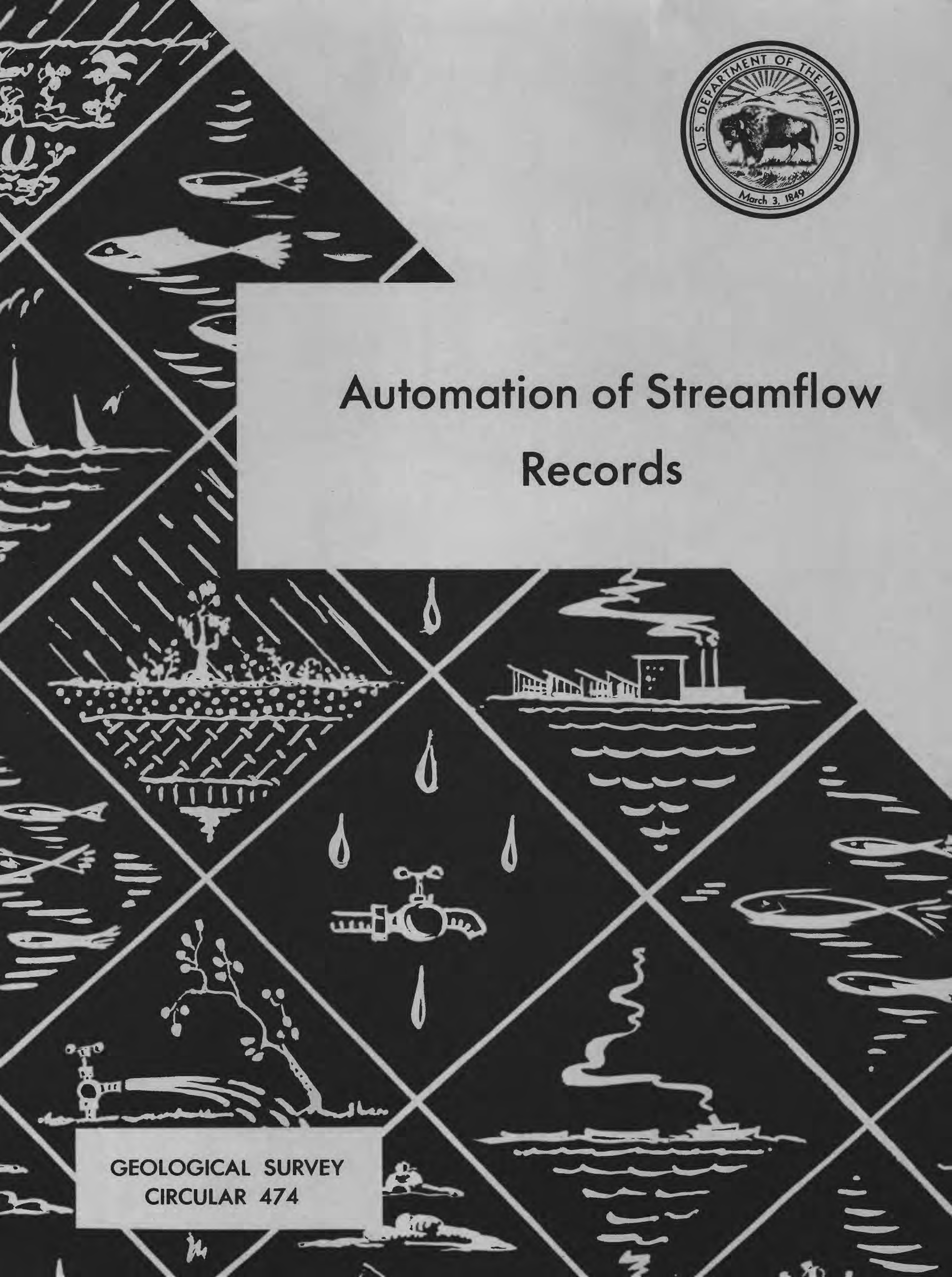
Automation of Streamflow Records



GEOLOGICAL SURVEY CIRCULAR 474

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Prepared by a work group composed of R. W. Carter, chairman,
W. L. Anderson, W. L. Isherwood, K. W. Rolfe, C. R. Showen,
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SUMMARY

A system for automatic computation of daily discharge records has been developed by the U.S. Geological Survey as a result of continuing studies since 1952. Basic components of the system, which is now in pilot operation at 268 streamflow stations, are a digital-stage recorder, a paper-tape translator, and a general-purpose digital computer.

The digital-stage recorder is a battery-operated slow-speed paper-tape punch which records a four digit number on a 16-channel paper tape at preselected time intervals. The recorder is basically a device for coding and recording the position of an input shaft, but it can be adapted to accept a voltage input, to record several variables in sequence, or to transmit data by wire or radio. The paper-tape format is a unique configuration which requires rearrangement before input to any present high-speed digital computer. Because input requirements for different computers vary considerably, this seemingly redundant translation step actually precludes obsolescene of the field recorder. The translation permits adaptation of the basic record to the input form required by any present or future computer.

A complete data-processing system, which utilizes specially designed translators and a standard Burroughs 220 computer, is now in pilot operation. The computation of 268 streamflow records for water year 1961 has provided experience for a critical analysis of this initial processing system and for developing the improved system proposed in this report.

A work group was activated in April 1962 to evaluate the pilot operation and to consider the expansion of the system to the streamflow network, which presently consists of 7,200 gaging stations. This report summarizes the studies and recommendations of the work group.

Streamflow records of most gaging stations are presently computed by manual methods from stage records on strip charts and from stage-discharge relations that are empirically defined by streamflow measurements. This data-reduction process is tedious and time consuming. Studies on automation indicate that much of the data reduction can be done efficiently on a digital computer. A digital system is also more adaptable to automated systems of publication and to rapid storage and retrieval of information. It should speed up the publication process.

The digital recorder was field tested and modified during a 3-year period. Results of intensive tests during the winter of 1961–62 on a modified production model established the recorder as an operational instrument equal in reliability to strip-chart recorders.

The presently used type of translator can be used for the full program recommended, and its use in an expanded system is economically feasible. The state of the art in this field, however, is advancing so rapidly that the development of a more efficient system of translation within the next 5 years appears certain.

The efficiency of the computer program used in the pilot operation was greatly improved through studies made by the work group. The new program, which is now ready for operation, is ideally suited to current computation of streamflow records. It incorporates several new concepts in data

preparation and computation and provides for efficient storage and printout of information. The format of the daily discharge (or daily gage height) tabulation, which is the final output from this system, is suitable as photo-offset copy for inclusion in the annual basic-data reports and is ideal for preliminary distribution by ozalid or xerox duplication.

The expansion rate of the automated system will be limited by financial considerations and the need for training in new techniques. In view of these problems, the work group recommends an expansion rate of 1,000 stations per year. Plans have been formulated within the Water Resources Division for approaching this magnitude beginning in fiscal year 1964. Acquisition of recorders will be financed by Federal funds, and the instruments will be issued to the field offices on a rental basis.

Detailed analysis of the costs of manual and automatic computation indicates that overall savings of about 10 percent can be achieved when 2,000 stations are included in the program. Realization of these savings is tied in with a reduction in personnel assigned to the manual computation phase of the data collection program. The relatively slow rate of expansion, on a nationwide basis, will preclude need for reduction-in-force actions. The normal attrition rate is many times the displacement involved. District programs will need to be diversified, however, to retain enough man-power for field work during flood periods.

Efforts to date have been directed toward automation of routine streamflow computation procedures, but automation also offers great flexibility in special computations, and its application will streamline procedures presently used in manual computations. The advantages of the digital system will doubtlessly increase with advances in computer technology, and utilization of the digital recorder to record other hydrologic parameters will permit automation of many complex computation problems.

INTRODUCTION

Streamflow records are presently computed from a record of stage, recorded in analog form on a strip-chart recorder and from stage-discharge relation that is defined empirically by current-meter measurements. Many of the steps in the data reduction process require tedious and time consuming manual work that could be accomplished more efficiently by digital computers. Records from strip-chart records, however, are not suitable for direct input into automatic computers, nor are manual computation procedures particularly efficient when transferred directly to machine processing. In consequence, the search for applicable automation techniques has involved changes in the basic method of recording information as well as changes in computation procedures.

Studies during the past 10 years on the use of automation in computing streamflow records have lead to a system that utilizes digital-stage recorders in the field, translation equipment at a central unit, and a general-purpose digital computer. Pilot tests of the system during the 18 months ending in May 1962 included the installation of digital-stage recorders at 268 streamflow stations and the automatic computation of discharge records for these stations for water year 1961. These tests have established the feasibility of the digital recorder approach to automation.

A work group composed of personnel of the Water Resources and Administrative Divisions of the Geological Survey was established in April 1962 to study the feasibility of extending this pilot automation system to as much of the whole network of streamflow stations as practical.

The studies and recommendations of the work group are summarized in this report. Attention was given to the following aspects of the program: (1) evaluation of the existing pilot operation, (2) development of a more efficient data-processing and computation system for large scale application, (3) adaptation of the basic program to include current computation of daily discharge and to include provision for computing discharge for shorter time intervals during flood events, (4) evaluation of the cost of producing final discharge records by manual computation and by automation, (5) feasible rate of extension of the automation program, and (6) the impact of automation on field operations and personnel.

The group confined its study to the computation of streamflow records, because these computations represent a major part of the standard data-collection and computation program of the Water Resources Division. A broader study of the application of automation in other phases of the program would be a logical sequel to this report.

HISTORY OF AUTOMATION PROGRAM

Automation efforts within the Geological Survey began in 1952. Initial steps were toward the development of a device that could automatically read graphic strip charts and convert the position of an inked line representing gage height into a discharge record by means of a special-purpose computer that was partly analog and partly digital. This effort was not successful, primarily because of the variable quality of the graphic records and because of the maintenance problems associated with a one-of-a-kind computer. In 1958 the conclusion was reached that successful automation would require the development of a recorder that would produce a digital record of stage so that processing could be done on a general-purpose digital computer.

RECORDER DEVELOPMENT

An automatic digital recorder was developed under contract with the Fischer and Porter Company to record river stage at gaging stations. The instrument, shown in figure 1, is a slow-speed paper-tape punch

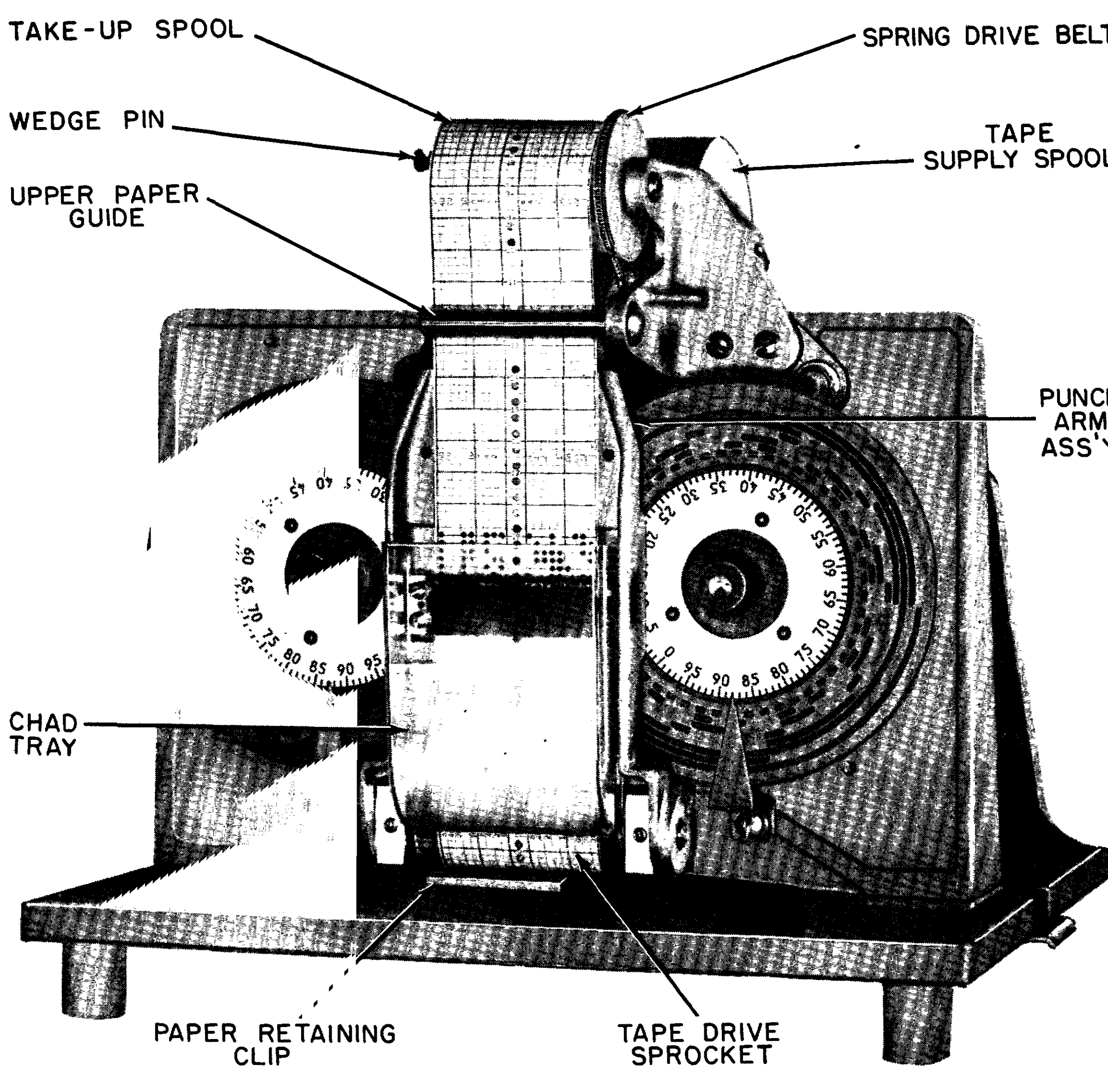

Figure 1.—Fischer and Porter Digital Recorder.

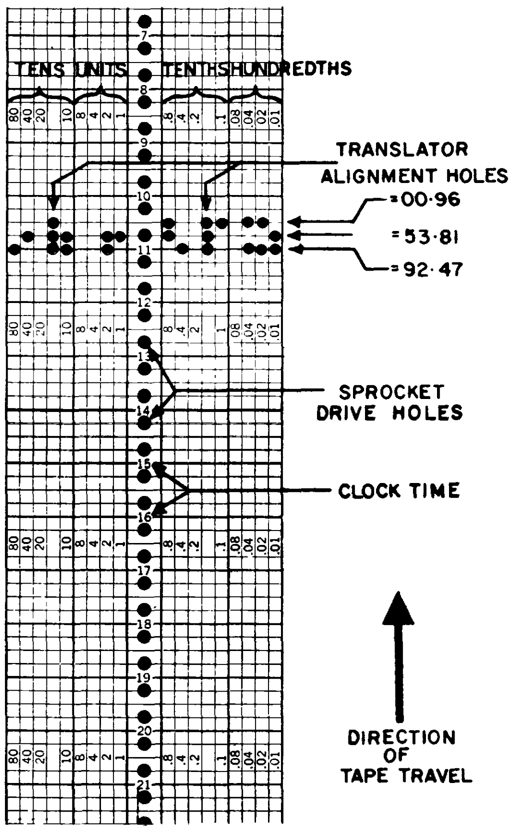

Figure 2.—Facsimile of data tape record from Digital Recorder.

that records a four digit gage height on a punched tape in configuration of holes in a single transverse row across a tape 2-1/8 inches wide. (See fig. 2.)

The tape is punched in binary-decimal code. In this code, each binary digit is related to the other by powers of 2, rather than 10 as in the conventional decimal system. The four binary digits, one, two, four, and eight, are combined in various ways to form a single decimal digit. The digital recorder tape is preprinted with the decimal values of the 16 binary digits (the equivalent of 4 decimal digits). Note in figure 2 the preprinted figures: 0.01, 0.02, 0.04, 0.08, 0.1, 0.2, 0.4, 0.8; and 1, 2, 4, 8; and 10, 20, 40, 80. Hence, the decimal range of gage readings on this particular tape is 00.00 to 99.99 feet. Each readout is on a separate line, therefore a value of gage height is read by adding the total of the punched positions on a given line. The large holes down the middle of the tape are for the feed mechanism on the recorder. The holes in the center strips are for the feed mechanism of the tape reader on the translator. One-tenth inch of paper tape is required for each reading and a roll of tape is 500 feet long, so at 15-minute readings, the tape will last for 1 year. The punch is triggered by a timer at preset intervals.

The paper tape format described above is a parallel-by-character arrangement, an arrangement that requires a minimum of recording equipment and battery power in the field installation, whereas present digital computers require serial-by-character coding in paper tape for direct input. No coding system is universally acceptable, however, because each manufacturer's computer has its own unique requirements for character coding and digit arrangement. The system developed for use in the Survey uses the compact form of basic recording by interposing a translator equipped with pinboards to produce serial-by-character tape in any 5- to 8-channel character coding and any digit arrangement required. This will preclude the obsolescence of thousands of field recorders whenever it is necessary or desirable to change computers. The rapid advance in computer technology indicates that changes in computer equipment will be inevitable within the next few years, probably before the proposed streamflow automation system is fully installed.

The prototype of the digital recorder, delivered in December 1958, was subjected to extensive tests in an environmental chamber to determine its performance under extremes of temperature and humidity. After slight modification in design, 100 production models were procured and distributed for trial in actual field installations. The first deliveries to the field were made in February 1960. Later 400 slightly modified instruments were procured, 200 of which were delivered to the field in October 1960, the other 200 held in reserve.

Field trials of the production models revealed only minor problems with the recorder itself but immediately pointed up the need for additional work in design of the timer unit. Three different types of timers were employed during the first 18 months, none of which gave satisfactory preformance. Finally in May 1961, Fischer and Porter Company supplied 50 Ergas timers that performed so well that 150 more were procured and installed in the field in November 1961. In June 1961, a contract was let for 100 battery-wound, spring-driven Chelsea timers. These also were delivered and installed in November 1961.

Coincident with the procurement of the Ergas and Chelsea timers, and as a final phase of field testing, all recorders were returned to Fischer and Porter Co. in the fall of 1961 for slight modification and adaptation to the new timers. This was followed in November 1961 by a well-documented field test program to determine the performance of the new timers and the modified recorders. By mid-January 1962 it was apparent that the only significant cause of malfunction was the drive motor of the recorder. This problem was easily resolved by substituting a new type motor, which has given excellent service. Performance of the Chelsea timers was significantly better than that of the Ergas timers, although the latter were also considered acceptable. This test program firmly established the Fischer and Porter Digital Recorder, equipped with the Chelsea timer, as a reliable operational instrument. Continuation of the testing program through May 1962 has shown a loss of less than 3 percent of record during the period since modifications were ccmpleted, a loss ratio which compares very favorably with the performance of strip chart recorders.

The digital recorder can be used for recording a variety of data. It is basically a device for coding and recording the position of an input shaft and consequently can be used to record any event that can be expressed in terms of shaft position. It can be adapted to record rainfall, temperature, wind-speed, or other hydrologic parameters. Equipped with a multiplex input system, it can record several variables in sequence. Fitted with contact points in the punch assembly and suitable transmission equipment it serves as a telemetering device to transmit data by wire or radio to a remote location. The digital recorder is thus a versatile instrument which can be used to record hydrologic events in remote locations in a form that permits rapid and economical machine analysis of the data.

SYSTEM DEVELOPMENT

Other components of the automation system have been developed to utilize the record from the digital recorder. A data processing unit was activated and a program for computation of daily discharge was written for the Burroughs 220 computer. Equipment at the processing center consists of translation units, add-punch machines, and other equipment required for mass-handling of punched paper tape.

The computer program used for processing of 1961 water-year records is patterned rather closely after manual computations procedures. Principal output forms are machine adaptations of manual computations forms. A significant block of gage-height data (6 months or 1 year) is translated, edited, listed, and stored on magnetic tape during one or more computer passes. After the ratings have been supplied by the field office the computer computes the daily discharge using the stored gage-height data and lists daily mean gage heights, shift corrections, and discharges on a special form. It also stores daily mean discharges on magnetic tape and lists all peak flow figures above a given base. After quality control checks are performed by personnel at district level, a list of needed corrections are fed into the computer to update the magnetic tape record for the stations, and a final output is produced listing all daily mean discharges on a form suitable for offset reproduction.

EVALUATION OF SYSTEM

Evaluation of this system by the work group revealed several areas where improvements could be made in the interest of overall economy and usefulness. For instance, the storage of all basic data on magnetic tape was originally considered necessary because discharge values were not computed until the end of the water year. Reevaluation of the entire system in the light of almost 2 years of experience led to the development of a new system which requires a minimum of data storage and computes daily discharge on the first pass through the computer. This makes the system more economical as well as more useful in meeting the need for current reports.

RECOMMENDED AUTOMATION SYSTEM

The computation system recommended by the work group is described in the following paragraphs. The computations have been programmed for the Burroughs 220 computer and the system is ready for operation, in an Automatic Data Processing Unit located in Washington, D.C. Several of the new features in the computer program that deserve special mention are as follows: Final discharge records are computed on the first pass through the computer, up-to-date tabulation of daily discharge may be produced at the end of any computation period to satisfy the need for current records, discharges can be recomputed or revised on a second pass through the computer without recourse to the instantaneous gage readings, the input for the stage-discharge relation may be a set of points picked from a conventional rating table at the ends of tangents (or as an alternative as much smaller set of points selected from a graphical log-log plot), for all discharges above a preselected base, gage heights are printed out for 2-hour intervals, and automatic editing features are incorporated in the program. The system is described in sequence of operation:

1. River stage is punched on 16-channel tape by the digital recorder in the gage house.
2. Tape is removed by field personnel at intervals of 30 to 60 days. Upon removal the tape is checked for continuity and quality of record, and appropriate notes concerning identity of the station and quality of the record are made on the tape.
3. The tape, rating table, datum correction, and table of shifts is forwarded from the field office to the Automatic Data Processing Unit. Ratings may be submitted in one of three alternate forms. Discharge may be tabulated for each 0.01 foot of gage height for the part where curvilinear expansion between tenths of feet is necessary, it may be tabulated for each 0.1 foot, or it may be defined by a series of coordinate values at the ends of straight-line segments on log-log plot of the rating curve. The entry of ratings directly from the log-log plot would eliminate the preparation of a rating table in the usual form. Shift adjustments will be prorated with time to give a shift for each day between the days for which values of shift are submitted. A new rating may be put in use at any time during a day, and any shift applicable to the old rating on the same day will be dropped when the new rating takes effect.

   The refinement considered in ratings for the initial run through the computer depends upon the complexity of the rating problem and the completeness of the data available. Sometimes final ratings can be prepared at the outset, at other times the output from the first run will be needed to complete the analysis. In the latter situation only base ratings and approximate shift corrections are supplied.

   Data from the 16-channel tape are translated by the central processing unit onto 7-channel paper tape suitable for input into the digital computer. The information on ratings, shifts, and datum corrections are manually punched on paper tape with an add-punch machine. These two tapes comprise the input data to the computer.

4. The computer converts each instantaneous reading of river stage into a discharge value by a table look-up routine. Discharge application is made to each 0.01 foot in stage up to 20.00 feet. Beyond this limit, application is made to the nearest 0.1 foot. Both daily mean discharge and daily mean gage height are computed as an average of instantaneous values. An equivalent daily mean gage height (the gage height corresponding to the mean daily discharge) is computed for each day so that recomputation, if necessary, can be made at a later date without reference to the individual items of the original base data. Daily mean values of gage height, discharge, and equivalent gage height are stored on magnetic tape. The printed output from the first computer pass consists of two items; a primary computation sheet, which is standard, and a daily discharge sheet, which is optional.

   The primary computation sheet, table 1, gives for each day the maximum, minimum, and mean gage heights, equivalent mean gage height, the datum and shift corrections applied, and the daily mean discharge. In addition, bi-hourly gage heights and the time when maximums occurred are printed out whenever any discharge during the day exceeds a given base figure, or when the difference between successive gage heights is greater than a specified control value.

   The print-out of daily discharge, table 2, which is suitable for outside distribution, lists daily mean discharges for the period from the beginning of the water year to the end of the record being computed.

5. The field offices will use the primary computation sheet in quality checks of the original and computed data, in further

Table 1.—*Primary computation of gage height and discharge*

2–4538.00 Little Cahaba River near Brierfield, Ala., water year ending Sept. 30, 1962

Rating 3 to 9–30

Bi–hourly gage heights, base 3800 CFS (range 0.3)

S	Date	Max.	Min.	Mean	Hr.	EQ–GH	Datum	Shift	Mean Q	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400	Tmax
	3–14	2.92	2.82	2.87	23	2.87			275													
	3–15	2.85	2.77	2.83		2.83			266													
	3–16	2.77	2.65	2.71		2.71			241													
	3–17	2.64	2.55	2.59		2.59			217													
	3–18	2.55	2.51	2.53		2.54			206													
	3–19	2.51	2.47	2.49		2.50			199													
	3–20	2.48	2.47	2.47		2.48			195													
	3–21	3.28	2.48	3.02		3.04			314													
	3–22	2.85	2.54	2.65		2.65			229													
	3–23	2.54	2.46	2.50		2.50			200													
	3–24	2.46	2.37	2.42		2.43			186													
	3–25	3.07	2.37	2.65		2.67			233													
	3–26	3.07	2.58	2.75		2.77			252													
	3–27	2.58	2.44	2.51		2.52			202													
	3–28	2.44	2.37	2.43		2.43			187													
	3–29	2.39	2.37	2.38		2.39			179													
	3–30	2.51	2.35	2.37		2.38			178													
	3–31	7.98	2.56	5.83		5.97			1220													
	4– 1	5.89	3.66	4.45		4.48		0.01	728													
	4– 2	3.65	3.15	3.36		3.36		.02	406													
	4– 3	3.15	2.91	3.02		3.03		.04	322													
	4– 4	2.91	2.79	2.85	21	2.85		.05	282													
	4– 4	2.79	2.78	2.84		2.85		.05	280													
	4– 5	3.52	2.74	2.87		2.88		.05	289													
	4– 6	6.87	3.57	5.42		5.45		.05	1060													
	4– 7	6.76	4.74	5.89		5.92		.05	1220													
	4– 8	4.71	3.80	4.21		4.22		.05	661													
	4– 9	3.78	3.34	3.54		3.55		.05	466													
	4–10	3.33	3.10	3.21		3.21			359													
	4–11	3.29	3.08	3.14		3.14		- .01	338													
A	4–12	15.53	3.32	11.32		11.84		- .02	3690	0456	0702	0912	1025	1167	1315	1447	1534	1548	1475	1286	1002	1745
A	4–13	9.67	4.50	5.74		5.80		- .03	1150	0778	0678	0623	0592	0566	0542	0522	0503	0487	0473	0460	0450	0015
	4–14	4.48	3.81	4.10		4.11		- .04	599													
	4–15	3.81	3.39	3.62		3.62		- .05	459													
	Period	15.53	2.35																			

Table 2.—*Print-out of daily discharge*

Discharge, in cubic feet per second, water year October 1959 to September 1960
(Station no. 1–4780.00)

Day	October	November	December	January	February	March	April	May	June	July	August	September
1-----	11	8.6	11	20	18	21	27	25	16			
2-----	12	11	8.8	18	16	18	17	18	14			
3-----	6.6	7.0	8.7	264	14	15	150	15	13			
4-----	2.3	9.0	10	49	15	14	473	15	13			
5-----	7.5	6.4	8.4	29	15	14	640	14	14			
6-----	5.4	8.0	12	22	124	14	82	14	12			
7-----	4.9	140	222	20	34	14	48	12	12			
8-----	4.8	31	41	19	21	14	34	14	13			
9-----	35	15	24	16	17	14	30	103	11			
10----	11	12	19	16	16	15	26	33	12			
11----	5.0	10	15	16	183	14	23	20	10			
12----	9.4	9.4	291	16	34	14	24	28	112			
13----	5.2	10	168	43	18	14	22	33	67			
14----	21	7.5	33	31	16	14	21	19	16			
15----	16	7.6	22	136	15	15	20	17	40			
16----	8.6	10	20	48	17	23	18	16				
17----	6.4	11	17	23	33	98	18	15				
18----	5.7	11	22	27	132	70	23	20				
19----	9.8	9.5	22	49	372	44	22	15				
20----	6.6	8.8	16	24	37	28	18	14				
21----	6.7	8.3	16	19	23	24	17	14				
22----	6.1	6.2	17	15	24	23	17	20				
23----	7.6	8.6	14	15	20	21	15	94				
24----	22	40	12	15	18	19	16	28				
25----	15	62	15	14	32	17	15	19				
26----	11	16	17	14	200	14	17	36				
27----	8.6	14	17	17	34	16	18	18				
28----	7.9	13	28	59	23	16	16	15				
29----	8.2	15	207	31	23	15	16	69				
30----	7.6	13	49	21	--------	17	15	29				
31----	6.4	--------	25	18	--------	60	-----	22				
Total	301.3	538.9	1,407.9	1,124	1,544	729	1,898	824				
Mean	9.72	18.0	45.4	36.3	53.2	23.5	63.3	26.6				
CFSM	.474	.878	2.21	1.77	2.60	1.15	3.09	1.30				
Inches	.55	.98	2.55	2.04	2.80	1.32	3.44	1.49				
AC-FT												

analysis of the computer stage-discharge relation, and in selecting instantaneous peak discharges to be published. Daily discharges from this sheet can be plotted for comparison with adjacent streams, and the usual studies can be made for periods of ice effect, no gage height record, or backwater from various sources. Estimates can be made for all anomalous periods, and ratings can be revised, if necessary, so that daily discharge can be recomputed from the effective mean gage heights on the second pass through the computer. The information necessary for revision or recomputation is forwarded to the Automatic Data Processing Unit.

6. The final tabulation is the same as table 2 except that it is complete for the year and is produced on the second pass through the computer. Where rating changes have been made as a result of the quality control analysis or where individual discharge figures have been estimated, the recomputation will involve substituting the estimated figures on the magnetic storage record, recomputing other discharge figures from revised ratings and the equivalent daily mean gage height, and printing out of the final discharge figures. The print-out from this final computer pass will be for the complete year. The format of the output is suitable for direct offset reproduction. The data on this form will be also be stored on magnetic tape for permanent storage.
7. A tabulation of daily mean gage heights may also be printed out during the second computer pass for stations designated by the field offices. The tabulation will be prepared only for those stations for which there is a specific need.
8. The documentation file in the field offices will consist of the original measurement notes, the 16-channel tapes, a station analysis, a list of discharge measurements, a rating curve, the primary computation sheet, a table of daily mean discharges from the final computer run, and possibly a rating table.

SPECIAL SYSTEMS AND COMPUTATIONS

The availability of data in digital form will permit great flexibility in meeting special problems, and auxiliary programs are being planned to take advantage of this potentiality. Programs now being considered include the following:

1. Computation of instantaneous discharge for unit hydrograph studies.
2. Computation of daily discharge where water slope is a rating factor.
3. Computation of daily discharge where rate of change of stage is a factor.
4. Computation of daily discharge in tidal reaches.
5. Development of the basic computation routine to include shifts that vary with gage height.
6. Computation of discharge, both instantaneous inflow and daily mean inflow where the gage is located in a pond.
7. Computation of discharge from sonic observations of velocity.
8. Automatic plotting systems.
9. Automatic quality control of data.

In addition to these surface-water items, serious consideration could be given to developing a program for computation of sediment and chemical load from the discharge records and samples of concentration.

EXPANSION OF AUTOMATION SYSTEM

RECORDER ACQUISITION AND DISTRIBUTION

The Geological Survey and its cooperating agencies presently operate about 7,200 streamflow stations at which the installation of digital recorders might be considered. The rate of expansion from the present pilot operation to such a large scale program will be regulated by several factors. Limitations are imposed by available money, by the plant capacity of the instrument manufacturers, and by the ability of our own organization to install the new units and to become familiar with the new procedures involved. Operational problems inherent in the switchover from a manual to an automated system may actually control the expansion rate. Training is thus a dominant factor in the expansion process and is an item that needs to be given a high priority. District personnel must learn to operate with digital recorders and to efficiently utilize the records obtained. Development of efficient data handling methods in the Automatic Data Processing Unit will also require time. In light of these factors it is recommended that the installation of digital recorders be limited to a rate of about 1,000 per year.

It is estimated that the automation system can be profitably applied to 5,000 streamflow stations now operated by the Geological Survey. Additional installations will be feasible when programs are developed for stations where discharge is not a function of stage only, and when more elaborate instrumentation systems are developed to record simultaneously several variables. Dual operation of the strip chart and digital recorders will be desirable at some sites, such as key sites used in computation of ice-affected records.

The most profitable expansion scheme is to equip one or more moderate-sized districts and subsequently to distribute other recorders in blocks of about 50 each to other districts. Other installations would of course be permitted at new stations or where special applications of the recorders are involved. In succeeding years, efforts would be made to complete the coverage in selected districts in preference to obtaining partial coverage on a country-wide basis. The recommended pattern of distribution should contribute to the solution of operational problems and provide the experience needed to refine processing techniques.

In line with this philosophy, arrangements have been made to install a digital recorder at each gaging station in the Boston district, which cover the states of Massachusetts, New Hampshire, and Vermont. This district has had experience in the pilot operation and is interested in further development of the program. Also, a block of 50 instruments will be installed on the Gila River research project in Arizona to record rainfall, river stage, and ground-water levels. This is a new application of the digital recorder.

PROCUREMENT POLICY

The following plan for procurement and financing has been developed jointly by the Water Resources and Administration Divisions.

1. Initial procurement of digital recorders by advance budgeting of Federally appropriated funds will start in fiscal year 1964 and continue in 1965 and 1966 at a rate of 1,000 recorders per year for each of the 3 years.
2. Recorders will be rented to the district and project offices at a uniform rate. The rental rate, which is based on an estimate of the probable useful life of the recorders and other considerations, has been set at $40 per year. The rental rate in future years will be governed by actual experience on the life span of the recorder.
3. The instrument maintenance costs will be borne by the using office or project.
4. The rental system will become effective July 1, 1963.
5. Field offices will be permitted to make advance payment of rental charges to help even out fluctuations in other operating costs.

EXPANSION OF CENTRAL PROCESSING SYSTEM

Increase in the number of digital recorders will require proportional increases in personnel and equipment in the Automatic Data Processing Unit. Present translation equipment is adequate for processing the output from about 1,000 digital recorders, and the system can be expanded gradually as the load increases. About 8 high-speed translators will be needed to handle data from 5,000 digital recorders. There is little likelihood, however, that the ultimate data processing equipment will consist of modules of the equipment now used. Within the next few years equipment may be available at reasonable cost to translate the 16-channel recorder tape directly onto magnetic tape in a format suitable for high-speed input to the computer. Such equipment will make obsolete the present translation equipment and will speed up processing rates. Economic expansion of the program, however, does not hinge upon development of high-speed translation equipment, because extention of the present system to meet the ultimate needs is economically feasible.

COMPUTER FACILITIES REQUIRED

A general-purpose digital computer is an integral part of the automation system. The proposed system is based on the use of the Burroughs 220 computer, which is currently maintained and operated in Washington, D.C. by the Geological Survey. This computer is currently operated for one 8-hour shift per day.

Computation of 5,000 records will require about 4 hours time each day on the present computer, and thus a two-shift operation will be required. However, expansion of other programs within the agency will very likely require an increase in computer capacity either at a central location or at regional centers. Decentralization of computer facilities would facilitate the computation of streamflow records as the work load approaches its ultimate level.

FINANCIAL ASPECTS OF AUTOMATION

To evaluate the economic aspects of shifting from manual computation techniques to an automated system, cost studies were made on each system, and the costs involved were compared.

COST OF MANUAL COMPUTATION

In June of 1959, ten districts were asked to keep detailed records of the time spent in various phases of manual records computation. A breakdown was requested showing costs in each of six major computation steps, gage-height analysis, rating analysis, discharge computation, special computations such as those for ice effect and periods of no gage-height record, preparation of the table of daily discharges, and preparation of the station description. This cost study covered a full year, and represents documentation of work done in preparation of a total of 1,146 station years of record. Results of the study are shown in table 3. The costs shown are computed on the basis of salary charges at each grade level increased by 33 percent to account for retirement, leave, health insurance, and cost of direct supervision. The figures do not include overhead items such as traveling expenses, rent, or other significant non-salary items pertaining to overall operations, because the shift from manual to automated procedures may not effect such items. Comparable factors in the study are salary charges for manual computation steps which can be compared with the machine costs for the same operations. Shift from manual to automated computation procedures will eliminate 90 percent of the work in gage height analysis, 10 percent of the work in rating analysis, all of the discharge application work 80 percent of the work preparing the daily discharge table. Additional saving in manuscript preparation is possible if the machine-produced daily discharge table is used as the offset copy for publication. The dollar value of work shifted to the automated program is computed on page 12.

Table 3.—*Summary of cost for manual computation*

[Cost in dollars per station-year of record]

District	Recorder chart analysis	Rating analysis	Discharge application	Special computations	Preparation of daily table	Manuscript preparation	Total cost of office computation	Field operations	Total of office and field costs
A-----	109	211	137	43	16	38	554	342	896
B-----	112	99	83	11	17	74	396	306	702
C-----	131	143	55	18	11	43	401	293	694
D-----	105	109	99	73	22	40	448	240	688
E-----	77	64	73	29	14	27	284	307	591
F-----	86	86	65	14	9	18	278	290	568
G-----	68	79	77	24	11	29	288	260	548
H-----	52	92	52	28	11	26	261	294	555
I -----	73	125	58	25	10	14	305	196	501
J -----	27	45	36	13	6	15	142	---------	-------
Average of 8 central values	85	100	70	24	12	30	321	272	594

Computation step	Cost by manual techniques (dollars per station year)	Percent of work done by automation	Value of work done by automation (dollars per station year)
Gage height analysis	85	90	76
Rating analysis	100	10	10
Discharge application	70	100	70
Special computations	24	0	0
Preparation of table and daily discharge	12	80	10
Preparation of station description	30	0	0
Field operations	272	0	0
Total	----------	----------	166

COST OF MACHINE COMPUTATION

Machine computation costs consist of instrumentation costs, data preparation costs, and computer costs. Instrumentation costs include the rental and maintenance costs of the digital recorder. Data preparation costs are those required for equipment, salaries, and supplies necessary for operation of the Automatic Data Processing Unit. Computer costs are charges for time on the computer and include related supplies and salaries as well as the larger item of computer rental.

The rental fee for the digital recorder has been set at $40 per year. Batteries and maintenance costs will add about $10 per year to make the total cost to the districts $50 per year.

Data preparation and computer cost are related to the number of recorders in operation and the amount of data collected at the individual site. A record of 24 readings per day will pass through the translator in one-fourth the time required for a record of 96 readings per day, and input of this same record into the digital computer is also proportionally faster. The difference in total cost, however, is not in direct proportion to the number of gage readings on the data tape because handling costs and the cost of preparing supplementary data are not reduced, and also because the same amount of computation time is required for the final pass through the computer. A conservative estimate is that overall costs for data preparation and computer processing can be reduced by at least 10 percent by changing the recording frequency from 96 to 24 readings each day. More experience in the data processing phase is needed before accurate figures of relative cost can be determined. For this study of comparative costs, the processing costs are based upon the capabilities of translating equipment now in use and on digital recorder records containing 96 readings per day.

Estimates of computations cost for the automated process are summarized below. Costs shown for data preparation are the overhead and materials cost of the Automatic

Estimated cost of automated computations system

[Cost in dollars per station-year of record]

Number of digital recorders in operation	Data preparation	Computer charges	Recorder rental and operation	Total annual cost	Net savings*
250	80	40	50	170	----------
500	50	40	50	140	26
1,000	35	40	50	125	41
2,000	30	35	50	115	51

*Computed using $166 as the comparative cost of manual computation.

Data Processing Unit divided by the number of records indicated. The unit costs for these items decreases as the number of digital recorders is increased. Other unit charges are more nearly fixed and do not vary significantly with increase in the size of the operation.

COMPARISON OF MANUAL AND MACHINE COSTS

Direct comparison of overall costs for manual and machine methods indicates that operation with about 250 digital recorders is near the break-even point. The use of digital recorders in numbers less than this would not be economical; however, significant savings can be achieved with 500 or more recorders in service.

The use of digital recorders during the high-cost period before significant numbers are in service can be justified by placing them at sites that are more difficult than average to handle by manual methods, such as streams that are subject to power regulation or frequent flood peaks and that require relatively large expenditures for manual analysis. Savings of significant magnitude can be obtained by the use of digital recorders on such streams even though the unit cost of mechanical computation is high.

It should be emphasized that figures for this comparison are based upon the configuration of equipment now available and on a system involving 96 gage readings each day. Additional savings can be achieved immediately by recording only 48 or 24 readings a day for those stations for which this is sufficient refinement. At some future time savings may be possible by use of improved translation equipment. Other savings will accrue through the use of discharge tabulations produced by the computer as photocopy for reproduction of annual basic-data reports and for reproduction in the Water-Supply Paper Series.

EFFECT OF AUTOMATION ON PERSONNEL

Present staffing practice centers around use of one crew for performance of both field and office phases of the data collection program. This practice provides a cadre of trained personnel for use during flood periods and permits considerable flexibility in the number of men assigned to field duty. As the shift of computations from manual to machine methods will eliminate over 50 percent of the office computations, a reduction in personnel will be required to finance automation costs if monetary savings are to be realized. This reduction in personnel may be realized within a district either by an actual reduction in force or by a seasonal shift or personnel from the basic data collection program to some other type of assignment. The increasing diversification of the Water Resources program in the Geological Survey may fit in well with this change in computation method.

Magnitude of the personnel shifts involved can be estimated from the cost studies. Table 4 shows the time spent in man-hours per station-year of record for each of the data collection steps. Figures shown are overall averages without segregation by grade. Arithmetic manipulation of these man-hour figures along the same pattern as was applied to the dollar cost figures shows a reduction of 45 hours in the time spent on the computation steps listed. Manual computation requires 83 man-hours per station-year; with automation, only 38 man-hours will be required. Conversion of these figures into terms of operating load per man gives a more graphic picture of the significance of the shift. There are approximately 1800 man-hours in a man-year. (260 days less 33 for leave and holidays equals 226 days or 1808 man-hours.) On the basis of 160 man-hours now required per station-year for both field and office work, the present work load is at a rate of 1800/160 or 11.3 gaging stations per man. If personnel is reduced in direct ratio to figures shown, the work load after automation would be 1800/115 or 15.7 gaging stations per man. If the amount of fieldwork is held constant, this would imply almost a 40 percent increase in the field duties of each man. At the present time the average ratio of field to office hours for each man is 48:52. The projected ratio would be 67:33.

A comparison may also be made between the normal separation rate within the Survey's Surface Water Branch and the displacement rate that will result. Installation of digital recorders at the rate of 1,000 per year would cause a displacement of about 25 people each year as compared with a total of 161 personnel separated from the Branch during 1961.

Although these figures are only approximate, they do indicate the degree of readjustment involved. As the conversion will be

Table 4.—*Summary of man-hours required for manual computation*

[Figures shown are man-hours per station-year of record]

District	Recorder chart analysis	Rating analysis	Discharge application	Special compu-tations	Prepara-tion of daily table	Manuscript preparation	Total cost of office computa-tion	Field operations	Total of office and field costs
A-----	30	57	34	10	4	8	143	88	231
B-----	30	23	22	3	4	19	101	88	189
C-----	39	38	16	5	3	10	111	92	203
D-----	28	26	27	16	5	8	110	63	173
E-----	23	16	21	7	4	6	77	86	163
F-----	25	24	17	3	3	4	76	88	164
G-----	18	20	19	5	3	7	72	69	141
H-----	16	22	15	6	3	6	68	80	148
I -----	19	31	16	6	2	3	77	55	132
J -----	6	9	8	2	1	3	29	---------	--------
Average of 8 central values	24	25	19	6	3	6	83	77	160

gradual, no reduction-in-force actions or large scale dislocations are anticipated. However, the present balance of field and office work will be significantly changed and the type of personnel hired may gradually change. In many districts expansion of diversified activities, which have been held up for lack of qualified personnel, will be made possible by the relief from a significant part of the computation load.

EFFECT OF AUTOMATION ON REPORTS

TIMING OF ANNUAL REPORTS

One of the objectives of this automation program is to reduce the delay in publishing annual reports of daily discharge. Economic considerations dictate that the capacity of the Automatic Data Processing Unit be geared to the total volume of records processed each year so that working at a uniform rate it could process 1 year's output from all the digital recorders within 1 year. Therefore, if records are submitted currently the Unit can operate on a current basis, but if records are held back and submitted annually there will be a year's delay in production. The computation system permits efficient processing of relatively short periods of record, the optimum period being about 3 months. Submission of records on a quarterly basis would permit records for the water year ending September 30 to be computed by about January 1.

TIMING OF CURRENT REPORTS

Success of the automation program will depend largely on how well the program meets the need for currently computed records. For some gaging stations records of discharge are needed soon after the end of each month, while for other stations an unexpected need may arise for several months of discharge records to be made available in a few days. The computation system is well adapted to the former condition. The limiting factor is the capacity of translation equipment, which now has a peak capacity of $7\frac{1}{2}$ station-years (90 station-months) per day. Although this rate cannot be maintained for any extended period, several hundred monthly records can be handled in a few days. Development of methods for handling emergency requests for quick computation of a large amount of record requires additional study. It may be desirable to place a premium on such requests that would permit financing overtime operation of the translating equipment so as to minimize delays and avoid disruption of the normal flow of data. If the volume of such requests becomes significant, a subunit should be set up to handle them. In any event a system should be devised within the framework of the automation scheme to permit rapid computation when needed. Elapsed time between the receipt of the 16-channel tapes and the mailing of primary computations sheets can be reduced to less than 48 hours under optimum conditions.

PUBLICATIONS TECHNIQUES

The automation system is well suited to the monthly distribution of current reports where required and to the preparation of the annual basic-data reports at District level. Current records distribution can be made by means of ozalid or xerox copy of provisional figures on the daily discharge table (form 9-211M). The final discharge figures, produced on this same form, can be assembled with the station description and used as photo-offset copy for the annual basic-data reports.

Further study of printing techniques is required to adapt the output of the automation system to the publication of the daily discharge in Water-Supply Papers. Present editorial standard and the diversity of copy material, some produced manually and some produced by machine, make automation of publication phases of the 5-year Water-Supply Paper series a more complicated process. One feasible system would be the production of all daily discharge or daily gage height tables on form 9-211M by the computer, using the records from automatic computations directly and hand-punched entry of manual computed data. These tables could then be assembled with the manually typed station descriptions for photo-offset copy.

SUPPORTING STUDIES

SIGNIFICANCE OF RECORDING FREQUENCY

Computations based on a series of discrete observations taken at uniform time intervals are subject to errors that depend upon the complexity of the hydrograph and on the time interval used. If the recording interval is reduced sufficiently, these errors can be eliminated, but because computation costs are directly related to the number of gage readings used, a moderate amount of error must be permitted. Errors in the mean discharge and errors in instantaneous discharge must both be considered.

Recording errors are of two basic types—random errors due to surge, and definition errors caused by undefined stage changes between gage readings. Errors due to surge may have a significant effect on instantaneous values, but because they are random in character they will not seriously affect daily means. Decrease in time interval will not reduce surge errors in recorded maxima, and acceptance of small errors from this source will be necessary where surge cannot be eliminated.

In contrast to problems with surge, which are minor in most instances, the size of the definition errors is directly related to the recording interval and to the rate at which stage can change. A decision on the recording interval will have to be made for each station on the basis of an allowable error in daily means. It should be pointed out that the maximum stage, between visits, can be recorded independently of the digital recorder by crest-stage gages or by very simple devices clipped to the float tape. Therefore, the allowable error in definition of the maximum stage for major peaks need not be the controlling criterion for selecting the recording interval.

Geographical location, drainage area, and proximity to sources of regulation are the most significant factors in selecting a recording interval. To give some measure of the significance of these various factors, a comparative study of the results of computations based on 96, 48, and 24 readings per day has been made on the computer. The 59 stations selected for study covered a range in drainage area in each of five districts; Boston, Massachusetts; College Park, Maryland; Tuscaloosa, Alabama; Topeka, Kansas; Menlo Park, California. Discharges were first computed by using 96 gage readings per day and were then independently computed using 24 and 48 readings per day. Daily discharges were compared using discharge values from the 96 per day computation as a base, and the standard deviations of the departures, expressed in percent of the base, were computed. Standard deviations for stations along the Atlantic seaboard and those for stations in Kansas have been plotted against drainage area in figures 3 and 4. The significance of drainage area and regional or climatic factors is very evident in these two graphs. For stations along the Atlantic seaboard the standard deviation of departures for computations based on hourly (24 per day) gage readings is less than 1 percent for drainage areas greater than 100 square

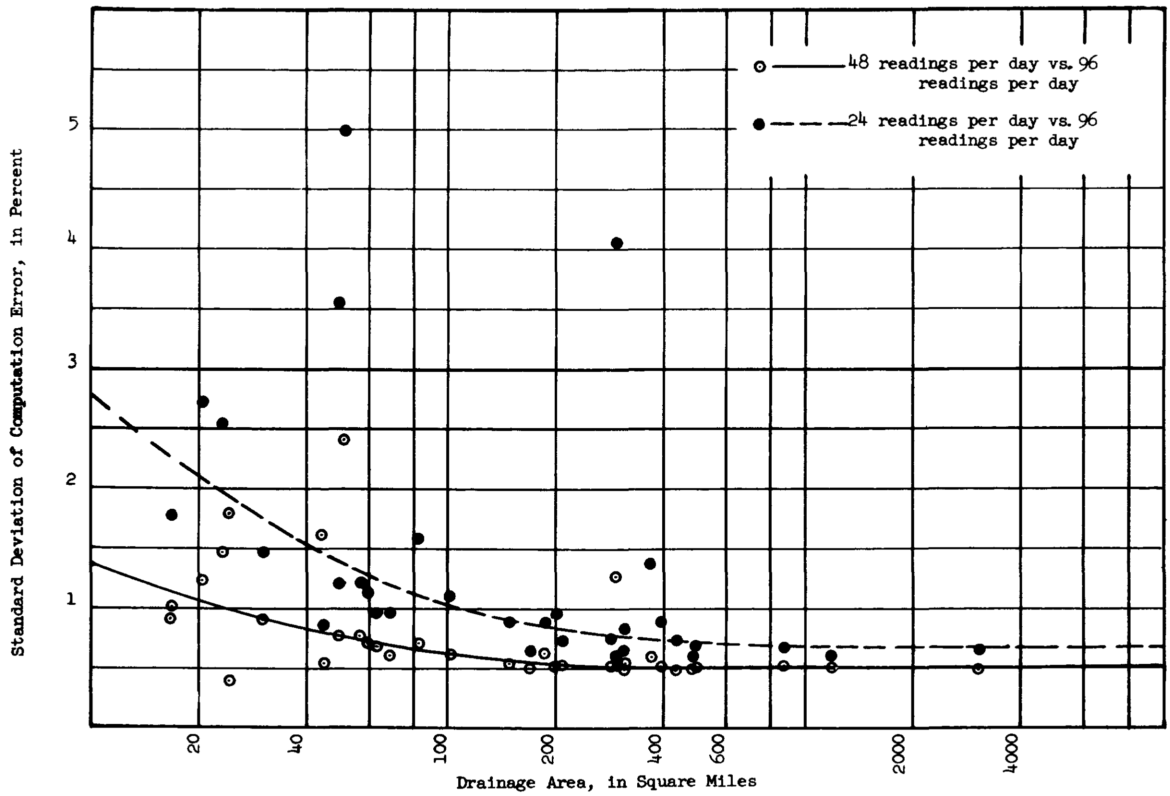

Figure 3.—Comparison of computations based on 96, 48, and 24 readings per day for stations along the Atlantic seaboard.

miles. Computations based on 48 readings per day retain this same accuracy for drainage areas as small as 40 square miles. For drainages smaller than 40 square miles 96 readings per day are required. In contrast, the same accuracies in Kansas require gage readings at 15 minute intervals (96 per day) for drainage areas of less than 300 square miles, and a recording frequency of at least 48 readings per day for all drainage areas below 5,000 square miles. Hourly gage readings in this area can safely be used only on streams with very large drainage areas.

Although decision as to the timing interval required at a given site will depend on the stage characteristics of the stream, a rough approximation of the number of recorders that will eventually be operated at various recording intervals can be computed from an average curve relating drainage area and required recording frequency. Using a 1 percent standard deviation as a criterion, average curves based on data from all 59 stations used in the analysis, suggest that definition of hydrographs at gaging stations on drainage areas of less than 200 square miles will require 96 readings per day; that records from drainage areas ranging from 200 to 2,000 square miles can be computed from 48 readings per day, and that records from drainages larger than 2,000 square miles can be defined by 24 readings per day. Of the gaging stations in the national network, 50 percent are on streams of 200 square miles or less drainage area, 35 percent are on streams ranging from 200 to 2,000 square miles in drainage area, and 15 percent are on streams whose drainage areas are over 2,000 miles. Projecting these figures to the ultimate system involving 5,000 digital recorders would indicate that 2,500 will record at 15-minute intervals, 1,750 will record at 30-minute intervals, and 750 will record at 60-minute intervals.

Operation of recorders in this general pattern will reduce the translation load by about 30 percent below the load if all stations used 15-minute intervals, and this will result in lower processing costs.

COMPARISON OF AUTOMATED AND MANUAL COMPUTATION ACCURACY

Consideration of the relative accuracy of automated and manual procedures involves assessment of the relative accuracy of both the base data involved and the actual computation steps employed. Base data and analytical work in connection with the rating are identical in either case; thus the comparison reduces to the relative accuracy of the gage height records and of the methods employed in converting these records into equivalent discharge figures.

Digital representation of data is inherently more precise than graphic representation; hence gage height records, recorded in digital form, are free from many small errors that are involved in strip-chart recordings. Once a digital recorder is properly set, the relation between float position and the information recorded on the paper tape is uniquely fixed. There are no corrections needed for paper skew, paper expansion, side play in pen carriages, or reversal point errors, and time corrections are minimal because the timer is not linked mechanically with a paper-drive mechanism. Reduction of data is much more accurate because translating equipment is much less apt to err than personnel who read and record chart values. The only errors that can occur are those due to recorder or translator malfunction (errors generally large enough to be readily apparent) and those due to recording interval (previously discussed). Assuming a properly selected recording interval, the definition of the stage record in digital form should thus be superior to that which can be obtained from a strip chart.

Manually computed daily mean discharges are normally obtained by application of graphically determined mean gage heights to the rating tables except on days when the fluctuation in stage is large enough to introduce an error of a predetermined amount in the resulting discharge. This manual system thus permits an error, always negative, in all days when significant changes in discharge occur. The maximum error allowed ranged from 2 to 4 percent depending upon standards determined in each district. By way of contrast a daily mean discharge computed from a digital record is based upon individual application of each of the gage readings to the rating. Each day is computed in identical fashion so that subdivision errors are almost nonexistent regardless of the variability of

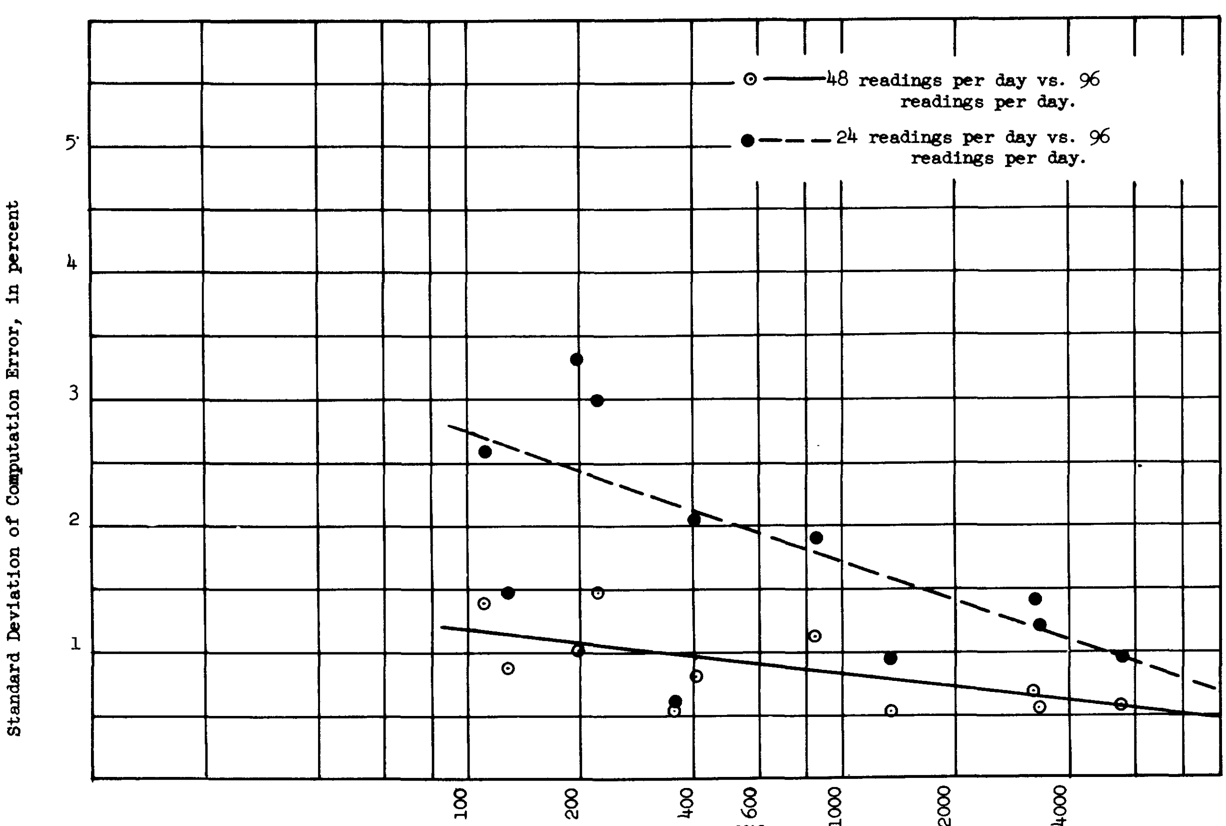

Figure 4. —Comparison of computations based on 96, 48, and 24 readings per day for stations in Kansas.

the stage. Computations of monthly summary figures by the automation system are also free from human error. Manual computations do permit greater flexibility in application of ratings by the use of variable shift corrections within a day, but provision in the automation system for a rating change at any time within the day allows enough freedom to meet all but very extreme conditions.

In summary, digital-recorder records are inherently more accurate except in certain very special circumstances, because the computational system is mathematically more precise and human error is eliminated from the routine; thus, a small but significant quality improvement in the average record is possible by a shift to automated procedures.

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