COMPUTERS AND HYDRAULICS

by

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ABSTRACT

Experiences of a hydraulic laboratory in using computers for simple and complex hydraulic problems showed that direct application of computers to everyday problems in a small engineering office is practical and easily established with reasonable effort. After about 30 hrs training in a mathematically oriented programing language, most engineers were able to program their own work for electronic digital computers, making programs for small routine problems practical. Most programs were small, but compared to manual methods, time was saved with each, adding up to a significant saving in man-days. This freed engineers for professional tasks, and more work was undertaken than would have been otherwise. Suggestions for computer application in small offices include: /(1) Use formal teaching methods to instruct engineers in a mathematically oriented programing language; (2) encourage engineers to write in a simple manner their own programs for small problems; (3) obtain the services of professional programers where large generalized problems are involved; (4) make the computer readily available to the staff; (5) obtain the cooperation of a large part of the staff./ Engineers trained in programing will attack complex problems previously impractical because of excessive arithmetical operations.

DESCRIPTORS-- *computers/ analog computers/ digital computers/ *hydraulics/ hydraulic models/ hydraulic engineering/ programming languages/ training/ calculations/ *engineering personnel/ economies/ mathematical analysis/ civil engineering/ research and development/ electronic equipment/ *computer programing
IDENTIFIERS-- FØRTRAN/ problem solving/ problem definition/ debugging runs/ electroplotters/ fluid computers/ repetitive tasks

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Introduction

It is inconceivable that engineers living and working in the "space age," surrounded by engineering and scientific marvels of all kinds, could question the value of modern electronic computer techniques applied to their everyday problems. If some do, it is probably because they have not become familiar with the capabilities and accomplishments of the ever easier-to-use computers. It is probably their lack of information on computer accomplishments that makes them insist that because their problems are not repetitive in nature the computer would be too much trouble; because their problems have always been solved with a slide rule or desk calculator that the computer is not adaptable to their needs. Occasionally these feelings are justified but more often the engineer is losing an opportunity to eliminate tedious, noncreative labor from his work when he refuses to recognize the computer. However, to take advantage of the tremendous scope of work that can be turned over, with complete confidence, to a computer, the engineer must understand the capabilities and limitations of computers and develop confidence in their use. He must learn their languages and learn, in effect, to talk to the machine.

The increasing difficulty of engineering tasks resulting from the necessity of constructing more complex projects and structures in

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less favorable sites results in a wide variety of engineering problems for the Bureau's Hydraulic Laboratory. Problems arise in: energy dissipation, pipeline distribution systems, air demand at gates and valves, irregularities and misalinements in surfaces, crest and transition sections for spillways, instrumentation, friction losses, discharge coefficients, canal structures, sediment control, channelization and bank protection, wave studies, and many special problems. Programs relating to many of these problems have been written by laboratory branch personnel for computer use. A brief description of a broad cross section of programs which have been written and utilized is:

1. Computations to determine seepage measurements from canals
2. Computations regarding fall velocity of particles in water
3. Channel volume and wetted surface area calculations
4. Integration of hydraulic forces on vertical stilling well
5. Computations of variation in hydraulic model pressures
6. Water surface drawdown profiles
7. Water surface backwater profiles
8. Offset generation for hydraulic model layout
9. Venturi meter calibration
10. Roughness calculations for circular conduits
11. Calculations of downpull on hydraulic model gates
12. Calculations regarding discharge measurements with radioisotopes
13. Calculations on a critical depth flume
14. Calculations on design procedures for spillway buckets

15. A fourth degree two-variable parley for correlation programs
16. Calculations on depth factors for inlet bucket design
17. Data reduction for a ground-water model
18. Flow nets for 90° offsets into the flow
19. Calculations for best fit curves to data points
20. Analysis of air demand for a jet-flow gate
21. Calculations for ground-water flow nets
22. Calculations regarding hydraulic model velocity conditions
23. Calculations to analysis electronic pressure transducer data
24. Farwell tractive force tests
25. Discharge computation for a Cole pitometer
26. Calculations of open-flow meter registration tests
27. Calculations to determine the fit of a tenth degree polynominal to a velocity traverse
28. Statistical analyses of physical roughness
29. Reduction of model data for comparing to prototype calculations
30. Calculations for machine shop in cutting complex hydraulic model parts
31. Computation of tables to aid in obtaining Preston tube data from hydraulic model

Contained in this paper are the experiences of one hydraulic laboratory in utilizing a computer and in applying the computer to both simple and complex hydraulic problems. Included are the reasons it was felt desirable to acquaint the engineering personnel with computer methods, how this task was undertaken, and how successful it has been.

Because computers are relatively new and some engineers may not yet have an understanding of the terms which have developed along with computers uses, an attempt has been made to define terms as they are used. To some readers this may be oversimplification; however, the author believes that the definitions will make the paper more readable for many engineers who have not had the opportunity to become intimately associated with computers.

Initial Considerations

An individual given the choice will always choose familiar tools and methods over the unfamiliar. If the unfamiliar tool is a computer he may exhibit an extreme reluctance to utilize it. This reluctance may be due to a number of factors including: (1) insufficient knowledge of computer capabilities, and (2) the inability to obtain the immediate use of a computer and thus the possibility of obtaining rapid results for small problems.1/

There are several facts regarding computers that are well known to everyone. The computer is a powerful tool which can economically be

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1/Numbers refer to references.

used for long and tedious or repetitious calculations. Computers require little supervision during operation, a short operating time compared to manual operations, and if properly programed, they leave little chance for error. The newer languages, oriented toward problem solutions, are greatly reducing programing difficulties.

Engineers learning to use the computer soon find: (a) that people who learn to use computers have confidence in them and continue to submit data for computer analysis; (b) that professional programers are primarily interested in methods and engineers are primarily interested in results; (c) that an engineer may be reluctant to explain his problem to a professional programer (who may not be an engineer, and because some of the time allowed for solution of the problem must be spent in explaining the problem to the programer small problems are thus made impractical); (d) that acquainting personnel with a simple language of the FORTRAN (FORmula TRANslation) type is not difficult; and (e) in doing so, many of the smaller problems which are usually worked on a desk calculator can be made practical for machine solution.

The information that was analyzed to provide a basis for writing this paper tends to indicate these thoughts are correct and that training in computer programing for engineers engaged in productive work is desirable.

Training

Although two types of computers are in general use (digital and analog) the largest potential for engineers lies in the electronic digital computer. The first step in development of this potential (in the laboratory which provided data for this report) was to teach a short course to all engineering personnel. In this course, emphasis was placed on how to obtain results rather than on the internal operation of the equipment. The course consisted of six 1-hour sessions using the first six chapters of a textbook.2/ The goal of this course was to provide the basic knowledge necessary to transfer a small problem into a practical computer program which would give results that could easily be interpreted by the engineer. Engineers were encouraged to program in as simple a manner as possible and to make no attempt to minimize the number of instructions to the computer in order to reduce either the time necessary for punching instructions into cards or the time necessary for the computer to execute the program.

Engineers were encouraged to take larger programs to the data processing center for professional programing and to seek the aid of professional programers whenever difficulties were encountered. The course was considered quite successful. Of the 16 persons taking the course, 11 wrote, or aided in writing, programs, and 5 of these individuals have become quite skillful at programing.

Following this course, a computer manufacturer's representative conducted classes and provided advanced training for many of the personnel, thus supplementing the earlier classwork. The advanced training was given during working hours and consisted of 30 hours of instruction over a 2-week interval. Tests, homework, and grades were given. An advanced form of FORTRAN, which is a mathematically oriented programing language, was taught. This training provided a firm background for participating engineers.

Training engineers in the use of analog computers for solution of problems associated with analog computers (such as the solution of differential equations) has been undertaken on a limited basis.

When the analog computer is used results of the computer solution are often desired immediately so that they can be used for continuing studies. Often it is desirable to search for optimum conditions during solution of the problem by changing the values of electronic components. Therefore an analog computer becomes most effective if those acquainted with the problem actually run the machine, or at least take part in its use. This simplifies the link between the physical problem being studied and the computer solution by allowing an engineer familiar with the problem to change the value of electronic components and observe the results on the desired output. To aid engineers to actually use the analog computer two papers emphasizing the basic characteristics of the fundamental computing elements of electronic analog computers (the high gain d-c amplifier, integrators, diode function generators and attenuators) were compiled as training aids by 2 staff members. The purpose of these papers was to give the engineer a basic understanding of the general purpose of the electronic analog computer, what it can do, how it can be programed, and how the results of the computations are obtained. These papers are each approximately 15 pages in length and both avoid complex mathematical derivations which require a knowledge of electronics. Characteristics of the fundamental computing elements were simply stated, and only basic derivations of formula necessary for programing the computer were made. Each engineer was furnished with copies of the papers and the papers were discussed in a meeting. Several small problems involving the fluctuations and damping of water columns with various friction coefficients have been programed for analog solution. Investigations of problems which show promise of analog solution are continuing.

Results Obtained

To obtain information regarding computer usage, after the courses of instruction had been completed and the engineering staff had applied their newly obtained knowledge of programing, 55 usable programs were chosen at random from the laboratory files for analysis. A review of these programs revealed the following:

1. All 55 programs had been written by 6 engineers. Eleven engineers have participated in writing at least 1 program. However, 5 engineers have been more active in use of the computer, and as a result, these 5 wrote the largest percentage of the programs picked for this study.

2. Seventy-eight percent of the programs contained less than 100 cards in the source deck (see Graph 1). Usually 1 statement (mathematical formula or other program information) is contained on a card. Therefore, the implication exists that most of the programs were fairly short, everyday-type problems.

3. Fifteen programs with an average of 54 cards in the source deck required no debugging runs.

4. Thirty-nine programs with an average of 70 cards in the source deck required 2 or less debugging runs.

5. The largest programs contained approximately 700 cards in the source deck and required 11 debugging runs.

6. The smallest program contained 20 cards in the source deck and required no debugging runs. For a short program of this type, where the engineer thoroughly understands the problem including problem definition, and the statements in the program

are relatively simple, the average engineer familiar with computer programing could probably write a 20-card program in less than 15 minutes.

7. There was a sharp increase in the number of debugging runs required as the number of cards in the source deck increased.

8. The majority of programs were used two times or less (see Graph 2).

9. Compared to manual methods, the average number of man-days saved per program was 11.

10. It was also possible to accomplish an average of 59 man-days of additional work per program. This additional work is defined as work which would not have been undertaken without the use of a computer. This work includes optimization of results, obtaining additional analysis of data and undertaking comprehensive calculations that would not have been feasible without the use of a computer.

These results indicate that the often heard statement "only large repetitious programs are practical for computer solution" is erroneous. The most common engineering problem encountered in most engineering calculations, in the Hydraulics Laboratory which furnished data for this report, is the type which requires 1/2 to 2 man-days to complete by manual methods. In the present analysis it was found that many of these problems have been programed in less than an hour's time by an engineer familiar with programing. Thus, the most spectacular results were obtained by utilizing the machine for what may be called everyday engineering problems. These problems required a minimum amount of programing and often no debugging. Being small, they are easy to check and debug if necessary.

In these problems the engineer is familiar with his data and the conditions for which he must make allowances in the solution. He is not faced with the problem of writing a large general-purpose computer program to cover all contingencies. In some cases it is faster and easier to write several small special-purpose programs than to write one large generalized program.

Many programs are used only once or twice and save only a few man-days. However, when these savings are summed over a period of time, a substantial total savings results.

An example of a typical short program with some of the information obtained from the computer is shown as Program 1. In this program no attempt was made to minimize either the number of instructions used in the program or the computer operating time. The program was written and used to determine the seepage rate with respect to elevation from a pond with a horizontal bottom and a well-shaped cross section. Results of the program were spot checked within minutes after program listing by checking a few random points on different ponds. Data were listed on special forms as the tests were being conducted, and several ponds were tested both before and after special treatments. It was estimated that the program saved approximately 10 man-days of calculating, typing, and checking time. The time of writing the program was less than 1 hour.

Program 1 consists of several arithmetic statements which any engineer can readily understand when a few definitions are understood, Table 1.

Table 1

Operation	Operator symbol
Addition	+
Subtraction	-
Division	/
Multiplication	*
Exponentiation	**

The program also contains statements which tell the machine what data to read (read statements); what data to type out (write statements);

the sequence for performing operations (IF and DO statments); and other program information (FORMAT statements). The IF statement provides a means of changing the sequence of operations depending on what happens during execution of the program, and the DO statement provides a means of repeating a portion of the program. Even those unfamiliar with FORTRAN can readily see that with a little study of this language they could rapidly read through this program. Program 1 was written in FORTRAN II, a mathematically oriented programing language, but more powerful programing languages which allow even simpler instructions than those used in this program are available.

Of course, the computer is also used for large or repetitive-type problems. Many of these problems which once required a large number of technical man-days to compute, for instance the calculation of discharge tables for Venturi meter banks, Program 2, may be completed in a few seconds on the computer. The output from the computer may be programed so that it is easy to read and interpret and can be obtained as typed sheets with the data arranged as desired. The sheets can usually be utilized directly in reports, thereby saving typing and proofreading time, and probably the time of an engineer engaged in the tiresome job of checking long and comprehensive tables.

Program 2 is typical of many repetitive problems occurring in engineering. This particular problem deals with the calibration of

Venturi meters. Because there are several apparently similar meters they require identification within the program. The program, therefore, provides a means for writing a variable title which identifies the meter being calibrated. Standard equipment used in calibrating the meter includes a graph of the meter coefficient which varies with discharge. Using data from the graph in the computer, a table is calculated to show the meter discharge for each 0.01-foot increment of water-differential gage reading. The computed table, shown with the program, may be used directly as a calibration table, or may be reproduced for a report or letter without the necessity of retyping, checking or proofreading. This program has saved over 16 man-days of tiresome, repetitive calculations and has allowed an additional 12 man-days of work to be accomplished which probably would not otherwise have been attempted.

As engineers work more and more with computers, it has been noticed that they tend to more readily attack large problems and to use improved or new methods of problem solution. Solutions which were at one time barely acceptable to the engineers are now made optimum. Engineers trained in programing do not hesitate to attack complex problems which previously would have been completely impractical because of excessive arithmetic operations.

For instance, large relaxation net problems have been neglected because of the tremendous amount of manual work necessary to solve them; however, when a computer is utilized the engineer does not find impractical the repetitive calculations necessary to solve a problem of this type. One such problem (the program is beyond the scope of this report), involves a relaxation net for a stable ground-water reservoir containing two soil layers; the bottom layer is saturated with salt water and the upper with fresh water. Irrigation water is then added to the ground surface. The problem concerns the determination of the position of the salt-water fresh-water interface and its movement with respect to time because of the pressure created by the surcharge. Laplace's equation may be solved for each node of the relaxation net to determine the equipotential and flow lines. Then from the resulting pressure pattern, the fresh water surface and salt water surface are moved for a short distance in a time, Δt. A new relaxation net is then established and the preceding calculations repeated. By this method both the movement of the salt water interface and the fresh water surface may be tracked. Results obtained from this program have been sufficiently promising that it is planned to check the results with a future model study. Because this program requires many solutions of a relaxation net, the amount of calculation would be completely impractical for an engineer to attempt using a desk calculator or slide rule.

Utilizing the computer to punch cards which can be used in an electromechanical X-Y plotter (a device that reads the data on the punched cards and plots the points or inks lines between points) has considerably reduced the time required to plot data. The X-Y plotter is much faster than manual plotting, and allows personnel to spend more time performing operations for which they are trained.

Future Applications

Even for the most advanced computer users, computer potential is still far from realized. New concepts in computer use are rapidly developing. While it is difficult to predict the form many future applications may take, there is one application which has been developed in the space industries and which shows promise for many applications in civil engineering. This is a system of automatic data collection. The test data could be collected on tape, and the data tape and program tape taken to a computer for reduction of results, or the test data could be fed directly into a programed computer, and results obtained with no intermediate steps. It is believed that a system of this type would increase the potential and flexibility of acquiring and processing data by: increasing the speed of data analysis to allow the results of studies to be made available faster; allowing more data to be taken when desirable, thus providing a more complete analysis of tests; eliminating much tedious manual labor in data acquisition and reducing the possibilities of errors; and allowing trained personnel to be more efficiently utilized by eliminating routine work.

Another field which may be of special interest to civil engineers is the rapidly developing fluid computer. A fluid computer is simply one which operates from the flow of fluids (usually water or air) instead of the flow of electricity. The fluid flow is capable of performing the same logic functions that electronic computers perform. Plastic or metal stampings by mass production methods may allow fluid computers to be built at a fraction of the cost of electronic computers, and considerable interest has been shown in these computers.3/4/ Although they are slower than the electronic type, fluid computers are demonstrating remarkable reliability and may in the future provide a reliable computer for small problems where cost and reliability are more important than speed.

Conclusions

Direct application of computers to everyday problems for the small engineering office is practical and may be established with a reasonable effort. From the experience of the author a few suggestions for computer application by the small office are:

1. Use a formal teaching method (a scheduled class at a scheduled time) to teach computer methods. Do not rely on hit and miss spare moment instructions or learning by trial. Put a man in charge, one who is interested and has full responsibility.

2. Teach the engineer, in effect, to talk to the machine in engineering language. The basic language of engineers is mathematics. Several mathematical oriented languages exist which the engineer can readily understand and learn to use.

3. Encourage interested engineers to write their own programs for everyday problems. For those engineers who have no interest in programing encourage the use of the services of professional programers.

4. Encourage programing for small problems in a simple manner using short and logical steps. Do not attempt to economize by grouping several operations into a few steps which the engineer may not then be able to check at a glance. No attempt should be made to minimize the length of the program or the operating time of the computer. For larger problems the services of professional programers should be obtained to develop programs which are as short in length as efficient programing can produce and which minimize the length of computer time required.

5. Encourage engineers to write programs only for their specific problems, not for problems of a general nature which would include many specific cases.

6. Where a large generalized program is desired, obtain the services of professional programers.

7. Consider the arrangement and form of the data on the original data sheets when preparing data for machine processing. This practice reduces the number of times data are handled and the corresponding number of possible manual errors.

8. Obtain the cooperation, understanding, and support of a large portion of the staff. Enthusiasm among the computer users is contagious and results in ingenious and simple solutions to everyday problems.

9. Make the computer readily available for small everyday problems.

10. Include executive and administrative personnel in the training program. Their support and encouragement are needed to establish the computer as a useful tool in the engineering office.

The Hydraulics Branch, Division of Research, Bureau of Reclamation, whose files were used for the information contained in this report, has found that the use of the ideas presented here has made practical the application of computers to everyday engineering problems. Analysis of the computer program files has indicated that a large percentage of programs are used only once or twice, that program source decks are usually less than 100 cards, that significant savings in man-days have resulted from use of the computers and associated equipment, and that it has been possible to accomplish a considerable amount of work which would not otherwise have been undertaken. As a bonus, the engineer has been relieved of some of the drudgery he has objected to in the past.

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* * * AUTOMATH 1800 SOURCE PROGRAM LISTING* * * 03/11/6

 EFN           PROGRAM: HESEEP                 JOB:    0830HESEEP

C      PROGRAM TO COMPUTE SEEPAGE FROM SMALL CHANNELS - SMALL SLOPES
       DIMENSION E(50), T(50), TLE(6)
C      E IS EL IN FT AND T IS TIME IN HOURS
C      READ IN XSECTIONAL PROPERTIES
     2 READ (2, 4) ALNTH, B, S, BELEV
C      ALNTH IS LENGTH OF POND IN FT, B IS BOTTOM WIDTH IN FT, S IS SIDE
C      SLOPE, BELEV IS AVG BOTTOM ELEV OF POND
     4 FORMAT (4F8.0)
C      READ IN TITLE INFORMATION
     1 FORMAT (I4)
       READ (2,51) (TLE(J), J =1,6)
       WRITE (3, 52) (TLE(J), J =1,6)
    51 FORMAT (6A6)
    52 FORMAT (1H1, 10X, 6A6)
C      READ IN NUMBER IN SET AND SET STARTING WITH HIGHEST ELEV
       READ (2, 1) NPNTS
       DO 5  J =1, NPNTS
     5 READ (2, 16) E(J), T(J)
    16 FORMAT (2F8.0)
       WRITE (3, 6)
     6 FORMAT (1H0, 8X, 40H AVG ELEVATION          AVG SEEPAGE RATE )
C      COMPUTE SEEPAGE RATES
       N = NPNTS - 1
       ADD = SQRT (1.0 + S*S)
       DO 7 K = 1, N
       D1 = E(K) - BELEV
       A1 = D1 * (B + S * D1)
       V1 = ALNTH * A1
       WS1 = B + 2.0*D1*ADD
       WS1 = WS1 * ALNTH
       D2 = E(K+1) - BELEV
       A2 = D2 * (B + S * D2)
       V2 = ALNTH * A2
       WS2 = B + 2.0 * D2 * ADD
       WS2 = WS2 * ALNTH
       DV = V1 - V2
       DT = T(K+1) - T(K)
       WSAV =(WS1 + WS2) / 2.0
       CS = (DV * 24.0) / (WSAV * DT)
       AEL = (E(K) + E(K+1)) / 2.0
       WRITE (3, 8) AEL, CS
     8 FORMAT (12X, F10.3, 16X, F10.3 )
     7 CONTINUE
       WRITE (3, 61)
    61 FORMAT (1H1,      11H END OF SET )
       GO TO 2
       END
```

MADERA LAT 24.2 17.0 POND B TEST 1

AVG ELEVATION	AVG SEEPAGE RATE
230.930	2.177
230.837	1.853
230.755	1.746
230.680	1.508
230.612	1.487
230.545	1.423
230.480	1.425
230.415	1.426
230.354	1.274
230.297	1.209
230.245	1.100
230.194	1.145
230.145	1.014
230.101	.926
230.061	.839
230.026	.707
229.995	.663
229.962	.796
229.925	.841
229.889	.731
229.855	.775
229.822	.709
229.790	.710
229.758	.710
229.723	.822
229.689	.711

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              * * * AUTOMATH 1800 SOURCE PROGRAM LISTING* * *

 EFN          PROGRAM:  HEMTER                      JOB:    0830HEMTER

C     PROGRAM TO CALCULATE VENTURI METER DISCHARGE TABLES
      DIMENSION  G(30),  Q(30,10) , C(30), Q1(30),  QMLS(30,10),  T(6)
      SQRTF(X) = SQRT(X)
      ABSF(XX) = ABS(XX)
    1 FORMAT ( I4)
   30 FORMAT (2I4)
    2 READ INPUT TAPE 5, 1, N
    3 FORMAT (2F8.4)
C     THESE STATMENTS ARE TO READ IN TITLE INFORMATION
      READ INPUT TAPE 5, 50,  (T(J),  J =1,6)
   50 FORMAT (6A6)
C     THIS IS RATING DATA IE. DATE RATED
      READ INPUT TAPE 5, 50, DR1, DR2
      DO 4 J = 1, N
    4 READ INPUT TAPE 5, 3, C(J), Q1(J)
      READ INPUT TAPE 5, 1, M
      R = 0.0
      DO 6 I = 1, M
      DO 6 J = 1, 10
      QT = C(1)* SQRTF (R)
      IF (R) 7, 8, 9
    8 Q(1,1) = 0.0
      GO TO 10
    9 DO 11 K = 1, N
      IF (Q1(K)- QT) 11, 12, 12
   11 CONTINUE
   12 SLOPE =(C(K) - C(K-1)) / (Q1(K)-Q1(K-1))
      CT = C(K-1)+SLOPE * (QT -Q1(K-1))
      QT1 = CT * SQRTF (R)
      IF( ABSF (QT1 - QT) - 0.0004 ) 16, 16, 15
   15 QT = QT1
      GO TO 9
   16 Q(I,J) = QT1
      QMLS(I,J) = Q(I,J) * 28.317
   10 R = R + 0.01
    6 CONTINUE
      ENC = 0.0
      DO 5 L = 1, M
      G(L) = ENC
    5 ENC = ENC + 0.1
      WRITE OUTPUT TAPE 6, 51, (T(J), J =1,6)
   51 FORMAT (1H1, 26X, 6A6)
      WRITE OUTPUT TAPE 6, 55, DR1, DR2
   55 FORMAT ( 38X, 2A6)
      WRITE OUTPUT TAPE 6, 22
   22 FORMAT (1H0,6H  GAGE)
      WRITE OUTPUT TAPE 6, 23
   230FORMAT (87H READING   0.00    0.01    0.02    0.03    0.04    0.05
     1    0.06    0.07    0.08    0.09)
      WRITE OUTPUT TAPE 6, 24
   24 FORMAT ( 28X,    31H DISCHARGE IN LITERS PER SECOND )
```

* * * AUTOMATH 1800 SOURCE PROGRAM LISTING* * *

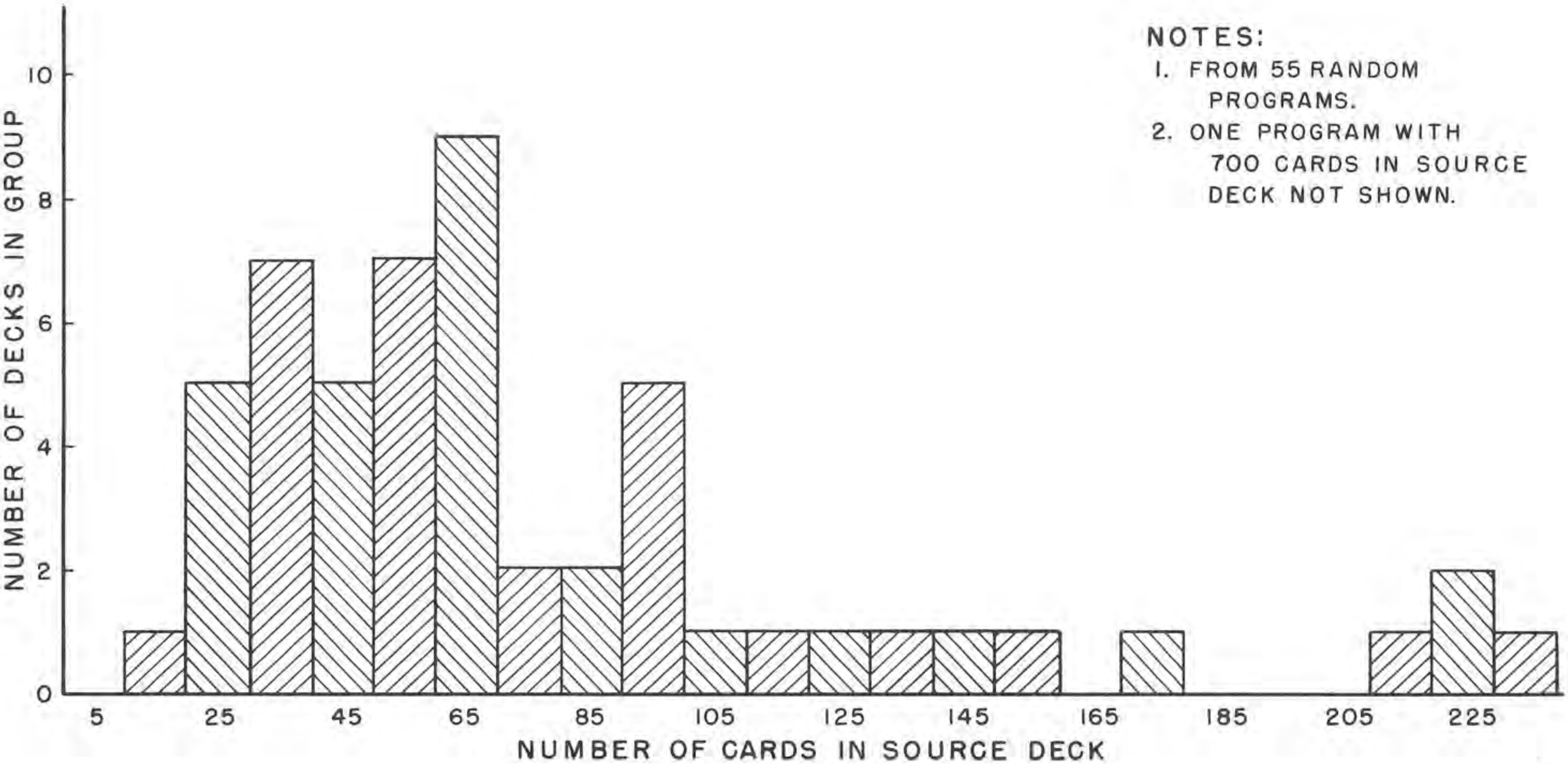
EFN PROGRAM: HEMTER JOB: 0830HEMTER

```
      DO 25 I = 1, M
   250WRITE OUTPUT TAPE 6, 26, G(I), QMLS(I,1), QMLS(I,2), QMLS(I,3),
     1QMLS(I,4), QMLS(I,5), QMLS(I,6), QMLS(I,7), QMLS(I,8),QMLS(I,9),
     2QMLS(I,10)
   26 FORMAT (11F8.3)
      GO TO 2
    7 WRITE OUTPUT TAPE 6, 27
   27 FORMAT (16H WHAT HAPPENED  )
      GO TO 2
      END
```

N.W. BANK 4-INCH VENTURI METER
RATED 2-63

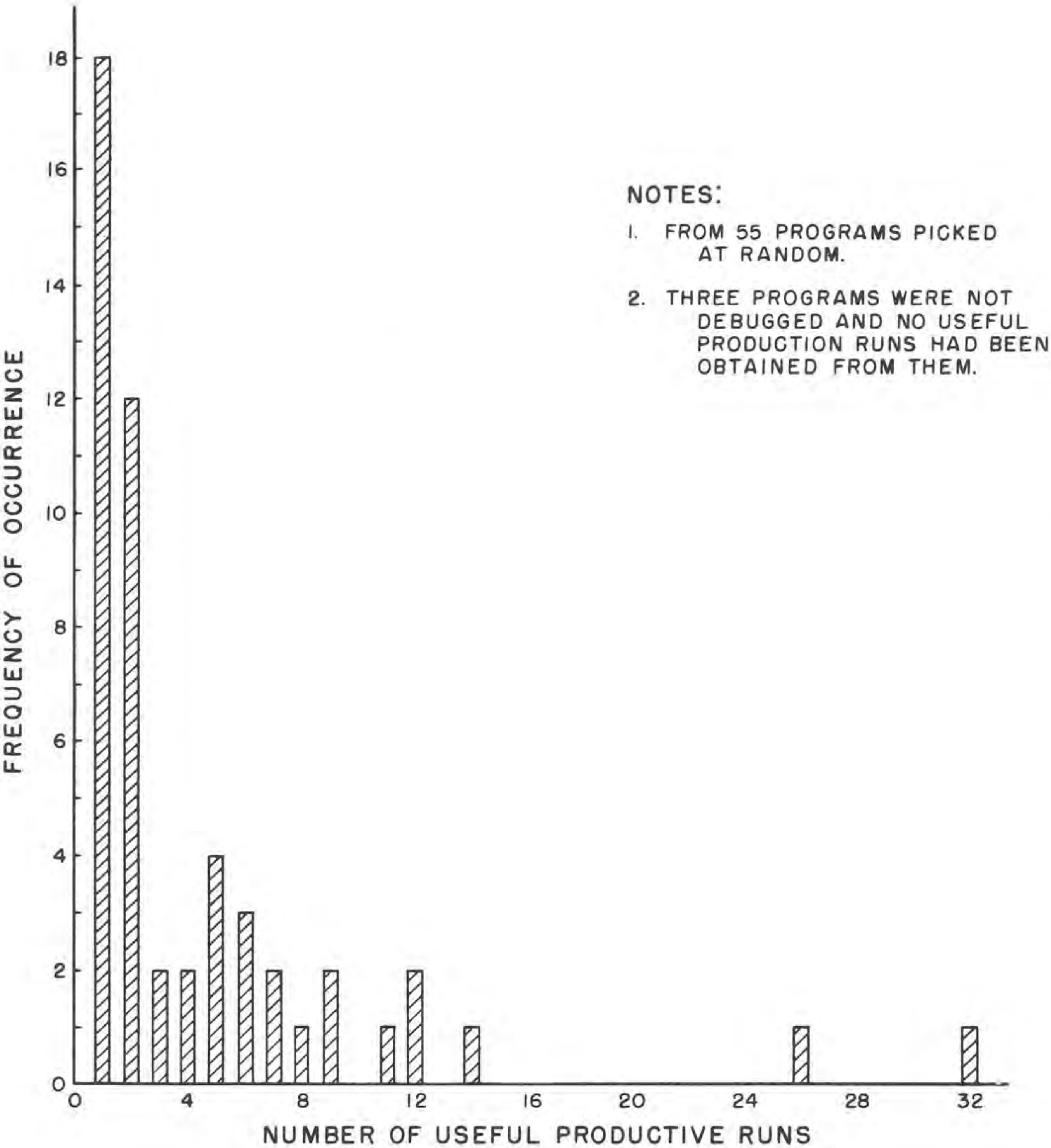
DISCHARGE IN LITERS PER SECOND

GAGE READING	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
.000	.000	2.060	2.913	3.568	4.120	4.606	5.046	5.450	5.827	6.180
.100	6.514	6.832	7.136	7.428	7.708	7.979	8.240	8.494	8.740	8.980
.200	9.213	9.440	9.663	9.880	10.092	10.300	10.504	10.704	10.901	11.094
.300	11.283	11.470	11.653	11.834	12.012	12.187	12.360	12.531	12.699	12.865
.400	13.029	13.191	13.351	13.509	13.665	13.819	13.972	14.123	14.273	14.420
.500	14.567	14.712	14.855	14.997	15.138	15.278	15.416	15.553	15.689	15.824
.600	15.957	16.090	16.221	16.351	16.480	16.609	16.736	16.862	16.988	17.112
.700	17.236	17.358	17.480	17.601	17.721	17.841	17.959	18.077	18.194	18.310
.800	18.426	18.541	18.655	18.768	18.881	18.993	19.104	19.215	19.325	19.435
.900	19.543	19.652	19.759	19.867	19.973	20.079	20.184	20.289	20.394	20.497
1.000	20.601	20.703	20.806	20.907	21.009	21.109	21.210	21.309	21.409	21.508
1.100	21.606	21.704	21.802	21.899	21.995	22.092	22.188	22.283	22.378	22.473
1.200	22.567	22.661	22.754	22.847	22.940	23.032	23.124	23.216	23.307	23.398
1.300	23.488	23.578	23.668	23.758	23.847	23.936	24.024	24.112	24.200	24.288
1.400	24.375	24.462	24.548	24.635	24.721	24.806	24.892	24.977	25.062	25.146
1.500	25.231	25.314	25.398	25.482	25.565	25.648	25.730	25.812	25.895	25.976
1.600	26.058	26.139	26.220	26.301	26.382	26.462	26.542	26.622	26.701	26.781
1.700	26.860	26.939	27.017	27.096	27.174	27.252	27.330	27.407	27.485	27.562
1.800	27.639	27.715	27.792	27.868	27.944	28.020	28.095	28.171	28.246	28.321
1.900	28.396	28.471	28.545	28.619	28.693	28.767	28.841	28.914	28.988	29.061
2.000	29.134	29.206	29.279	29.351	29.424	29.496	29.567	29.639	29.711	29.782
2.100	29.853	29.924	29.995	30.066	30.136	30.206	30.277	30.347	30.416	30.486
2.200	30.556	30.625	30.694	30.763	30.832	30.901	30.970	31.038	31.106	31.174
2.300	31.242	31.310	31.378	31.445	31.513	31.580	31.647	31.714	31.781	31.848
2.400	31.914	31.981	32.047	32.113	32.179	32.245	32.311	32.376	32.442	32.507
2.500	32.572	32.638	32.702	32.767	32.832	32.897	32.961	33.025	33.089	33.154
2.600	33.217	33.281	33.345	33.409	33.472	33.535	33.599	33.662	33.725	33.788
2.700	33.850	33.913	33.975	34.038	34.100	34.162	34.224	34.286	34.348	34.410
2.800	34.471	34.533	34.594	34.656	34.717	34.778	34.839	34.900	34.960	35.021


NOTES:
1. FROM 55 RANDOM PROGRAMS.
2. ONE PROGRAM WITH 700 CARDS IN SOURCE DECK NOT SHOWN.
NUMBER OF DECKS IN GROUP
0
2
4
6
8
10
5
25
45
65
85
105
125
145
165
185
205
225
NUMBER OF CARDS IN SOURCE DECK

GRAPH 1

GRAPH 2


FREQUENCY OF OCCURRENCE
18
16
14
12
10
8
6
4
2
0
0
4
8
12
16
20
24
28
32
NUMBER OF USEFUL PRODUCTIVE RUNS
NOTES:
1. FROM 55 PROGRAMS PICKED AT RANDOM.
2. THREE PROGRAMS WERE NOT DEBUGGED AND NO USEFUL PRODUCTION RUNS HAD BEEN OBTAINED FROM THEM.