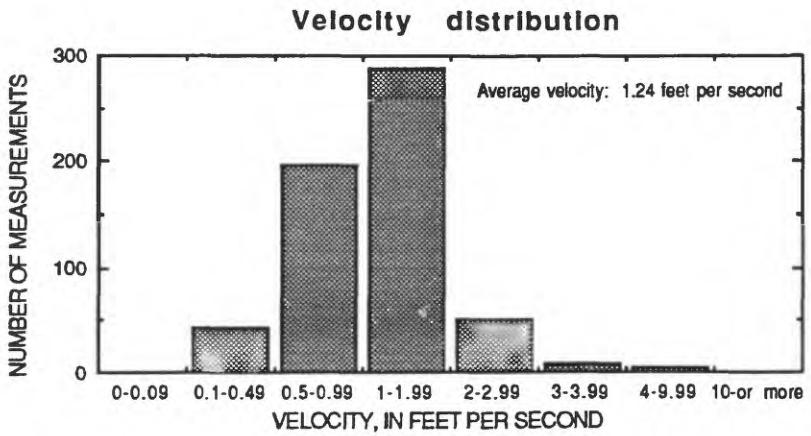
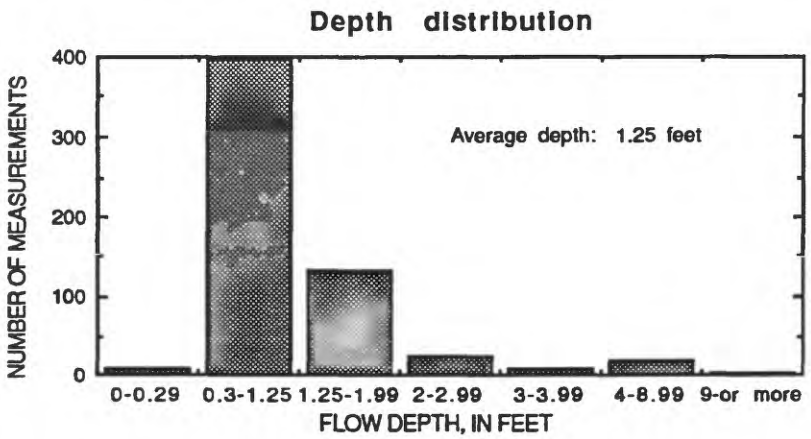
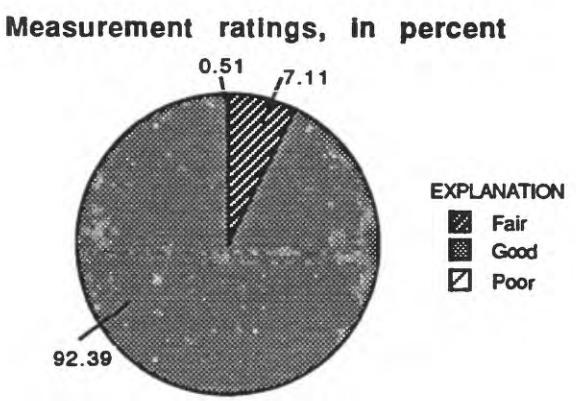


Figure 27.--Massachusetts's and Rhode Island's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







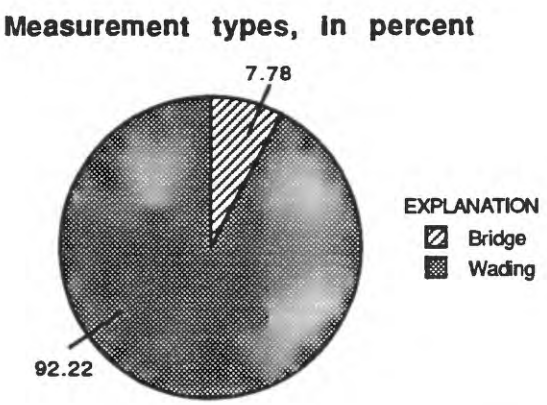
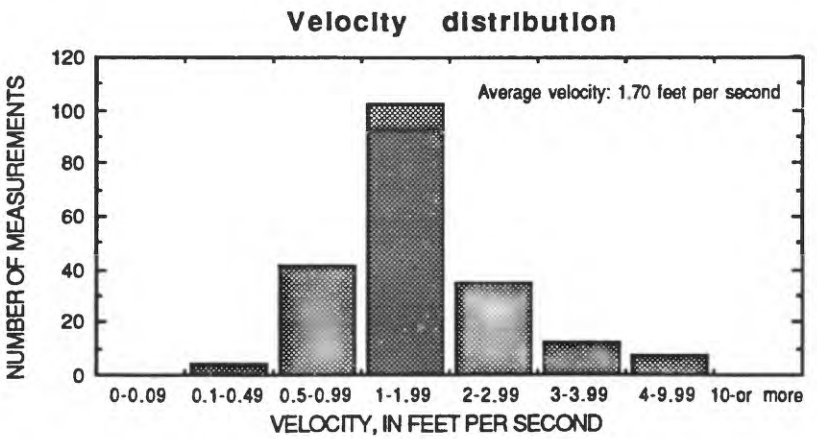
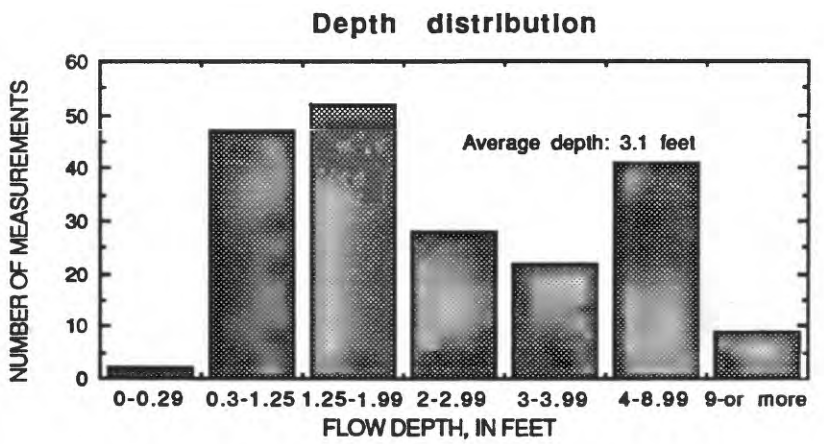


Figure 28.--Maryland's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





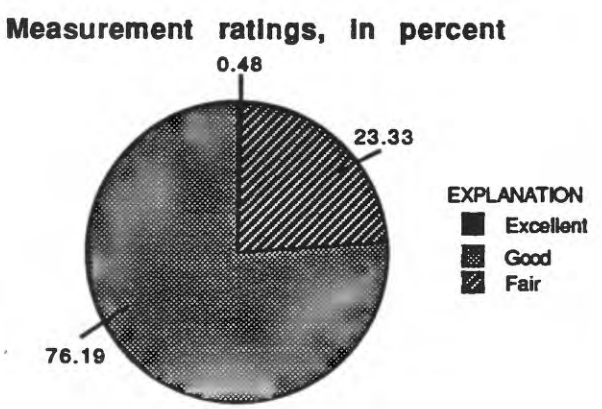
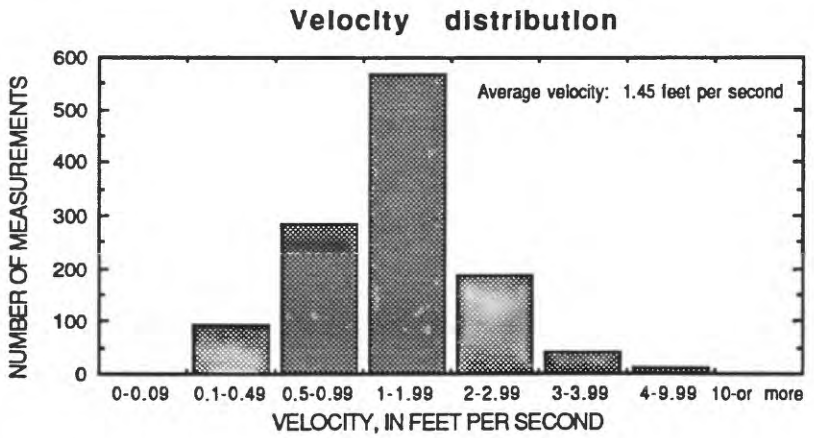
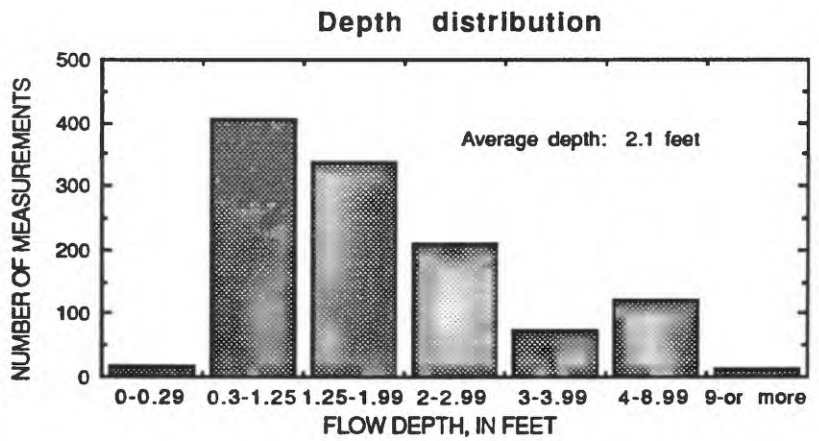


Figure 29.--Maine's velocity and depth frequency distributions and percentage of measurements by measurement rating for water year 1990.





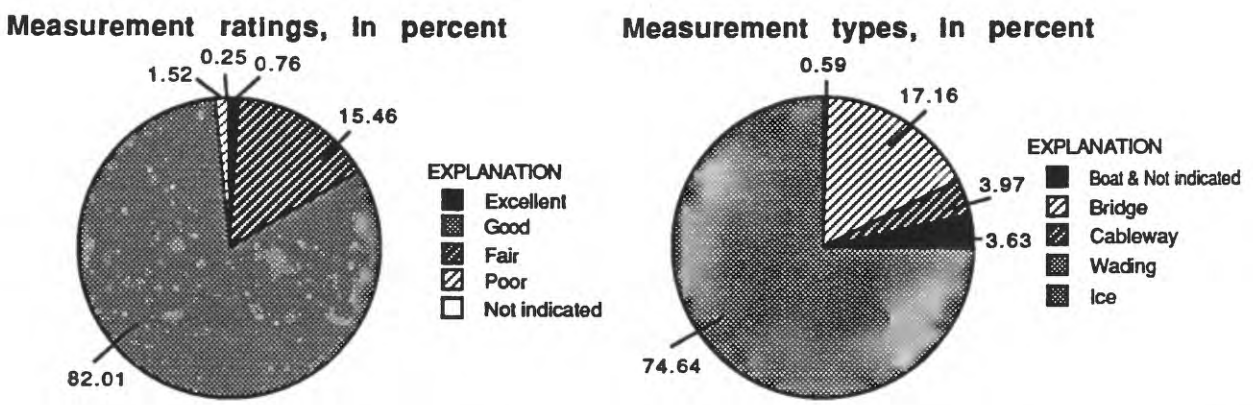
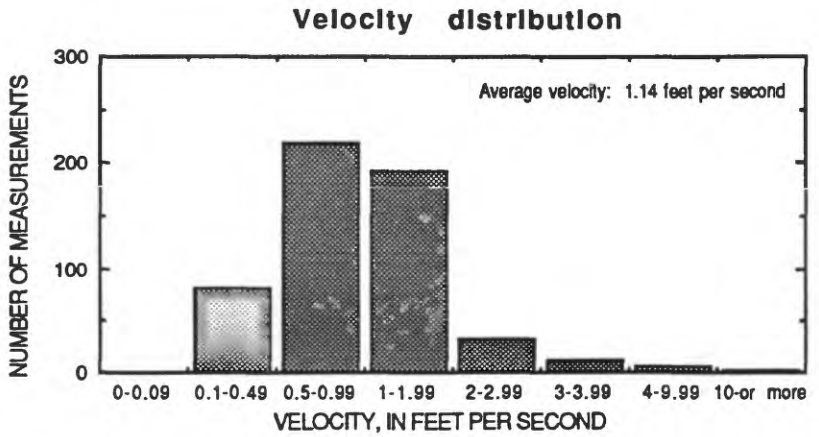
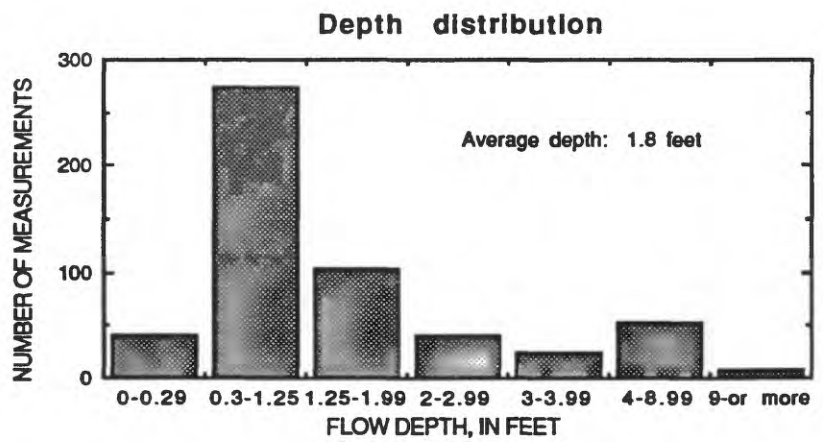


Figure 30.--Michigan's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





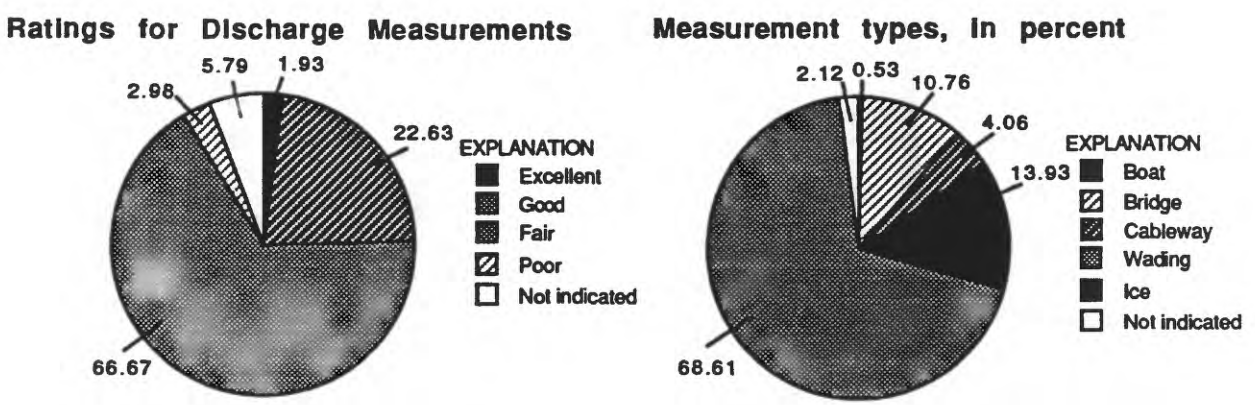
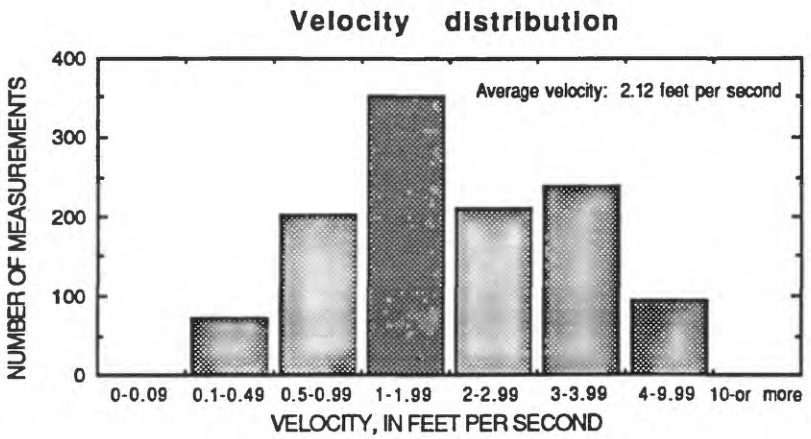
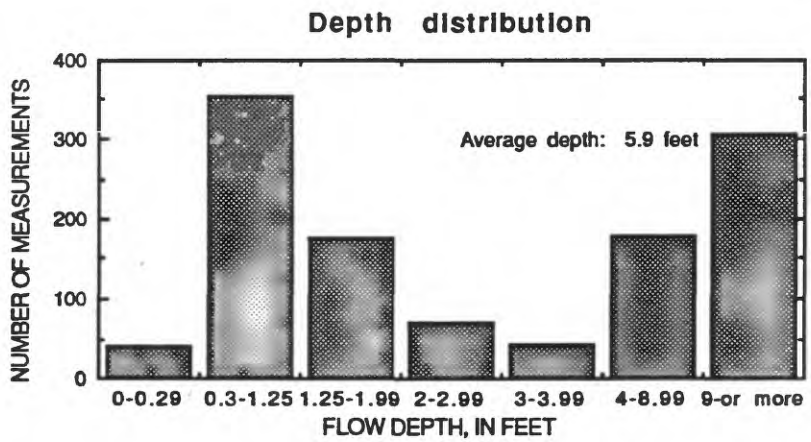


Figure 31.--Minnesota's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





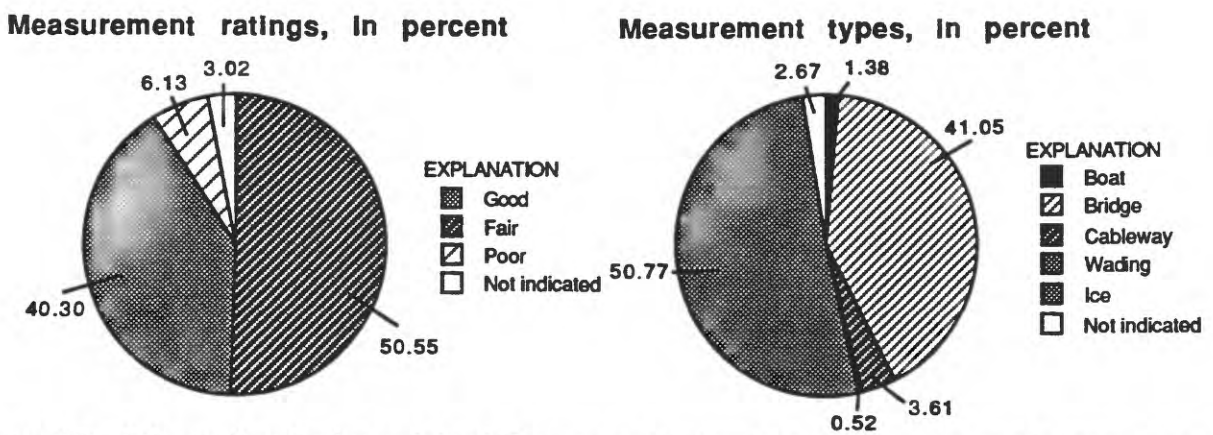
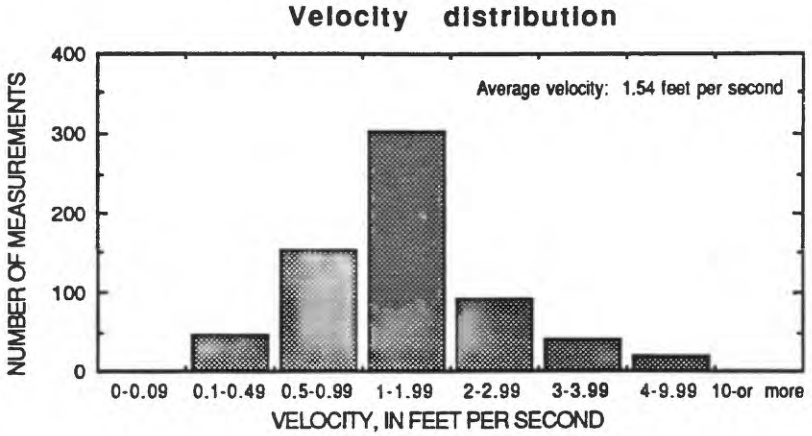
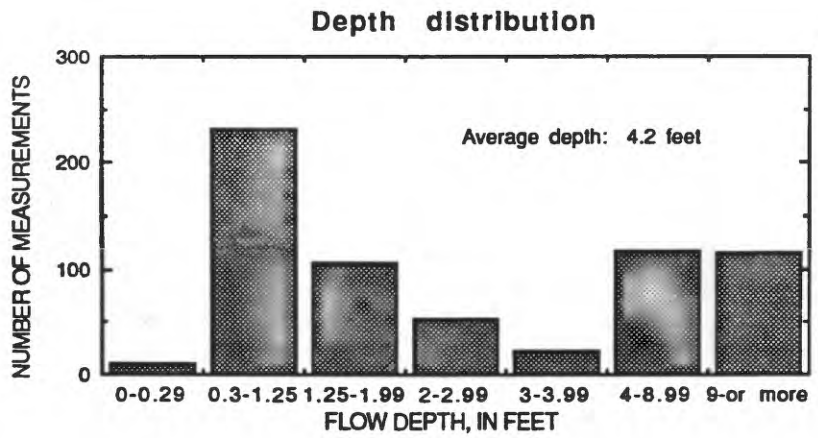


Figure 32.--Missouri's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





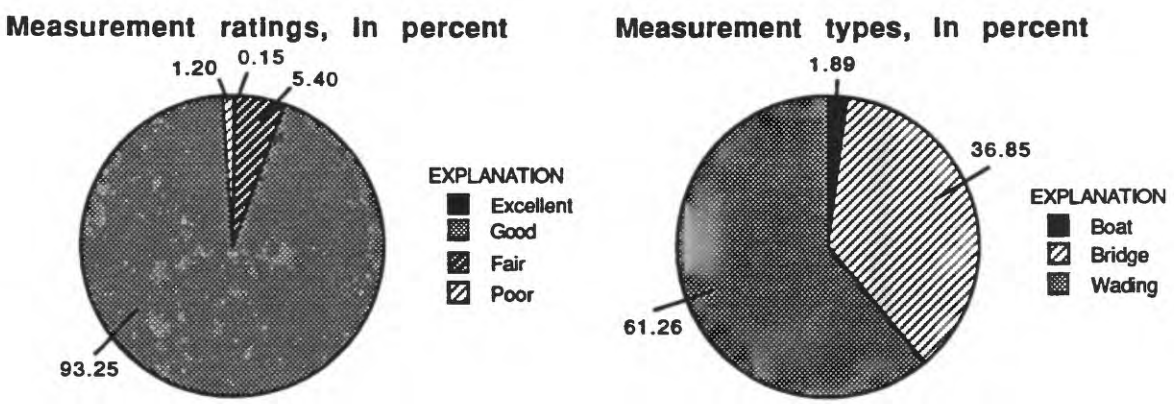
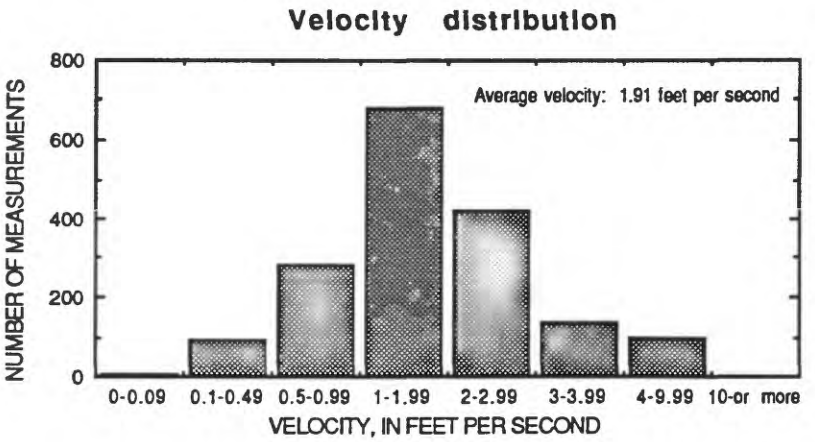
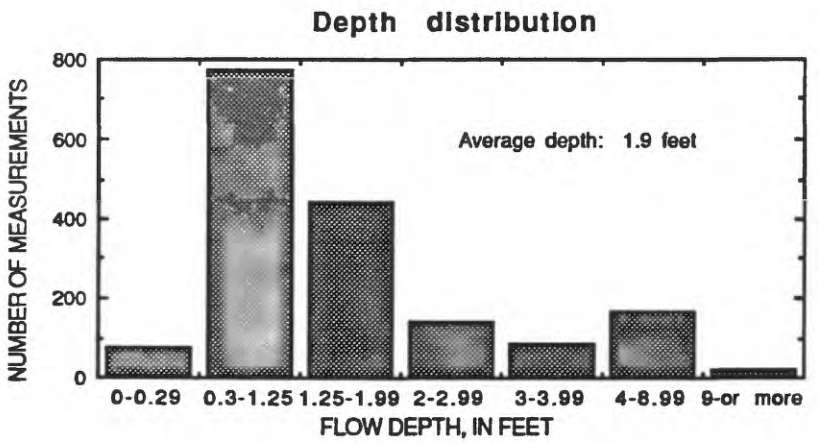
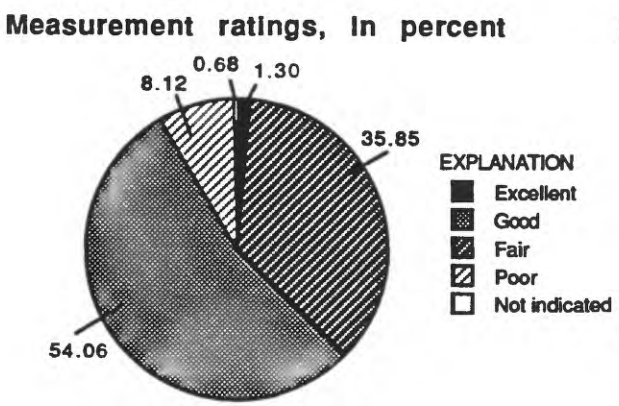


Figure 33.--Mississippi's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







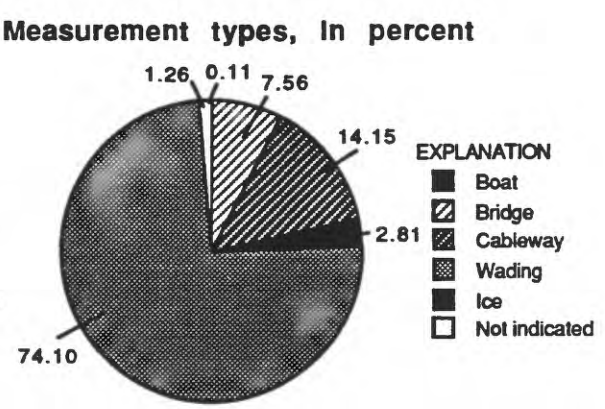
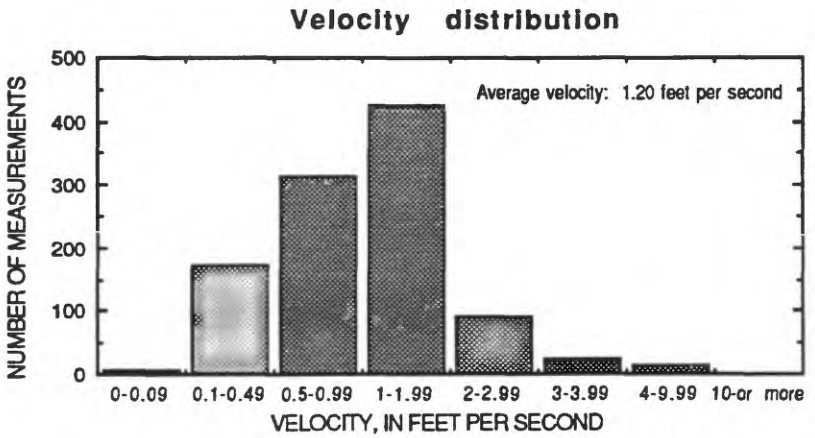
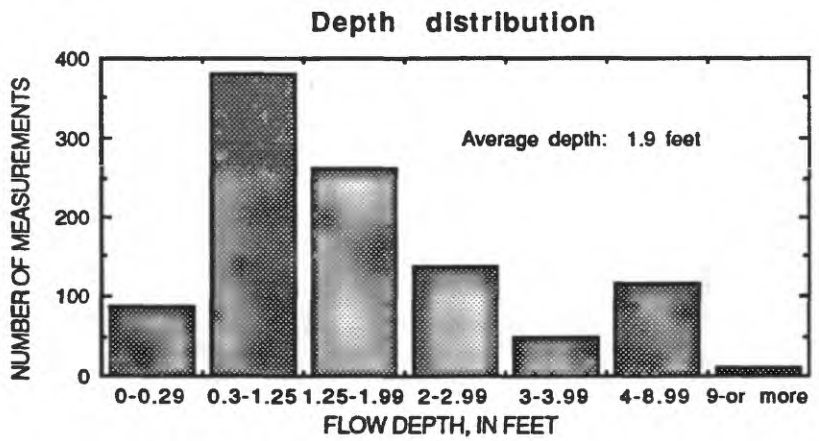


Figure 34.--Montana's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





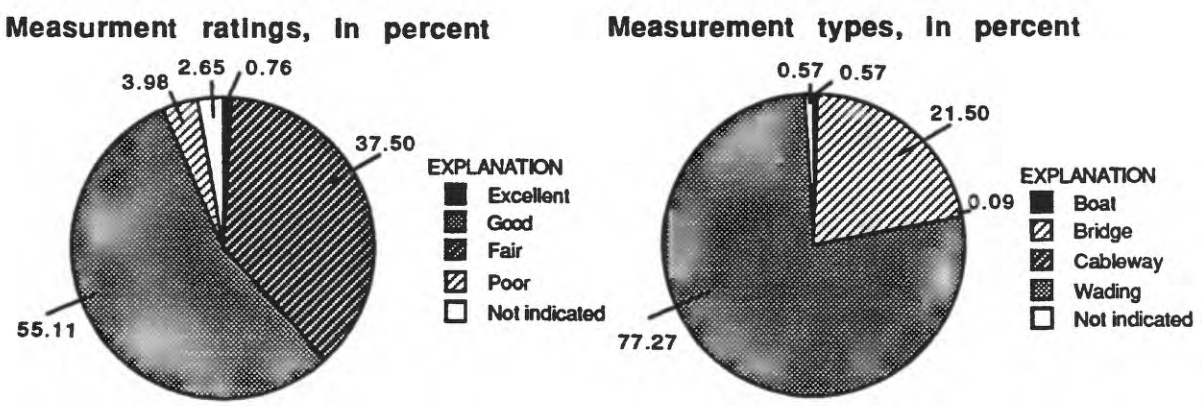
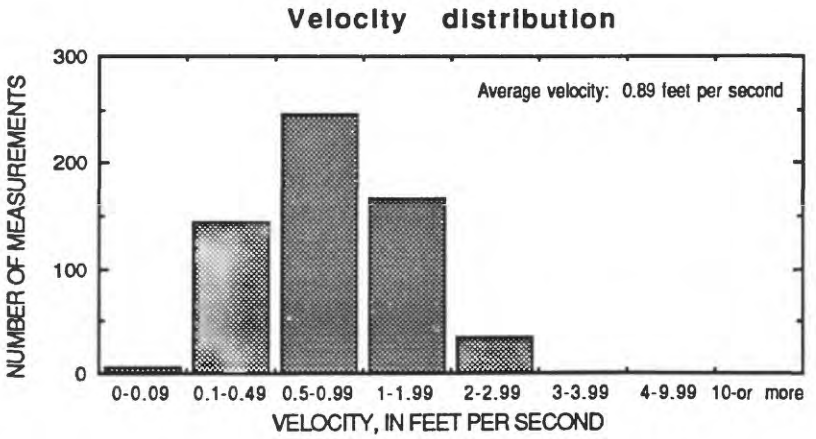
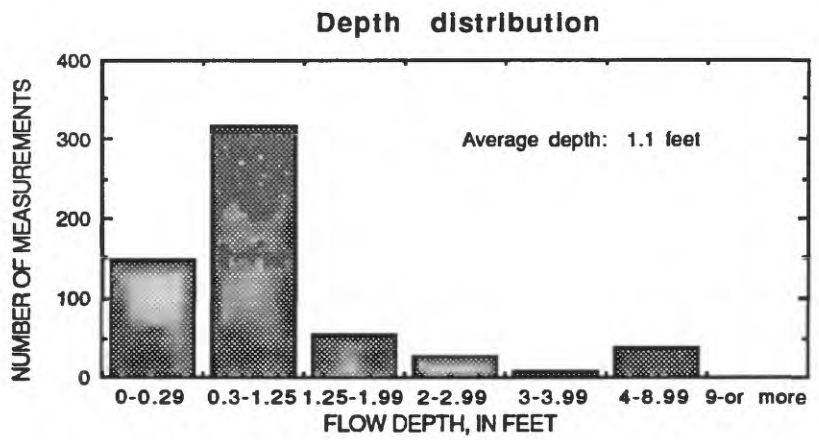


Figure 35.--North Carolina's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





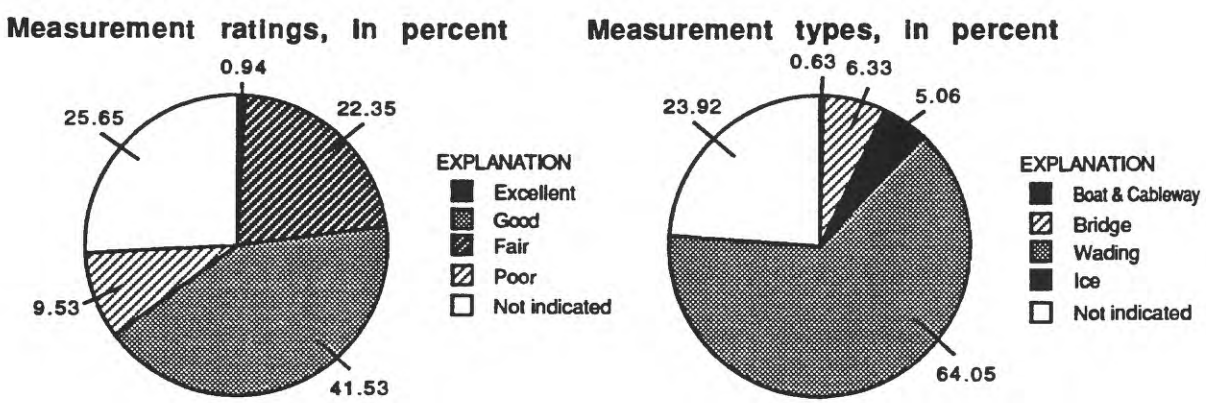
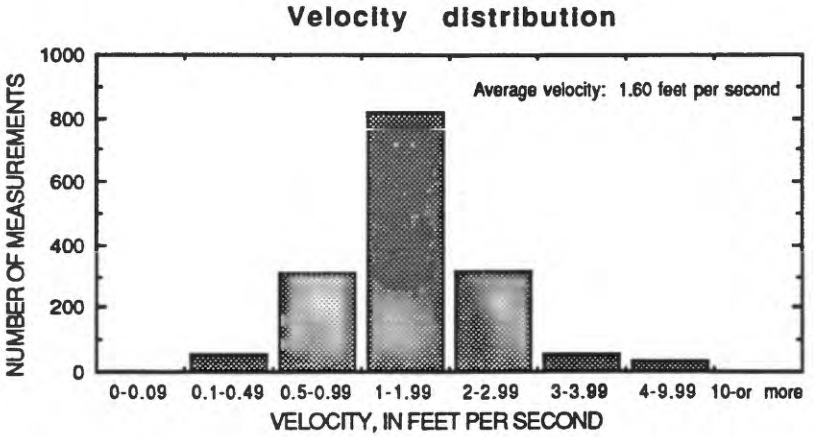
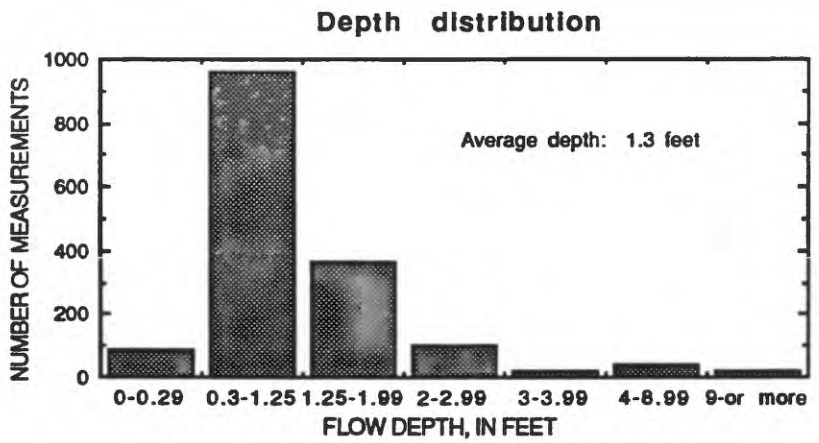


Figure 36.--North Dakota's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





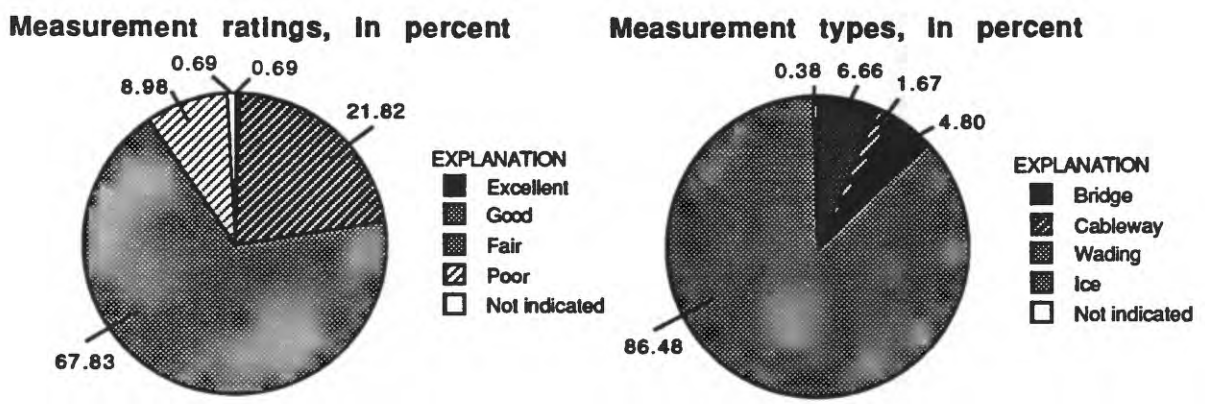
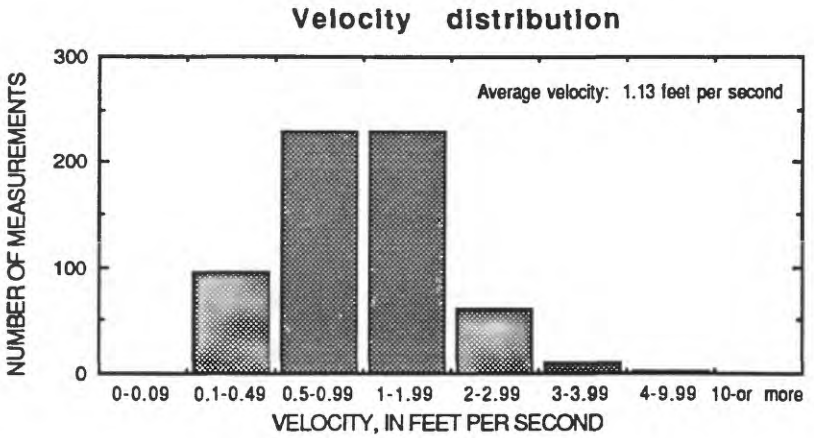
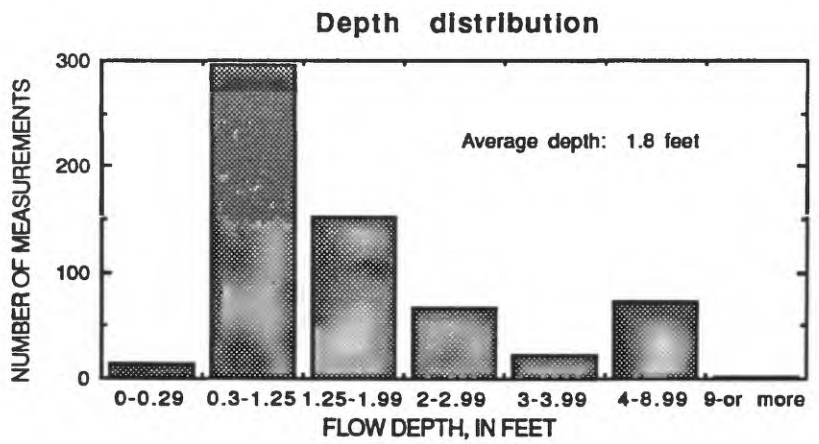


Figure 37.--Nebraska's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





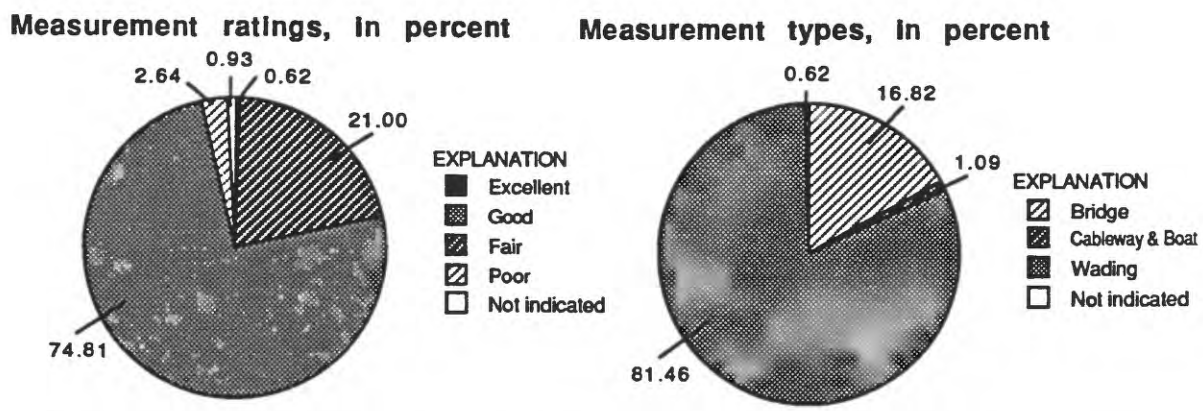
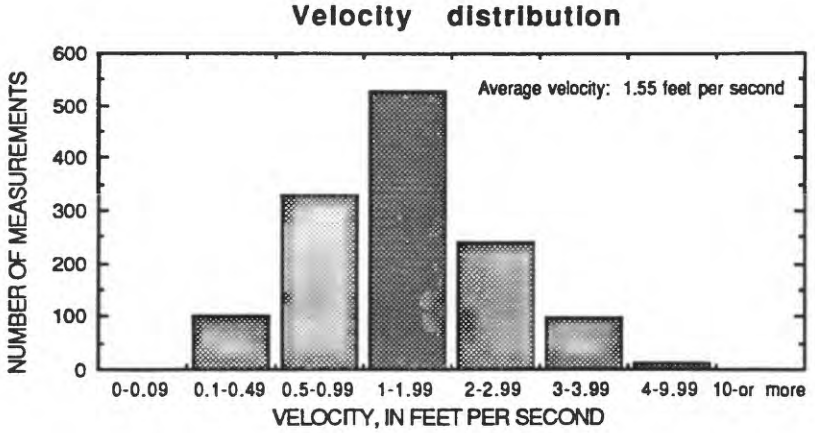
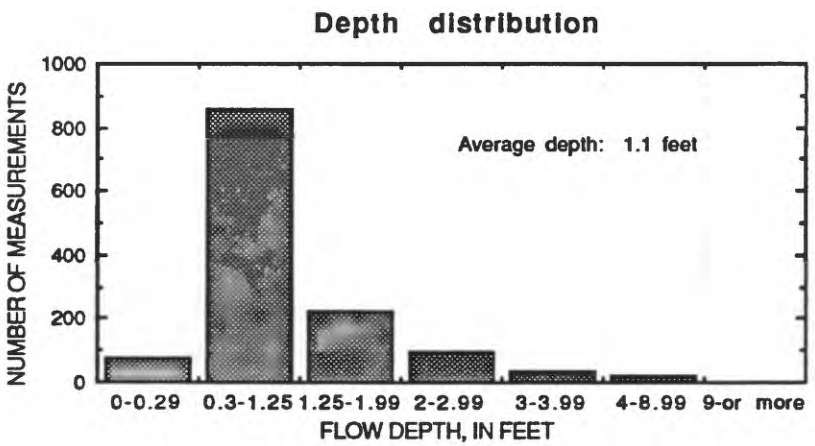
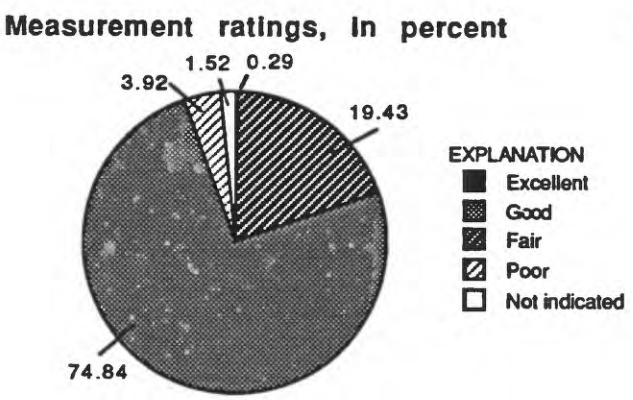


Figure 38.--New Jersey's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







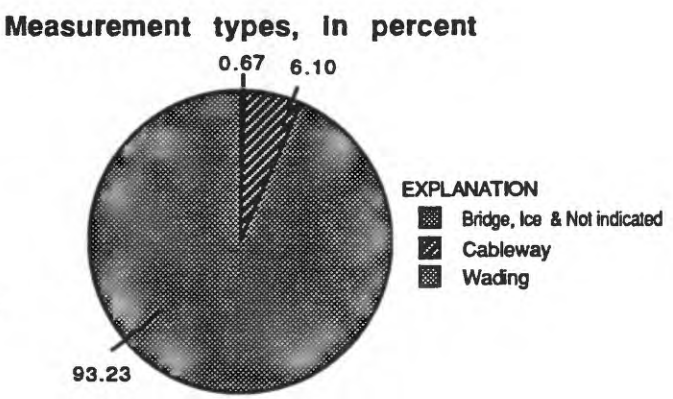
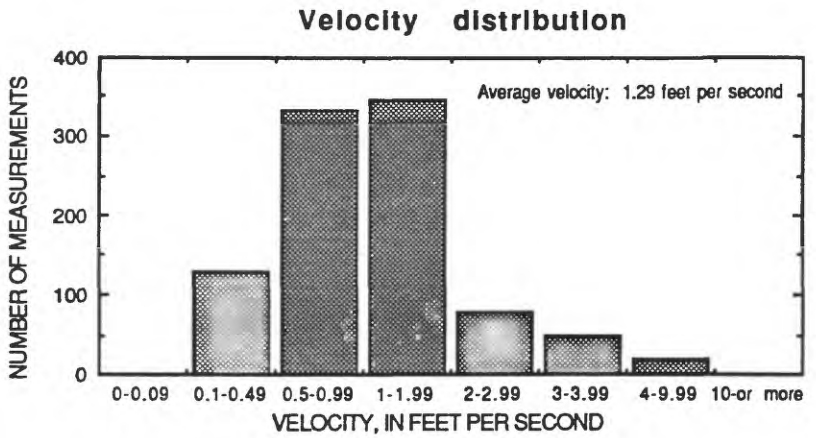
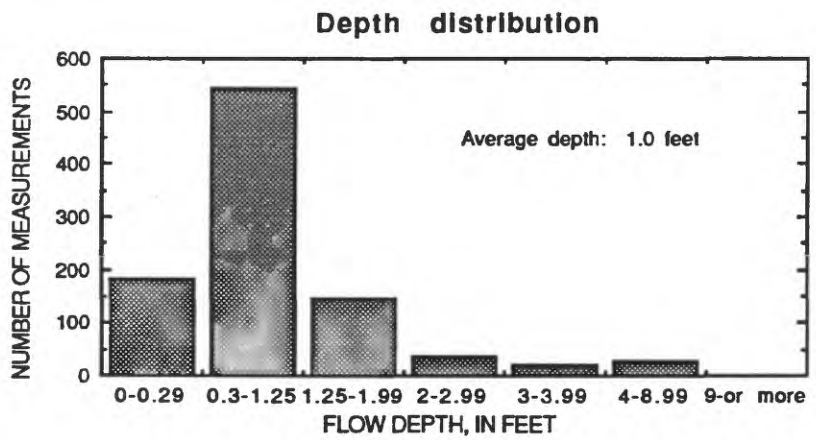
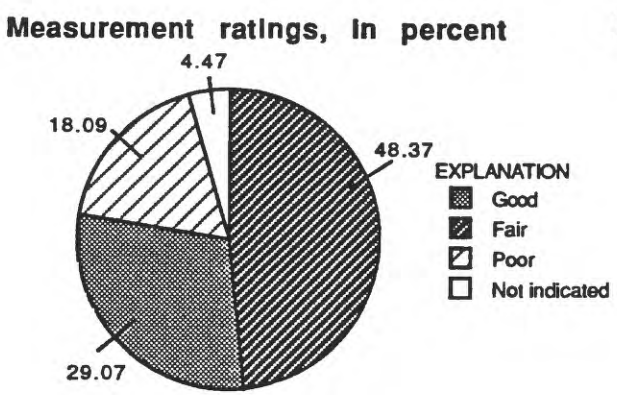


Figure 39.--New Mexico's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







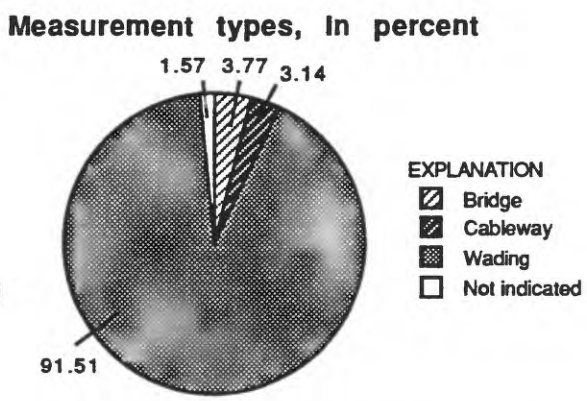
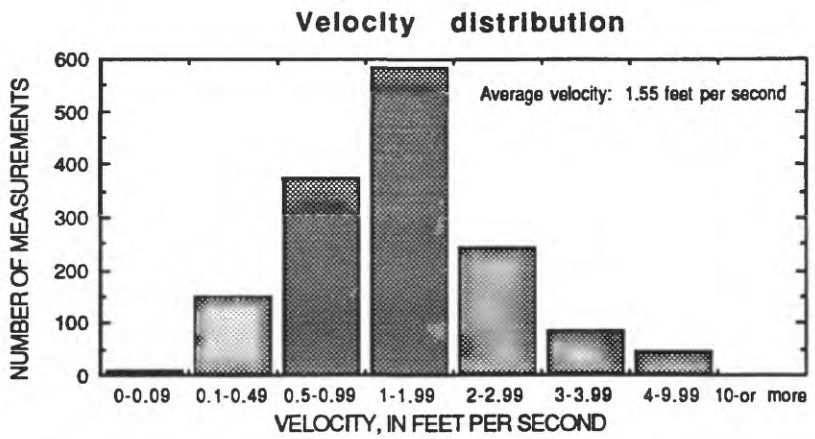
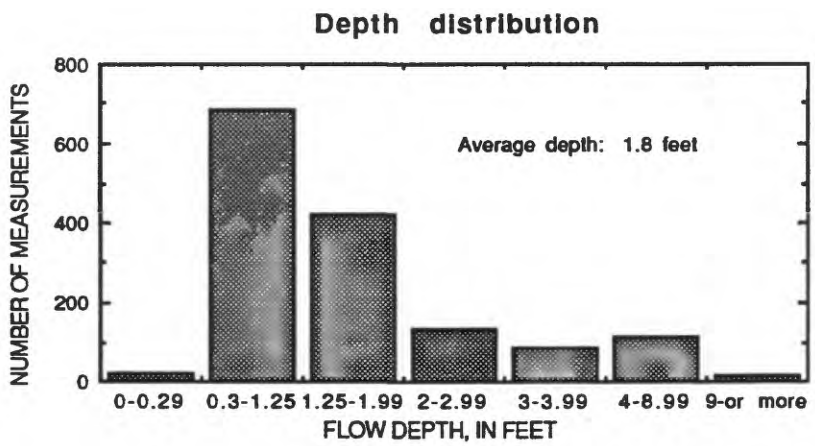
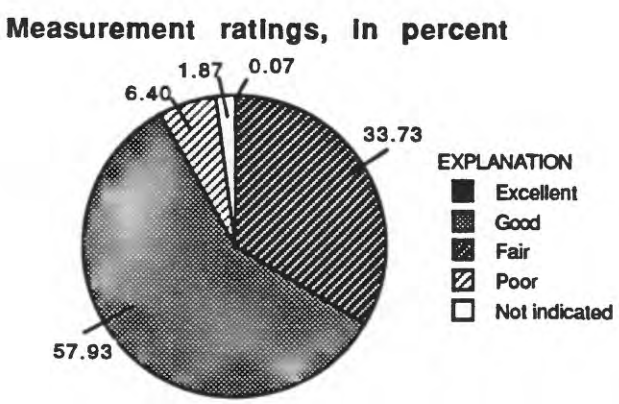


Figure 40.--Nevada's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







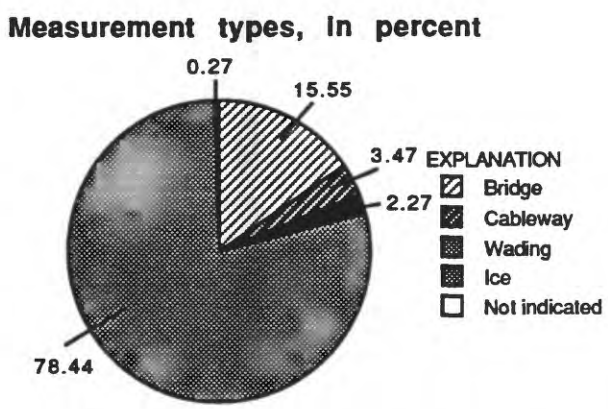
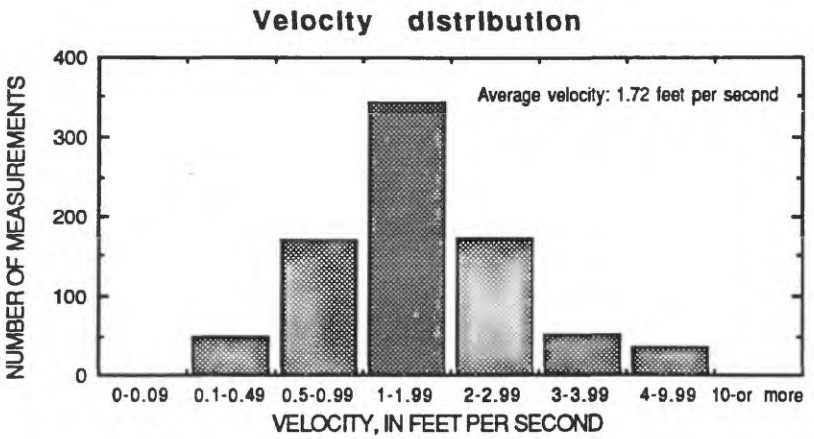
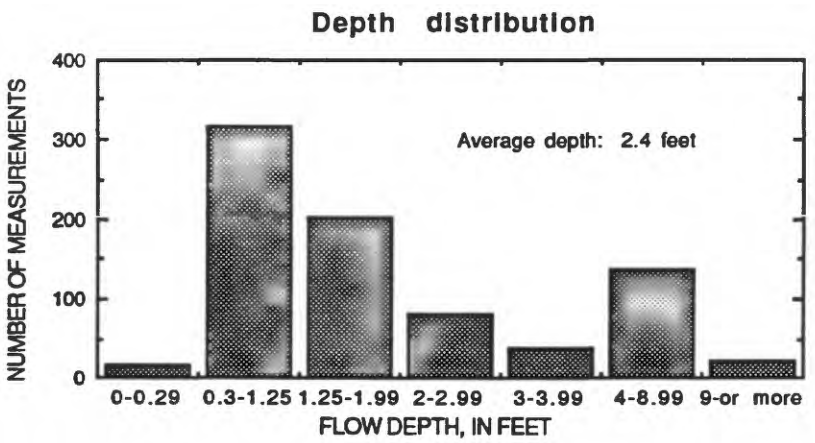


Figure 41.--New York's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





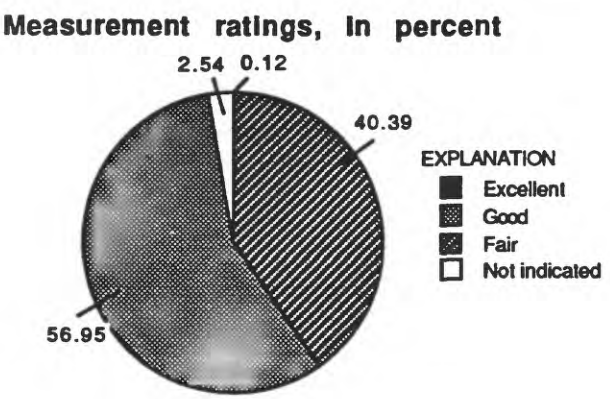
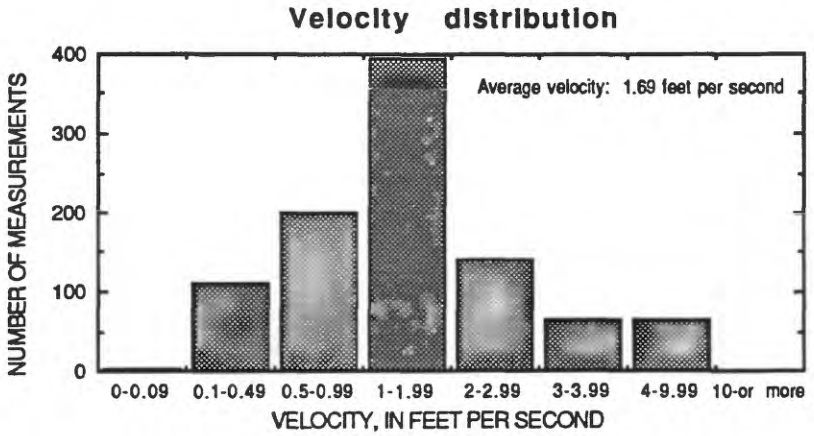
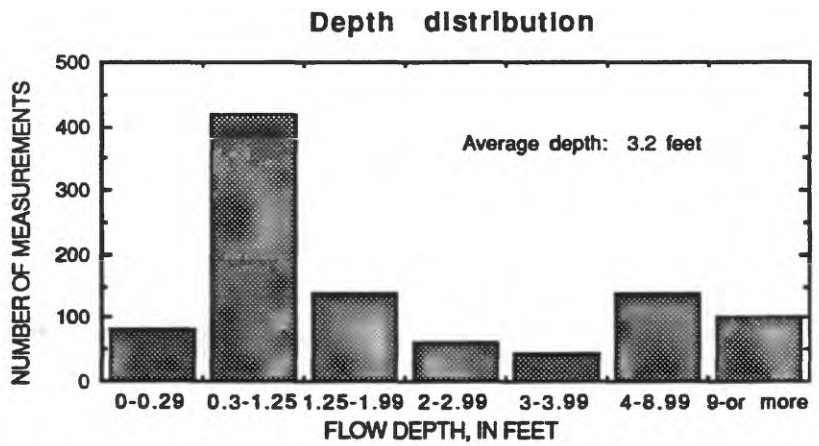


Figure 42.--Ohio's velocity and depth frequency distributions and percentage of measurements by measurement rating for water year 1990





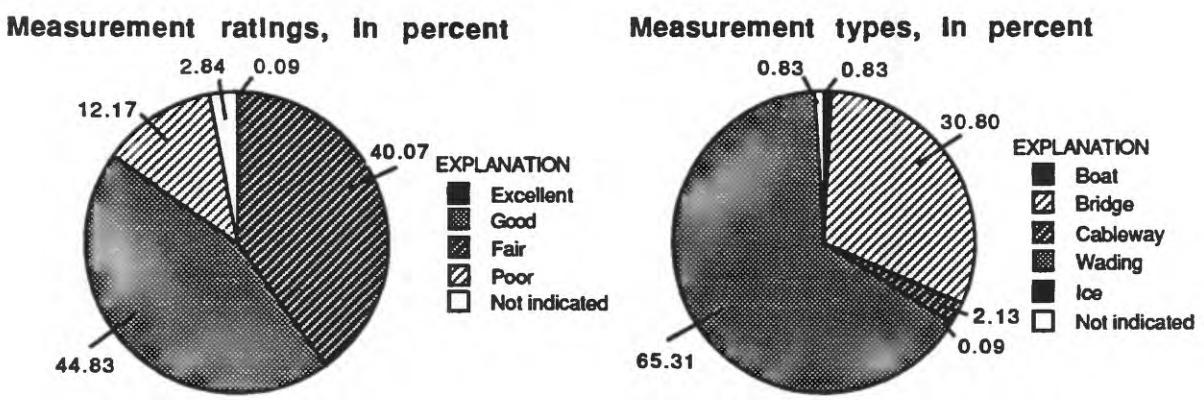
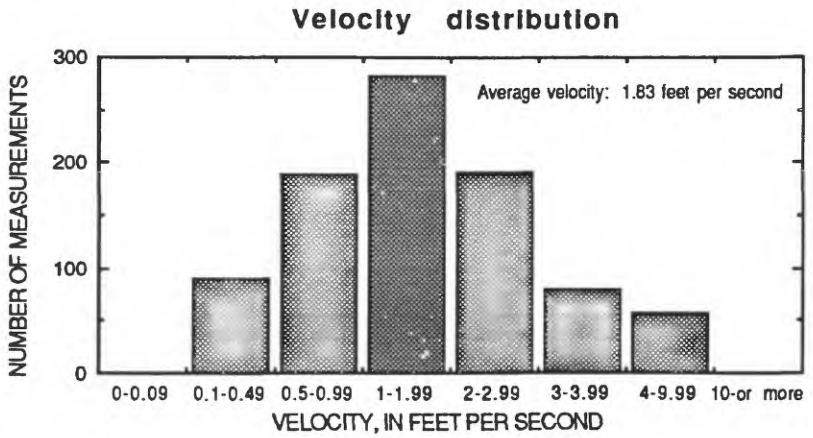
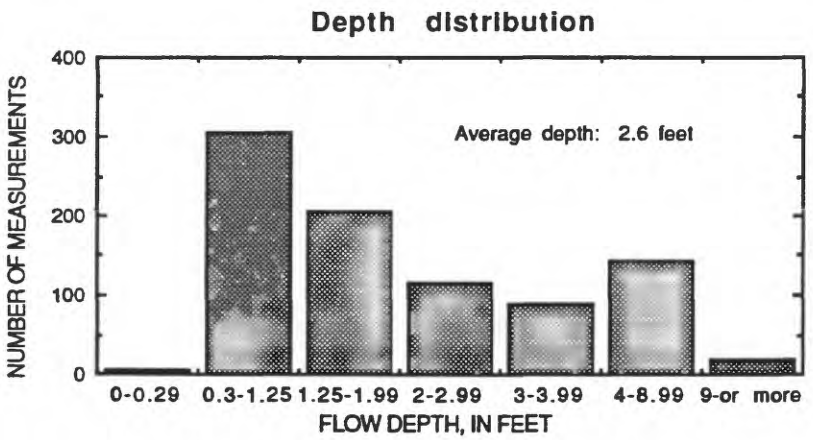
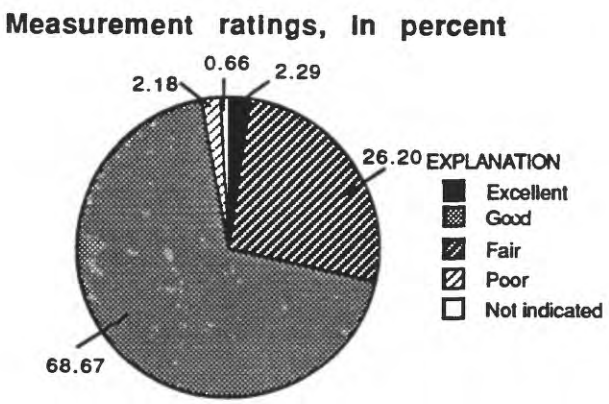


Figure 43.--Oklahoma's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







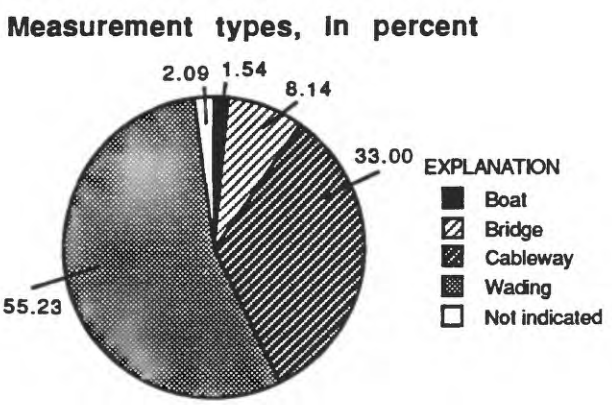
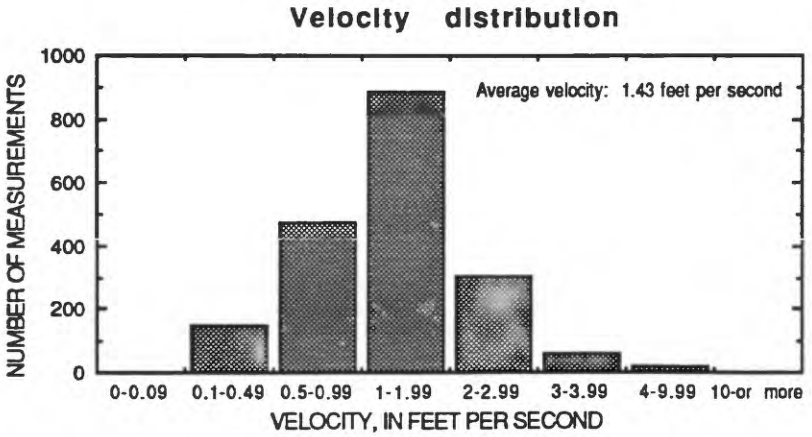
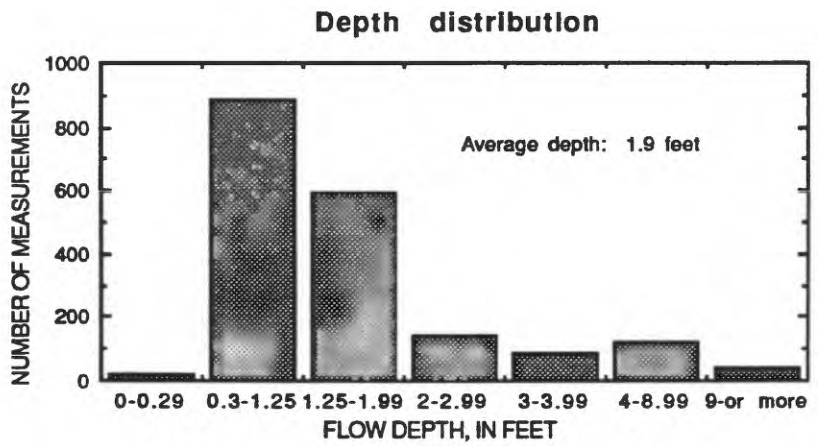


Figure 44.--Oregon's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





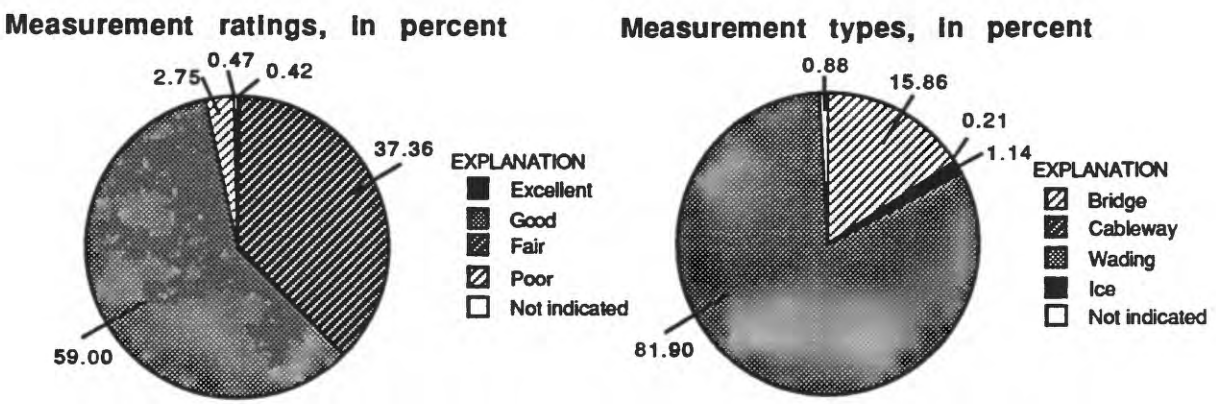
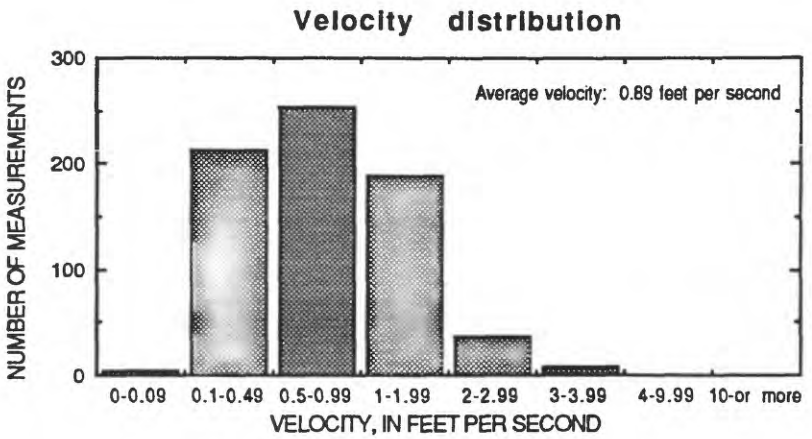
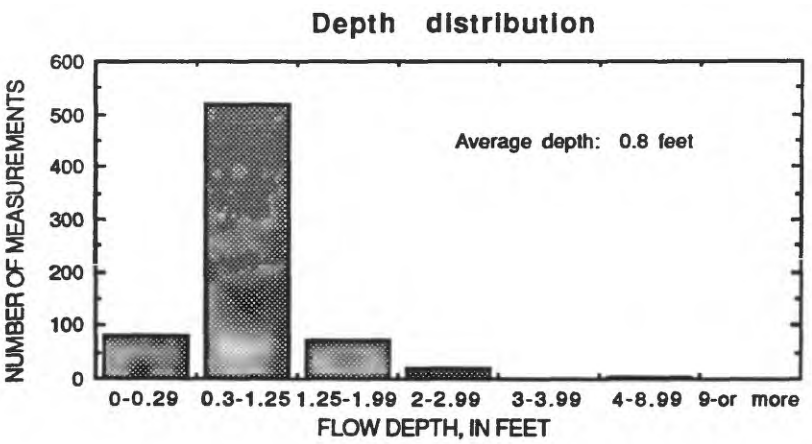
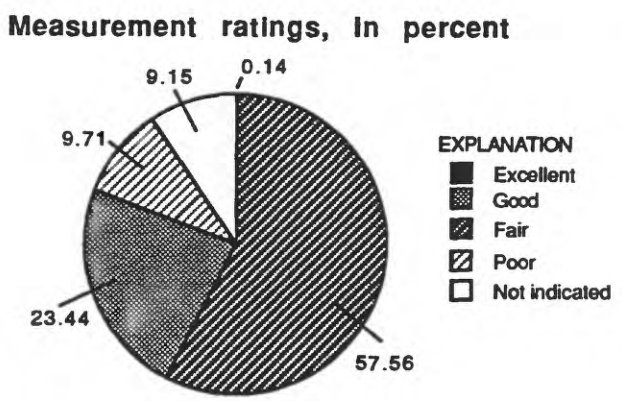


Figure 45.--Pennsylvania's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







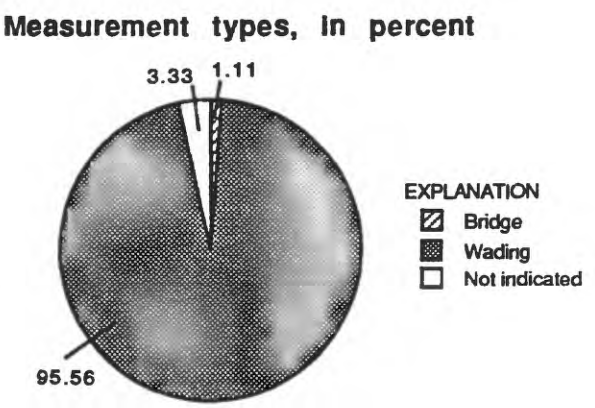
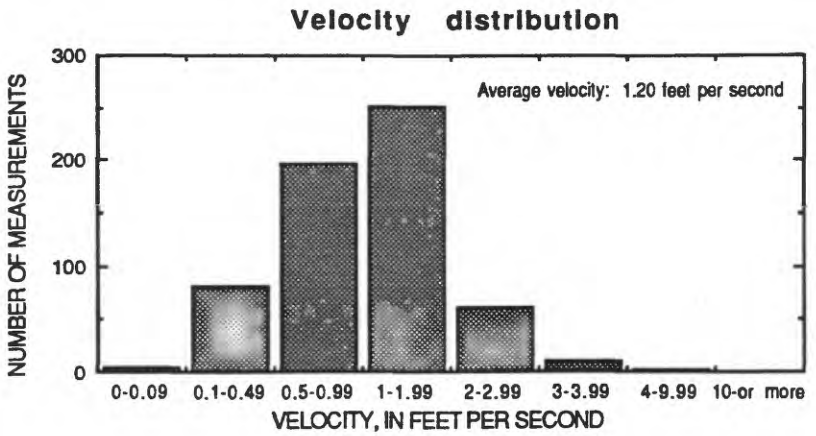
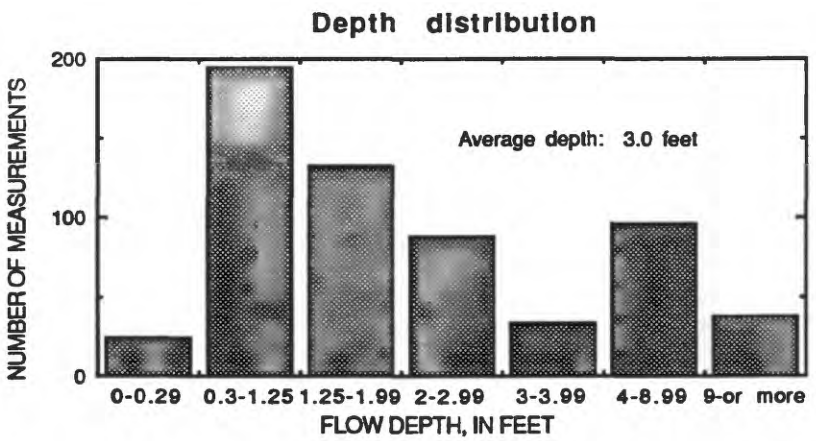
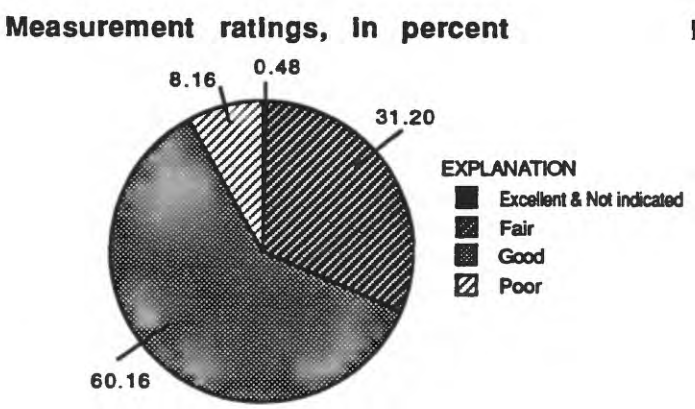


Figure 46.--Puerto Rico's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







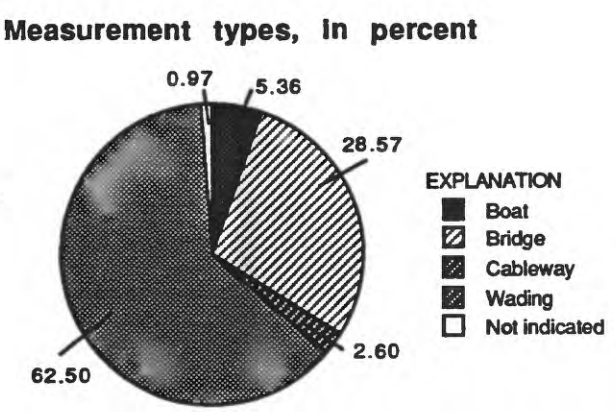
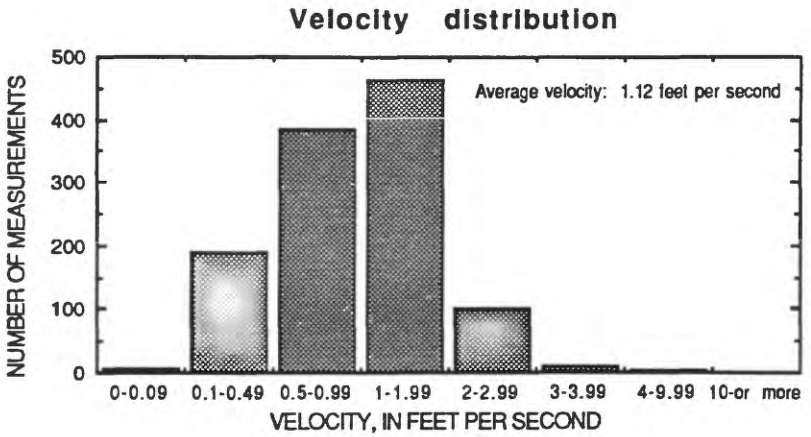
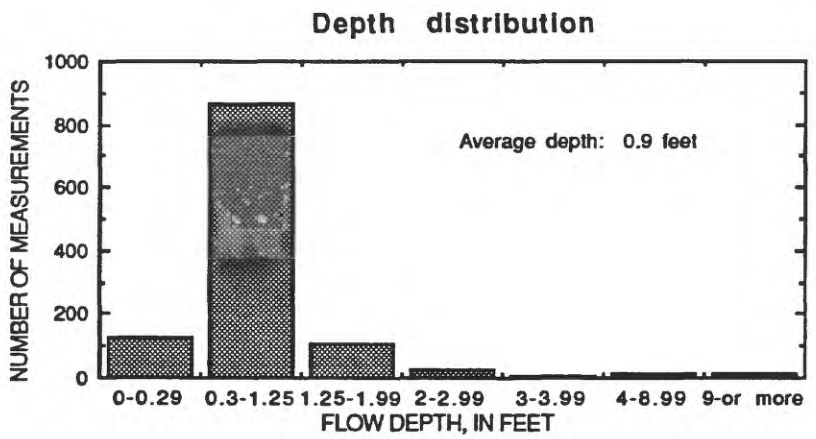


Figure 47.--South Carolina's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





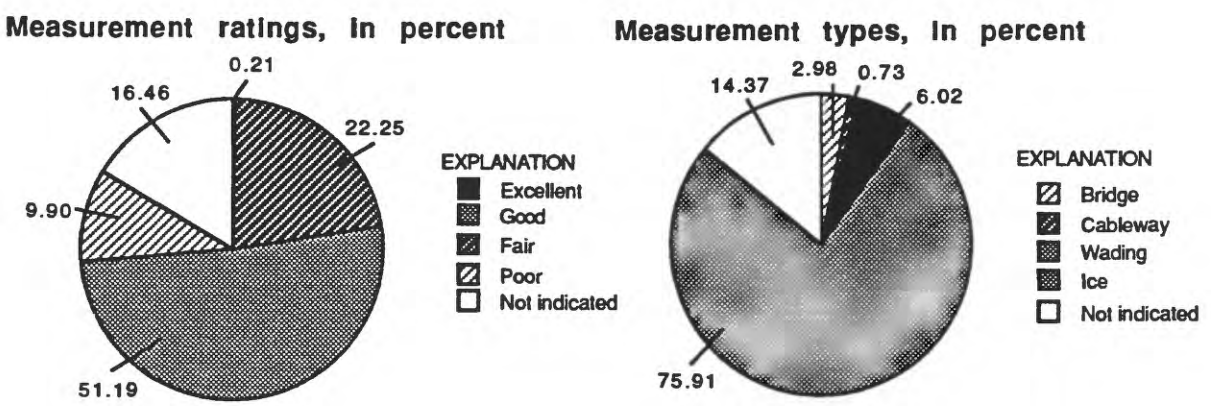
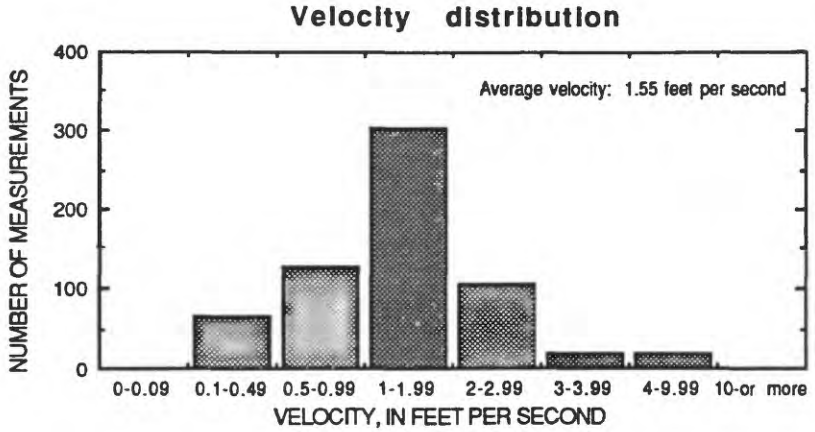
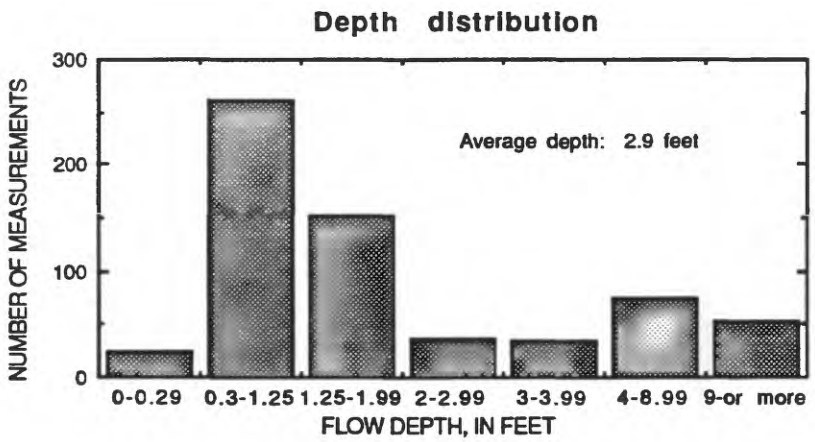
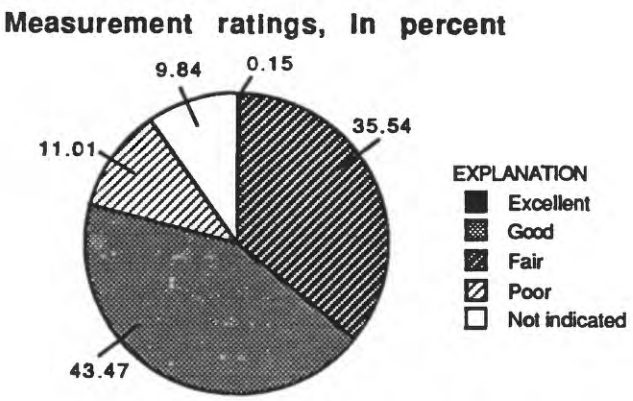


Figure 48.--South Dakota's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







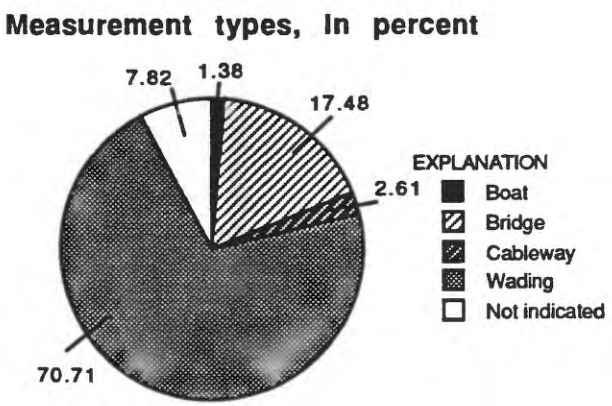
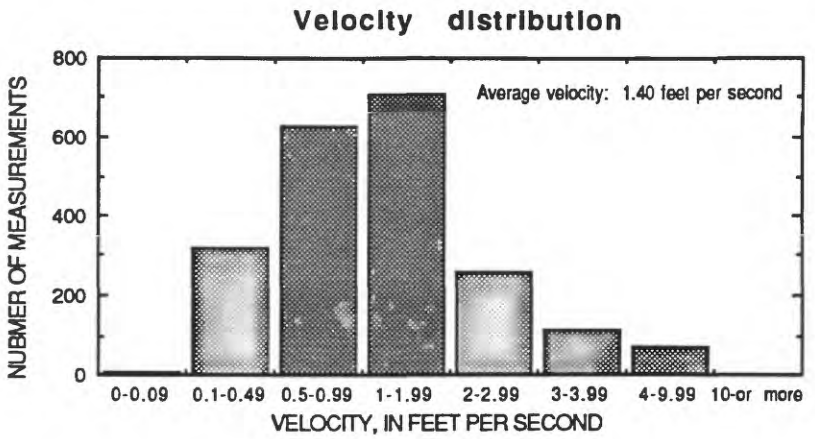
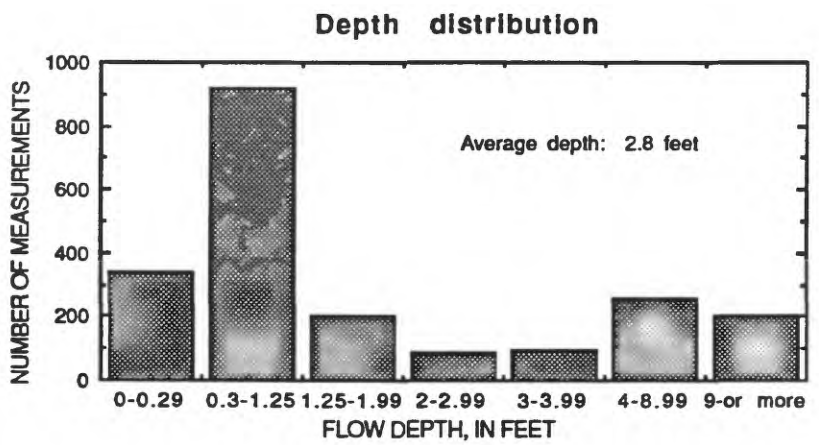


Figure 49.--Tennessee's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





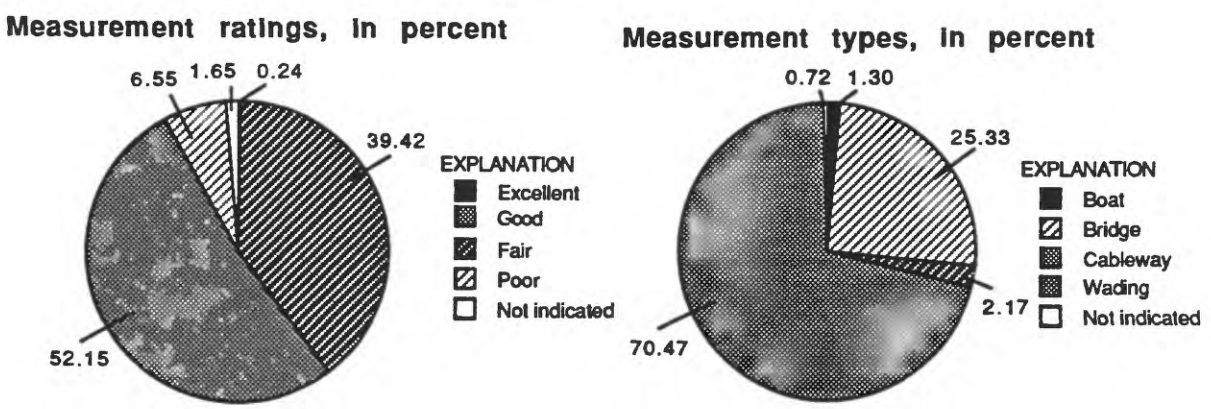
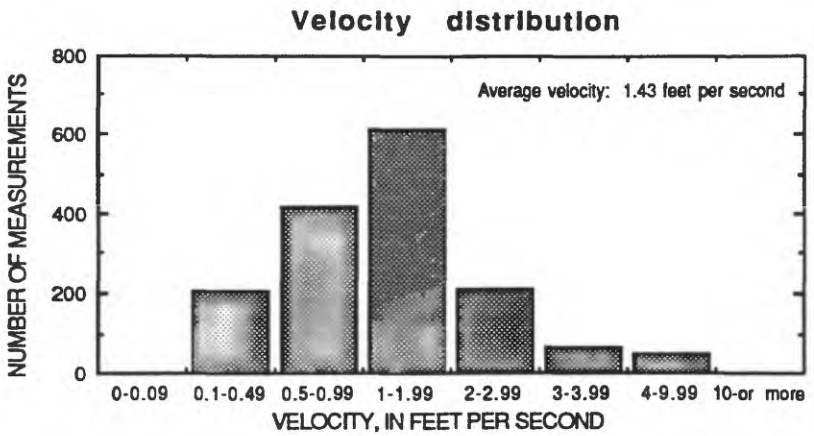
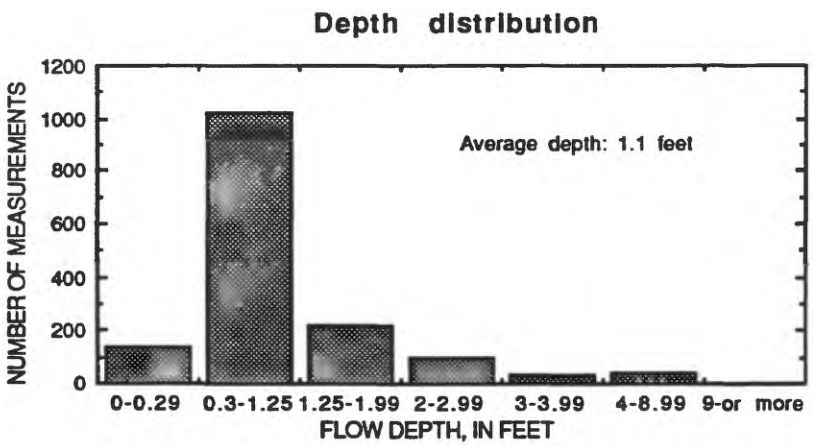
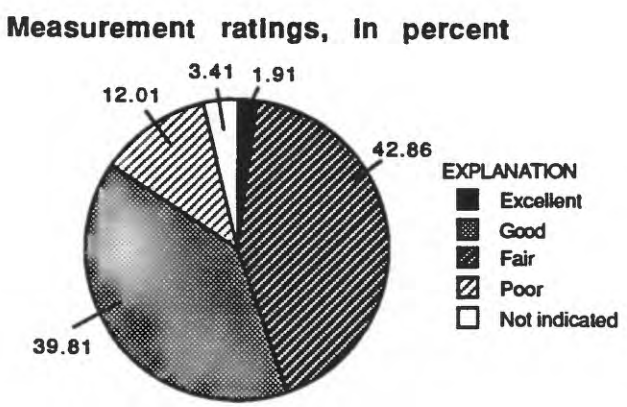


Figure 50.--Texas's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







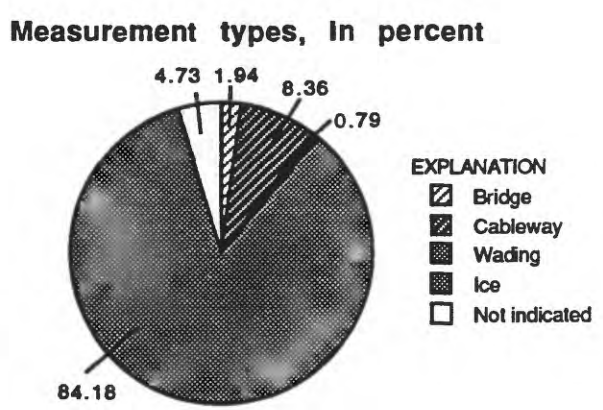
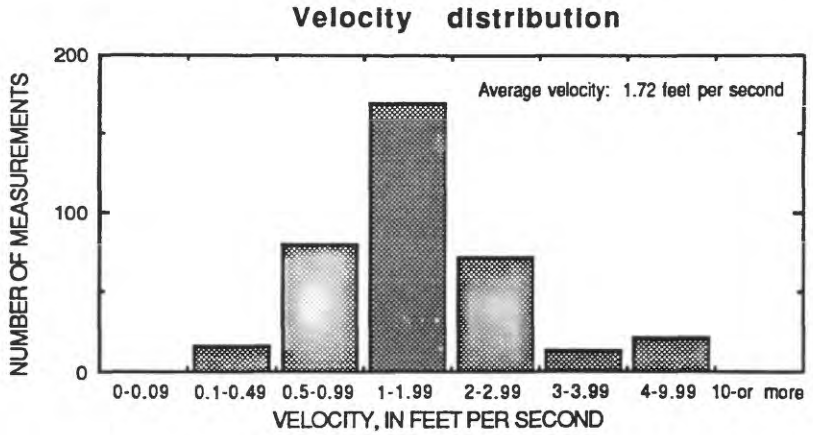
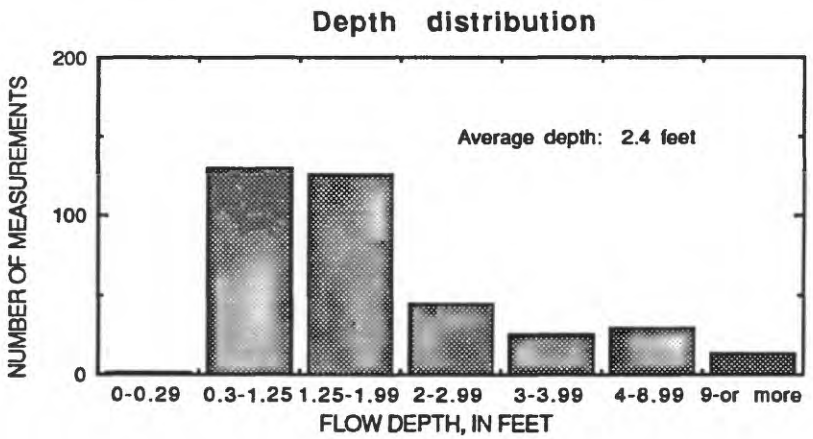
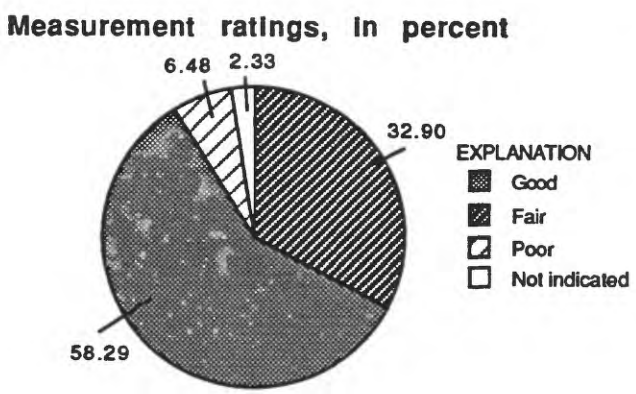


Figure 51.--Utah's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







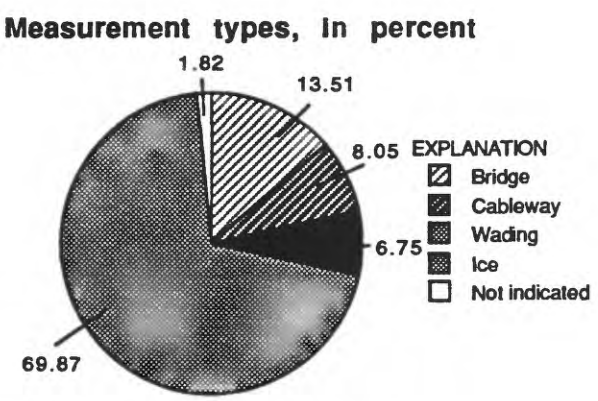
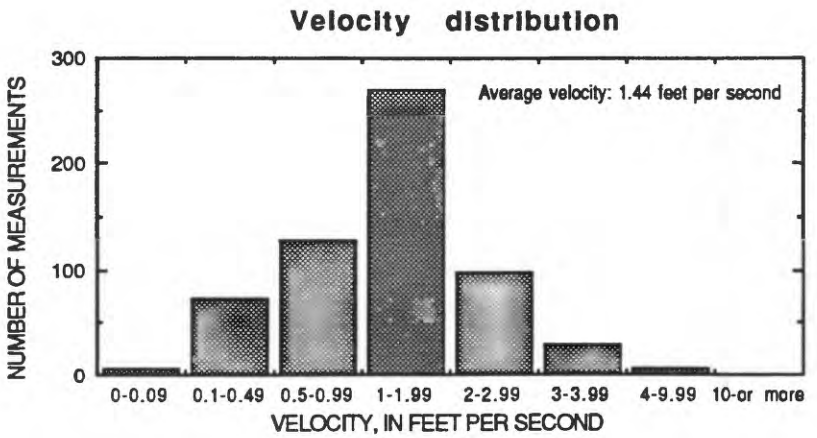
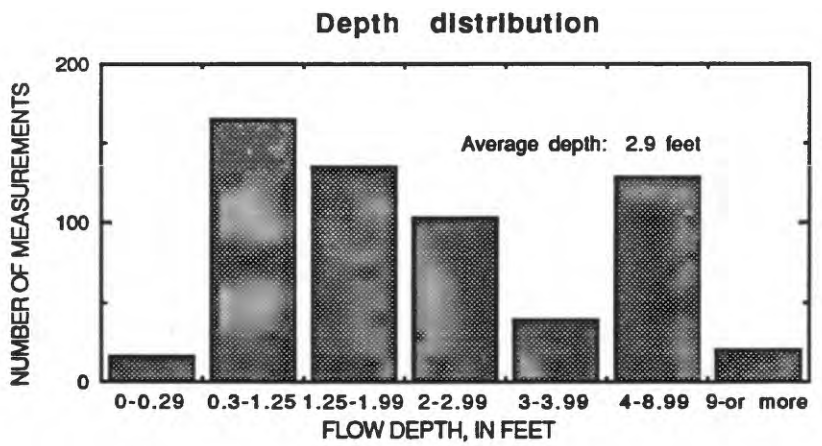


Figure 52.--Vermont's and New Hampshire velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





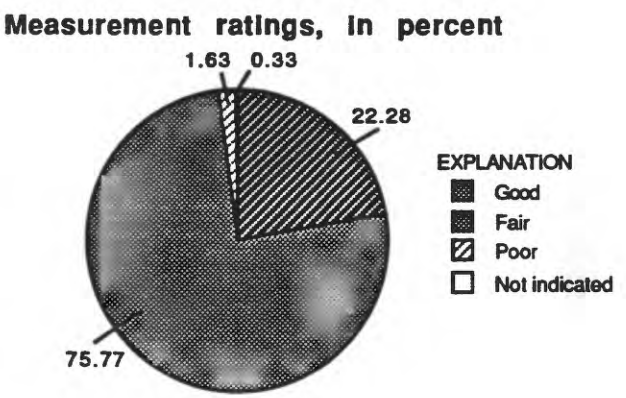
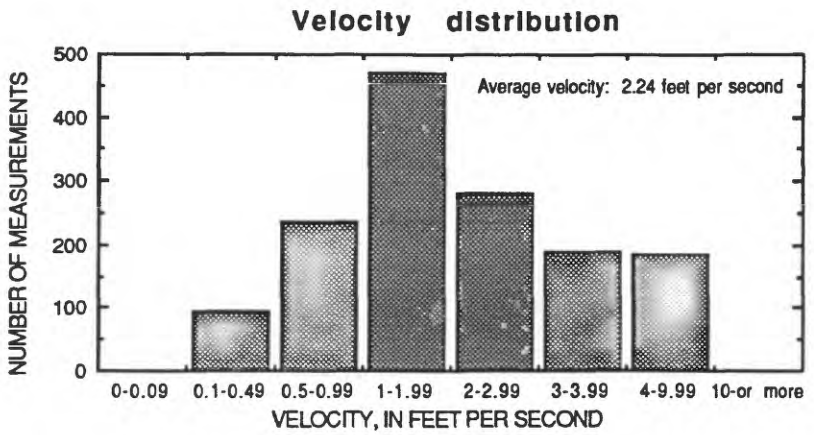
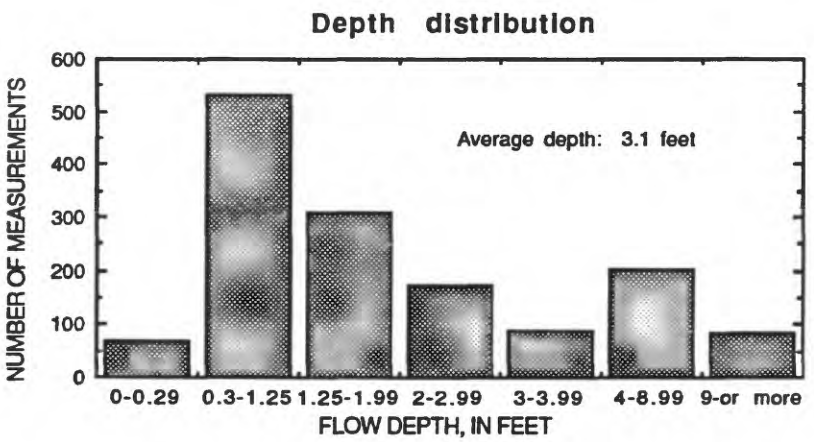
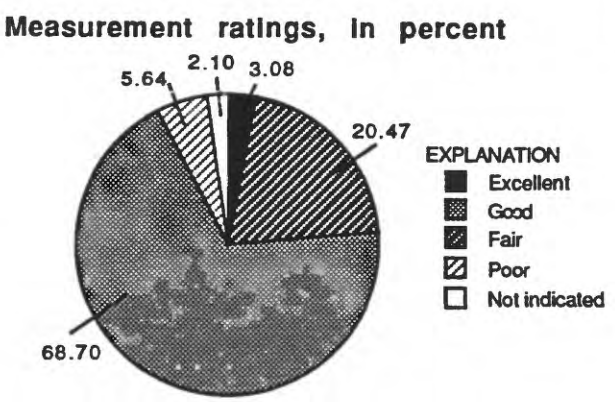


Figure 53.--Virginia's velocity and depth frequency distributions and percentage of measurements by measurement rating for water year 1990.







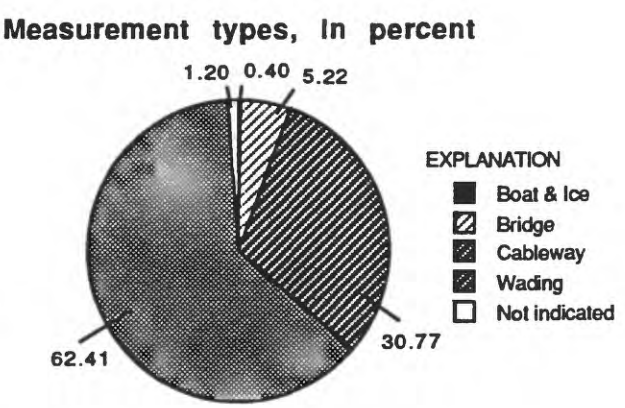
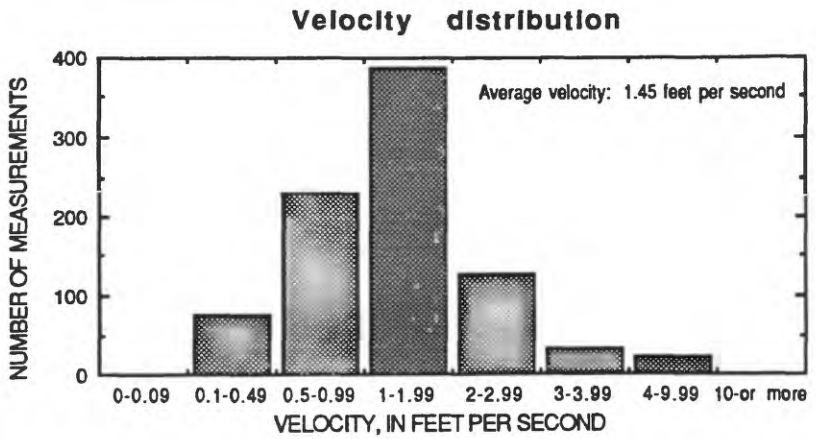
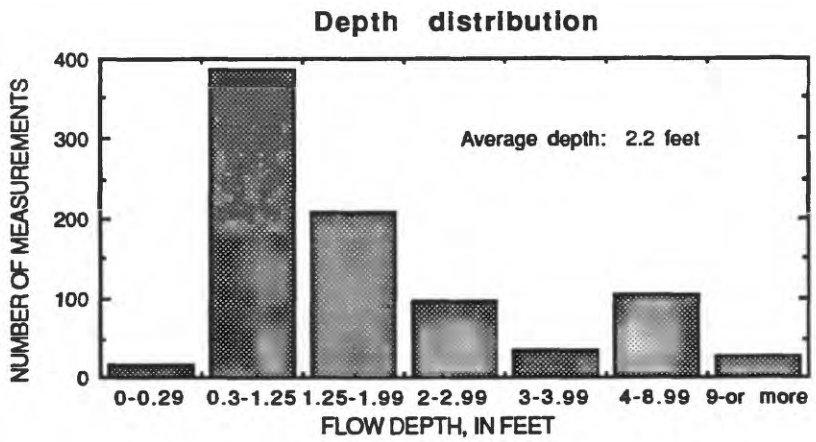
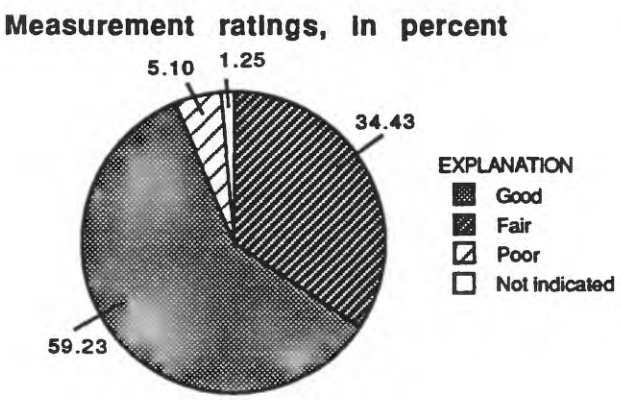


Figure 54.--Washington's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







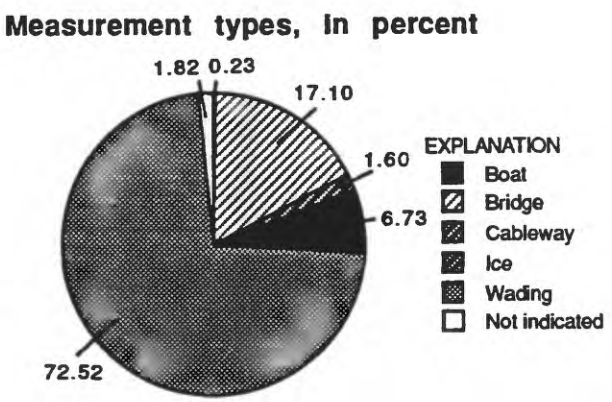
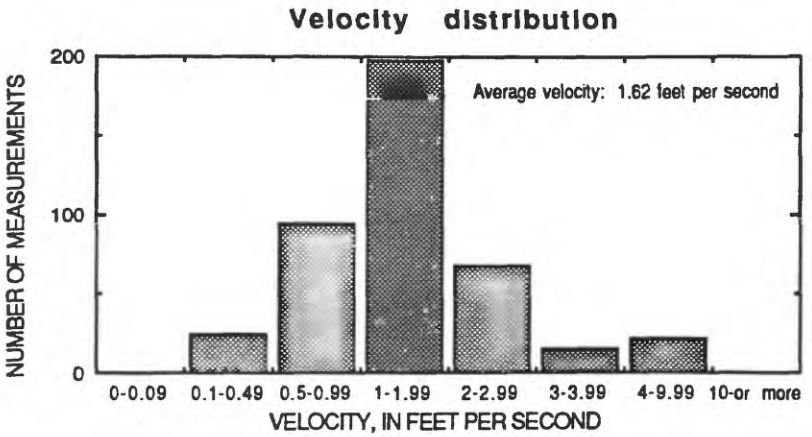
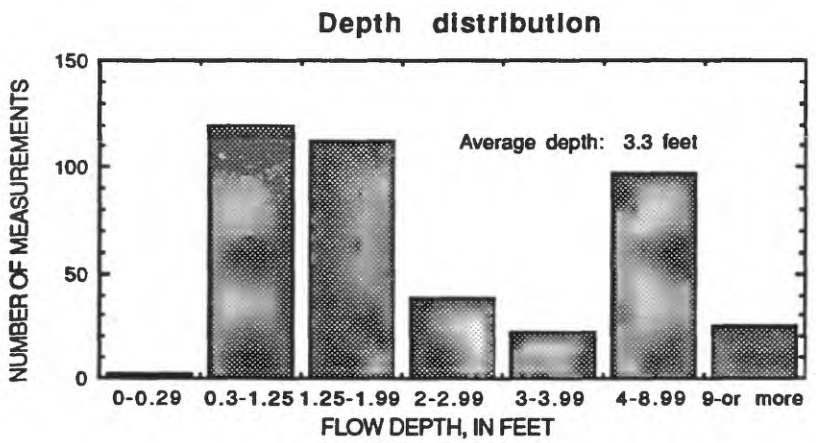


Figure 55.--Wisconsin's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.





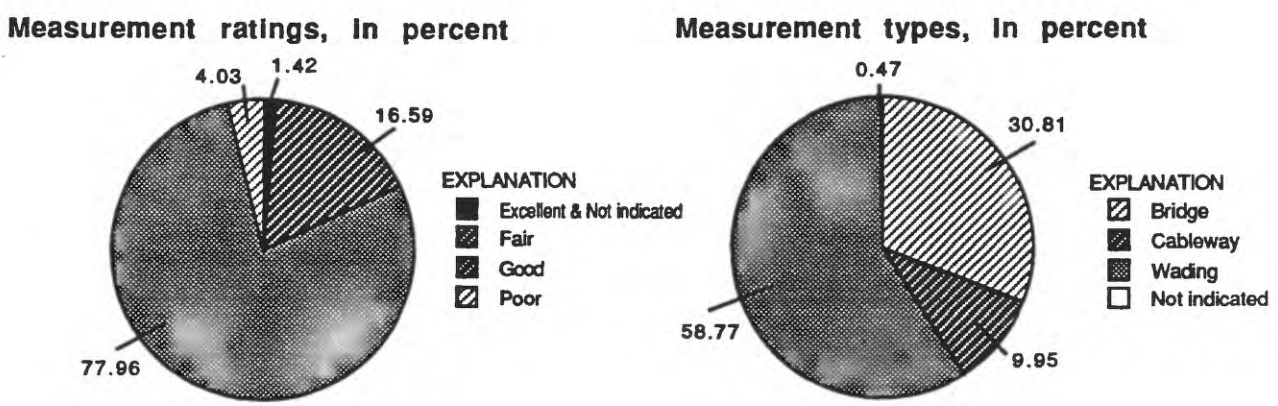
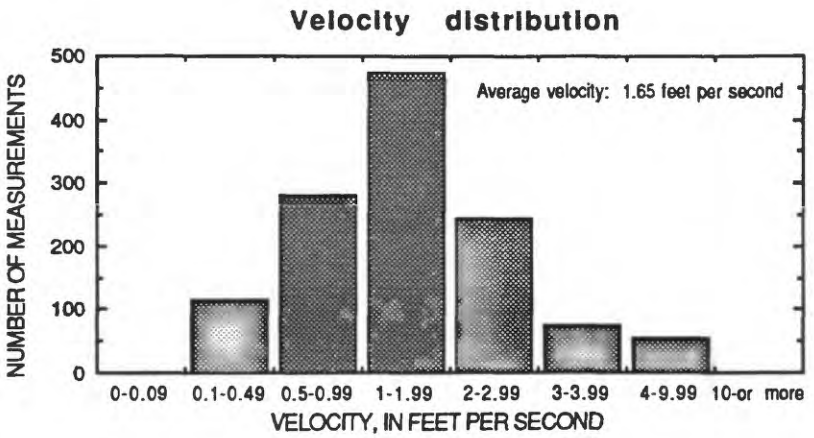
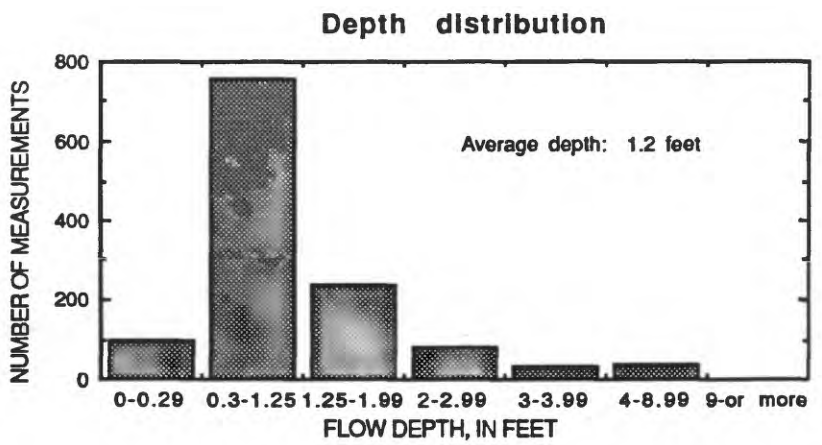
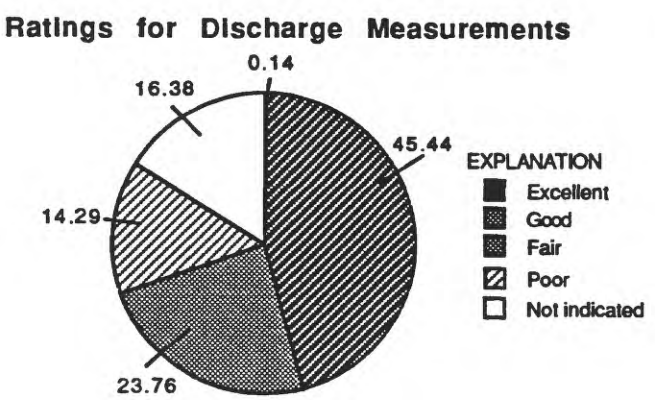


Figure 56.--West Virginia's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.







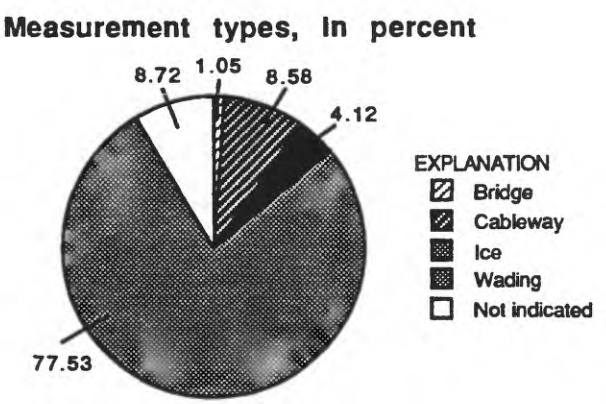


Figure 57.--Wyoming's velocity and depth frequency distributions and percentage of measurements by measurement rating and by measurement type for water year 1990.

Table 12.--*Summary statistics for computed flow characteristics for measurements made in water year 1990*

[ft, feet; Kn, conveyance times Manning's coefficient of roughness; ft^3/s, cubic feet per second]

Computed flow characteristic	Mean	Standard deviation	Low	High	Count
Wetted perimeter (ft)	110.2	237.2	0.1	13,701.2	51,069
Shape	57.4	537.7	0	110,653	51,066
Squared Froude number	0.069	0.14	0	12.44	51,000
Kn (ft^3/s)	5,177.	40,322.9	0	2,034,405.1	51,069

Computed Flow Characteristics

Hydraulic computations and flow models use characteristics that are computed from velocity, depth, roughness, and area of flow. Some of these common flow characteristics are the Froude number, the wetted perimeter, a shape number, and conveyance times Manning's n. Summary statistics for each computed characteristic are determined for all the 1990 water year measurements and for each District's measurements.

The selected flow characteristics are computed from the data for each measurement. The shape number is computed as a dimensionless ratio of width to mean depth for a given measurement. The wetted perimeter is an estimate of the actual wetted perimeter. It is computed as the width plus 2 times the depth.

The Froude number is a dimensionless number that represents the ratio of inertial force to gravitational force. The squared Froude number was computed for each measurement as:

$$F^2=\frac{v^2}{gD}$$

where v is the mean velocity, g the acceleration of gravity, and D is the mean depth of flow. Because open-channel flow is free surface flow, the Froude number is important to flow computations.

The conveyance times the Manning's coefficient (n values) of roughness is computed as:

$$Kn=1.49AR^{2/3}$$

where A is the cross-sectional area and R is the hydraulic radius. The quantity is a substitute for conveyance. The discharge measurement data lacks roughness values from which to compute conveyance directly.

Summary statistics for the computed flow characteristics for each state are listed in table 12 for all the measurements and in table 13 by state (or district). For most measurements the squared Froude number is less than one, signifying tranquil flow conditions. The average stream width is 50 times the depth.

Table 13.--*Summary statistics for computed flow characteristics listed by state for water year 1990*

[S.D., standard deviation; No., number computed; ft, feet; Kn, conveyance times Manning's coefficient of roughness; ft^3/s, cubic per second]

STATE	WETTED PERIMETER (ft)		SHAPE		SQUARED FROUDE NUMBER		Kn (ft^3/s)	
	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.
Alaska	193		58		0.118		13,129	
	356	477	62	477	0.133	474	52,205	477
Alabama	112		54		0.044		3,212	
	247	692	128	692	0.047	692	12,885	692
Arkansas	208		56		0.060		32,252	
	311	320	286	320	0.220	320	107,833	320
Arizona	79		49		0.087		3,747	
	122	744	109	744	0.429	743	12,991	744
California	58		41		0.083		812	
	90	3,364	125	3,364	0.178	3,362	3,756	3,364
Colorado	51		51		0.130		187	
	56	2,869	51	2,869	0.156	2,869	545	2,869
Connecticut	83		39		0.051		1,695	
	147	289	26	289	0.055	289	7,986	289
Delaware	42		31		0.044		393	
	33	164	24	164	0.056	164	944	164
Florida	107		38		0.020		5,905	
	468	1,361	87	1,361	0.038	1,357	43,955	1,361
Georgia	170		46		0.037		7,944	
	283	1,122	49	1,122	0.045	1,122	25,976	1,122
Hawaii	15		13		0.040		29	
	14	563	11	563	0.040	562	110	563
Iowa	252		75		0.045		15,454	
	340	1,656	208	1,656	0.047	1,654	36,431	1,654
Idaho	119		50		0.092		4,222	
	152	1,721	72	1,721	0.088	1,719	20,244	1,721
Illinois	113		46		0.050		3,888	
	218	1,485	130	1,485	0.069	1,482	15,045	1,485
Indiana	101		44		0.046		2,122	
	129	1,361	33	1,361	0.046	1,359	8,274	1,361

Table 13.--*Summary statistics for computed flow characteristics listed by state for water year 1990*

[continued; S.D., standard deviation; No., number computed; ft, feet; Kn, conveyance times Manning's coefficient of roughness; ft^3/s, cubic per second]

STATE	WETTED PERIMETER (ft)		SHAPE		SQUARED FROUDE NUMBER		Kn (ft^3/s)	
	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.
Kansas	101 174	1,153	70 110	1,153	0.067 0.098	1,152	1,689 6,628	1,153
Kentucky	107 138	888	55 129	888	0.062 0.161	888	7,036 69,996	888
Louisiana	230 369	362	33 25	362	0.015 0.023	356	58,408 199,909	362
Massachusetts & Rhode Island	54 44	515	34 26	515	0.058 0.052	514	531 2,993	515
Maryland	57 77	591	51 243	591	0.058 0.073	591	398 2,119	591
Maine	205 182	201	84 90	201	0.047 0.046	201	4,451 10,099	201
Michigan	89 85	1,183	50 155	1,183	0.048 0.056	1,183	1,113 4,447	1,183
Minnesota	75 85	545	46 35	544	0.089 0.740	544	1,306 6,232	545
Missouri	398 630	1,771	72 281	1,171	0.054 0.063	1,169	57,367 166,570	1,171
Mississippi	177 354	657	51 53	657	0.042 0.047	656	8,653 26,481	657
Montana	95 117	1,709	51 131	1,709	0.093 0.096	1,709	1,438 5,079	1,709
North Carolina	65 64	1,045	36 38	1,045	0.044 0.058	1,045	753 2,267	1,045
North Dakota	54 119	599	102 1,225	606	0.073 0.147	596	810 3,836	599
Nebraska	137 315	1,587	194 2,801	1,587	0.093 0.085	1,585	739 3,387	1,587
New Jersey	69 110	627	37 28	627	0.040 0.047	627	895 3,603	627

Table 13.--*Summary statistics for computed flow characteristics listed by state for water year 1990*

[continued; S.D., standard deviation; No., number computed; ft, feet; Kn, conveyance times Manning's coefficient of roughness; ft^3/s, cubic per second]

STATE	WETTED PERIMETER (ft)		SHAPE		SQUARED FROUDE NUMBER		Kn (ft^3/s)	
	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.
New Mexico	53 59	1,302	50 114	1,302	0.092 0.089	1,301	177 376	1,302
Nevada	30 33	958	29 26	957	0.092 0.138	955	95 243	958
New York	103 120	1,486	61 58	1,486	0.060 0.060	1,486	1,226 5,906	1,486
Ohio	116 112	819	67 154	819	0.065 0.079	819	1,989 5,963	819
Oklahoma	168 331	981	86 209	981	0.061 0.073	967	7,831 27,761	981
Oregon	105 106	884	48 116	884	0.067 0.080	884	2,642 21,292	884
Pennsylvania	140 213	1,890	86 598	1,890	0.056 0.128	1,889	3,224 18,206	1,890
Puerto Rico	39 29	703	59 65	703	0.047 0.057	703	73 240	703
South Carolina	157 417	608	57 236	608	0.037 0.064	608	6,551 26,974	608
South Dakota	41 92	1,159	43 84	1,159	0.070 0.121	1,157	848 7,840	1,159
Tennessee	126 206	637	52 50	637	0.075 0.234	637	5,438 27,298	637
Texas	151 432	2,099	60 178	2,098	0.065 0.089	2,094	7,417 29,861	2,099
Utah	46 59	1,555	38 30	1,555	0.089 0.102	1,555	233 807	1,555
Virginia	150 152	608	67 170	608	0.042 0.053	608	2,605 5,527	608
Vermont & New Hampshire	95 86	372	48 39	372	0.061 0.071	372	1,767 6,009	372

Table 13.--*Summary statistics for computed flow characteristics listed by state for water year 1990*

[continued; S.D., standard deviation; No., number computed; ft, feet; Kn, conveyance times Manning's coefficient of roughness; ft^3/s, cubic per second]

STATE	WETTED PERIMETER (ft)		SHAPE		SQUARED FROUDE NUMBER		Kn (ft^3/s)	
	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.	Mean S.D.	No.
Washington	115. 167.	1,463	44. 117.	1,463	0.099 0.110	1,457	11,883. 76,352.	1,463
Wisconsin	115. 151.	876	54. 46.	876	0.049 0.051	876	2,334. 7,915.	876
West Virginia	162. 169.	418	60. 41.	418	0.044 0.045	418	6,667. 29,927.	418
Wyoming	68. 75.	1,239	54. 50.	1,239	0.101 0.111	1,239	314. 850.	1,239

COMPARISON OF QUESTIONNAIRE RESULTS WITH COMPUTER DATA BASE

The two parts of the survey have some duplication. Both surveys have information on the number of continuous-record sites, number of measurements per site, and rating of particular measurement types. Data for rating of particular measurement types were not analyzed by the same technique and cannot be compared easily. Numbers for the two surveys that can be compared easily are in reasonable agreement.

The computer data base has 194 more continuous-record sites for 1990 than does the questionnaire. Because two states did not return a questionnaire, this difference is reasonable and not unexpected. Analysis of the questionnaire yielded half a measurement more per continuous-record site than did the computer data-base data. This difference is small.

SUMMARY

The U.S. Geological Survey uses current meters to make tens of thousands of discharge measurements each year. Because of interest in the performance and evaluation of current meters, a comprehensive survey of discharge measurement data and meter usage for water year 1990 was conducted. The survey has two parts: data from questionnaires on current meter usage that were sent to Districts offices and data on discharge-measurements that were retrieved from District computer data bases. Analysis of data from the survey provides summary statistics and information on meter usage, measurement conditions, and discharge data.

Using the mean values from the computer data-base retrievals, the average value of all measured discharges is 1,960 ft^3/s with a mean velocity of 1.52 ft/s. Three-fourths of the discharge measurements are made by wading and most measurements are rated good (error in discharge measurement is more than 2 and less than 5 percent). Most discharge measurements are made in tranquil flow conditions (Froude number <1). The Price type-AA meter is used for more than half the measurements. The pygmy meter is used for most of the remaining measurements. Questionnaire respondents indicated the presence of vegetation as the most frequent cause of fair or

than 8 percent; for poor ratings error is equal to or more than 8 percent). Irregular cross sections, low velocities, rapid stage changes, and shallow depths were also ranked high by respondents as causes of fair or poor measurement ratings.

This information quantifies the conditions in which USGS current meters must operate successfully and the problems encountered when using them. This data may also be of interest to open-channel flow modelers and other hydrologists because it quantifies the range of several common flow parameters for streams throughout the United States.

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