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TOWARDS A COMPUTER-BASED INFORMATION-RETRIEVAL SYSTEM FOR GROUNDWATER DATA

R. B. McCammon*

ABSTRACT

In the near future, most regional water boards in New Zealand will have on-going investigations into underground water. Because underground water represents a hidden resource, indirect methods, namely well drilling, must be used in any attempt to better understand underground water supplies. The information obtained from boreholes therefore is of paramount importance. With the greater number of wells being drilled at present, together with the well records already on file, computer-based systems for information retrieval offer definite promise for the future. A key factor in the design of such a system is the nature of the man–computer dialogue. Question-and-answer, menu-selection and natural-English type dialogues are particularly well suited for the retrieval of water-well records from data files. Whichever system is put forward, it is important that potential users of the system be involved in all stages of development.

BACKGROUND

Within this decade, it is likely that the majority of regional water boards in New Zealand will have on-going investigations into underground water. By the authority vested in them by the Water and Soil Conservation Act of 1967 and the subsequent Conservation Amendment Act of 1973, each board is responsible for investigating and recording all water resources within its district, and this includes underground water. At present, each board issues 'rights' to enable people to use water lawfully. To administer these rights most effectively, each board must have access to and maintain the most up-to-date information on water availability, its distribution in terms of quantity and quality, and present usage.

* N.Z. Geological Survey, DSIR, Christchurch.

Underground water differs from other natural water in that it represents a hidden resource. As a consequence, much of the information necessary for the proper management of underground water must be obtained by indirect methods; namely, from wells drilled at the surface and which penetrate underground aquifers at depth. The information obtained from boreholes is therefore critical for assessing the nature of any underground water supply. In the past, the information on water wells was recorded on forms and stored in binders. As new well locations were considered, records from nearby wells were reviewed as a means of determining the most favourable drilling sites. As time has passed, of course, more and more wells have been drilled. With demand increasing at the present time, it appears that an even greater number of wells will be drilled in the years ahead (provided that drillers can meet this demand). As an indication of how quickly this information is accumulating, Table 1 shows the number of new wells recorded during five-year intervals for the area under the jurisdiction of the North Canterbury Catchment Board (well records are at present stored in the Christchurch office of the N.Z. Geological Survey). The total number of records at present exceeds 5500. Approximately 175 new well records are being added each year. If the present increased demand for water continues, this latter figure would be even greater in the years ahead.

TABLE 1 — Acquisitions of water-well records in Canterbury.

Period	*No. of records*
pre 1955	2244
1956–1960	805
1961–1965	719
1966–70	885
1971–1975 (est.)	954
	Total: 5607

The basic information obtained for each water well can be conveniently classified into four main categories: (1) location and other identifying characteristics; (2) geometry of the borehole; (3) description of materials encountered during drilling; (4) aquifer characteristics. The fourth category includes such important parameters as static water level, and specific capacity and transmissivity of the aquifer, the latter being obtained only for a few wells where carefully controlled pump tests are conducted. More recently, concern over the quality of water has added a fifth category which could be described as: (5) the chemical content of water in aquifers. Taken as a whole, there is considerable information to be captured from a single well.

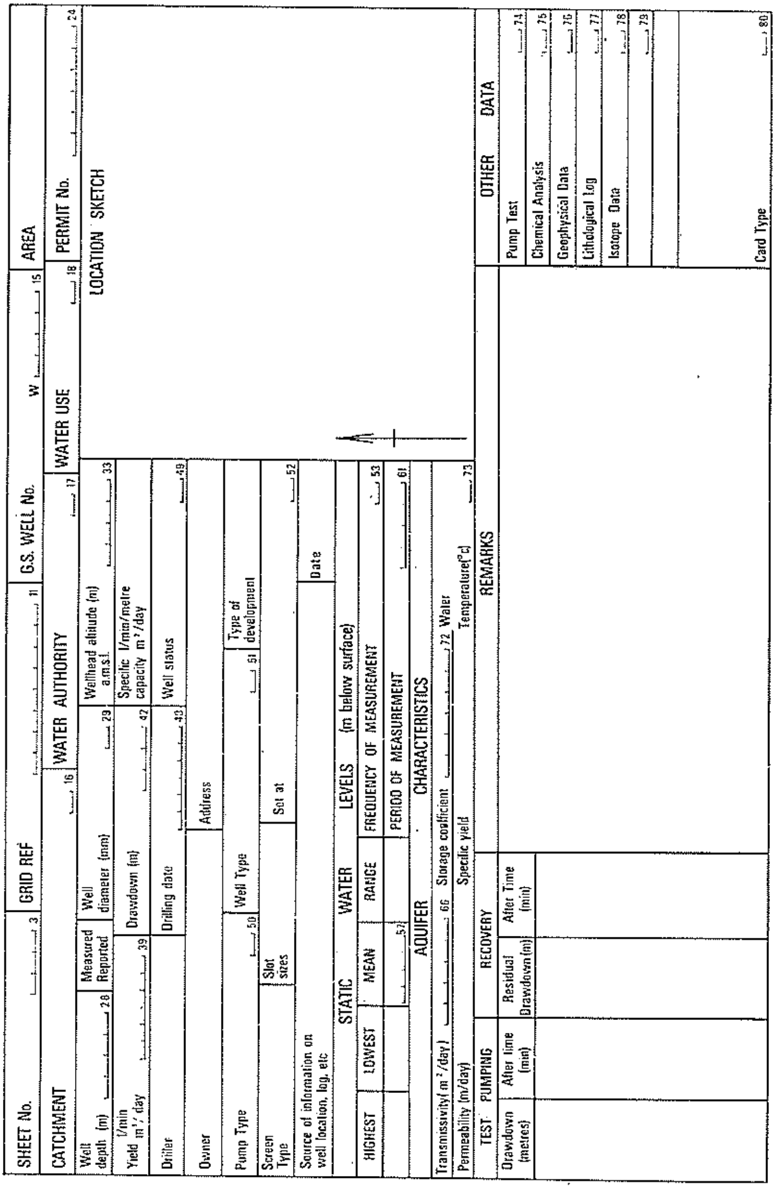

FIG. 1 — New Zealand Water-Well Data Form.

As a result, the Geological Survey have recently revised their standard form for the recording of water-well data. The revised forms are intended for use by Survey personnel in field offices throughout New Zealand, but are available also upon request to regional water boards. The front side of the form is shown in Fig. 1. The back side not shown is for stratigraphic information. These forms will serve primarily as a field office filing system and will enable geologists, hydrologists, engineers and other interested parties to assess easily and quickly the producing potential of new well sites within a given area. Recommendations for future drilling will depend heavily on the information contained in these stored records.

Where there is a large number of records – no matter how well organized – it is unlikely that any single person could, at a moment's notice, retrieve a particular set of well records having specified characteristics. For example, it may be desired to look at all records of wells for map sheet NZMS 1 S84 which have a driller's log. Or, an even more difficult example, it might be desired to locate all wells within an area which yielded more than a stated quantity of water found at less than some specified depth. Questions such as these and others could be handled quite readily if a computer-based system for information retrieval were available. The form in Fig. 1 was designed so that specific items of information can be transferred directly on to an 80-column IBM punch card and stored for automatic retrieval later by computer. Such stored information is not meant to replace the original data, but rather it is intended to select those wells having some specified attributes. The form in Fig. 1 is of a design such that the information can be encoded directly by a keypuncher. This reduces considerably the chances of encoding false data, by eliminating the need for transcribing the original data. What remains then is the development of the best-suited computer-based retrieval system.

DIALOGUE WITH THE COMPUTER

Time after time, where computer-based management information systems (MIS) have been advocated, subsequently developed, installed and later discarded, the reasons for failure are the same, namely:

(1) insufficient involvement of the potential users during the stages of development of the system;
(2) cumbersome and unnecessarily complicated instructions for initiating a request to the computer by users unfamiliar with computers and computing;

(3) intolerably long delays between the time a request is made to the system and the time when results are obtained.

It follows that in order to offset the risk of wasted effort in developing a computer-based retrieval system it is necessary that:

(1) users are involved at all stages of development;
(2) the system is designed so that users can formulate their requests in as natural a language as possible;
(3) every effort is made to ensure fast turn-around in the system, i.e. the time it takes for a user to get an answer.

From the attributes listed above it is clear that the system which would provide this capability to the fullest extent is one in which the level of communication between the user and the computer is interactive. Interactive systems are already operational at many computer centres and usually consist of remote terminals connected to a central computer which can be located almost anywhere. What is lacking is not the computer hardware but rather 'man–computer' dialogues. It is the latter which are of concern in the remainder of this paper.

In a recent book, Martin (1973) suggests 18 different approaches to man–computer dialogues. These range from simple form filling with a light pen on a visual display screen to standard programming. The former requires virtually no training on the part of the operator, whereas the latter requires that the operator is trained in the use of a programming language. One of the first types of dialogue developed, and still one which is widely used, is the question-and-answer type in which the computer asks the operator a series of questions. As Martin (1973: p. 12) points out, this is very simple for the operator and can be written with a simple program. The disadvantages are that such dialogues tend to be of limited flexibility and suitable only for certain applications. In the case of retrieval of water-well records, which is relatively straightforward, it would be ideally suited – provided, of course, that the right questions were asked. It is imperative, therefore, that users of such a system would be involved during any development. As a demonstration, a computer program with a question-and-answer dialogue was written in consultation with members of the Geological Survey. Some sample output is given in Fig. 2. The program runs by asking a series of questions, each requiring a response by the operator. The questions asked are self-explanatory; the geologist, hydrologist or engineer who runs the program needs no prior instruction other than how to turn the terminal on and off and how to get the program to run. Responses may be abbreviated – for instance, Y and N

WHICH ONE-MILE SHEETS DO YOU WISH TO SEARCH?(I.E. S75,S76,ETC.)
S85,S86

DO YOU WISH TO SEARCH A PORTION OF THIS AREA? (ENTER YES OR NO)
NO

WHAT IS THE MINIMUM YIELD FOR A WELL YOU WILL ACCEPT?
ENTER THE APPROPRIATE UNITS OF MEASUREMENT(I.E. L/MIN OR M3/DAY)
(FOR EXAMPLE, 400 L/MIN)
1000 M3/DAY

DO YOU WISH ONLY WELLS WHICH HAVE A DRILLER'S LOG? (ENTER YES OR NO)
I DON'T CARE

IS THIS YOUR REQUEST?

YOU WISH TO LOCATE WELLS ON MAP SHEETS S85,S86,
WHICH YIELD AT LEAST 1000 M3/DAY

(ENTER YES OR NO)
Y

THE WELLS WITH THESE ATTRIBUTES ARE:

#	WELL NO.	GRID REF	DEPTH (M)	YIELD(UNITS)	YEAR DRILLED
1	S85/117	7332	78	1370 M3/DAY	1966
2	S86/104	809402	113	1337 M3/DAY	1965
3	S86/ 32	597350	115	1396 M3/DAY	1966
4	S85/830	22044	34	1346 M3/DAY	1970
5	S85/159	703178	60	1680 M3/DAY	1971
6	S86/129	361338	86	1184 M3/DAY	1969
7	S86/861	976248	90	1265 M3/DAY	1965
8	S85/654	154504	96	1219 M3/DAY	1970
9	S85/ 59	689554	89	1039 M3/DAY	1969
10	S86/213	321646	76	1861 M3/DAY	1971
11	S85/794	318075	58	1430 M3/DAY	1971
12	S86/148	855187	90	1075 M3/DAY	1968
13	S85/876	786704	99	1367 M3/DAY	1971
14	S85/ 72	197905	27	1469 M3/DAY	1973
15	S85/239	772249	51	1272 M3/DAY	1966
16	S86/583	200015	105	1174 M3/DAY	1967
17	S86/531	20066	57	1939 M3/DAY	1966

DO YOU WANT A COPY OF THESE RESULTS?
(ENTER YES OR NO)
YES

DONE.

DO YOU WISH TO MAKE ANOTHER SEARCH? (YES OR NO)
YES

WHICH ONE-MILE SHEETS DO YOU WISH TO SEARCH?(I.E. S75,S76,ETC.)
S84

DO YOU WISH TO SEARCH A PORTION OF THIS AREA? (ENTER YES OR NO)
YES

FOR THE SUBAREA,ENTER EASTINGS BOUNDS, THE WESTERNMOST FIRST
(I.E. 20,22)
95,05

ENTER NORTHINGS BOUNDS, THE SOUTHERNMOST FIRST
(I.E. 72,75)
50,55

WHAT IS THE MINIMUM YIELD FOR A WELL YOU WILL ACCEPT?
ENTER THE APPROPRIATE UNITS OF MEASUREMENT(I.E. L/MIN OR M3/DAY)
(FOR EXAMPLE, 400 L/MIN)
500 L

DO YOU WISH ONLY WELLS WHICH HAVE A DRILLER'S LOG? (ENTER YES OR NO)
Y

IS THIS YOUR REQUEST?

```
YOU WISH TO LOCATE WELLS ON MAP SHEET 584,
WITHIN EASTINGS 95 TO  5 AND NORTHINGS 50 TO 55
WHICH YIELD AT LEAST      500  L/MIN
AND WHICH HAVE A DRILLER'S LOG

(ENTER YES OR NO)
YES

THE WELLS WITH THESE ATTRIBUTES ARE:

--   ------   -------   -----   ------------   --------

 #    WELL      GRID     DEPTH   YIELD(UNITS)    YEAR
       NO.       REF      (M)                   DRILLED

 1   584/ 59  975554      79      624 L/MIN      1971
 2   584/846  986537     109      677 L/MIN      1964
 3   584/982  989510      98      760 L/MIN      1973
 4   584/528  957506     112      786 L/MIN      1973
 5   584/281   33529      65      971 L/MIN      1969
 6   584/959   57542      63      938 L/MIN      1973
 7   584/501   44539      56      795 L/MIN      1974
 8   584/526   43532      92      506 L/MIN      1974
 9   584/835   58554      92      727 L/MIN      1967
10   584/607   15523      54      741 L/MIN      1969
11   584/446   11542      68      745 L/MIN      1970
12   584/811   26524      86      820 L/MIN      1965

DO YOU WANT A COPY OF THESE RESULTS?
(ENTER YES OR NO)
NO

DO YOU WISH TO MAKE ANOTHER SEARCH? (YES OR NO)
NO

HAVE A GOOD DAY THEN  SEE YOU LATER, TIGER.
#ET=6:06.1 PT=1.7 IO=0 6
```

FIG. 2 (*above and opposite*) — Sample outputs for question-and-answer dialogue.

can be used in place of YES and NO. This helps to reduce the time it takes for the operator to make a request once he becomes familiar with the program. To make sure that the right message is received, the program writes back the request which is made by the operator. This must be verified by the operator before going further. If not, the operator re-initiates his request. Once a request is verified, the well records having the specified attributes are retrieved and listed; if a cathode ray tube (CRT) is used to display the results, the operator can decide whether or not to obtain hard copy.

The well records which appear as output for the two examples given in Fig. 2 are fictitious. They were generated within the program solely for the purpose of the demonstration. For those who may be interested, a listing of the program written in ALGOL is given in Appendix 1. When such time comes that water-well records are stored on permanent file, it would not be difficult to, for instance, add a retrieval component to this program.

A second possible dialogue in which the form of input would be simple and also fast would be a menu-selection dialogue with a light pen as input on a visual display screen. The graphics hard-

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                    WATER WELL RECORD RETRIEVAL PANEL

ONE-MILE SHEETS:

     □ S          0  1  2  3  4  5  6  7  8  9
                  0  1  2  3  4  5  6  7  8  9

SUBAREAS:

   □ EASTINGS     □ W
                  □ E      0  1  2  3  4  5  6  7  8  9
   □ NORTHINGS    □ S      0  1  2  3  4  5  6  7  8  9
                  □ N

MINIMUM YIELD:

        □ 0
        □ 100
        □ 500           □ L/MIN
        □ 1000          □ M3/DAY
        □ 5000

DRILLER'S LOG:

     □ YES
     □ NO

                              □ RESTART
                              □ DEL LST ENTRY
                              □ END
```

FIG. 3 — Display panel for retrieving water-well record information.

ware for doing this is now available. In this type of dialogue, the operator simply uses a light pen to select various items which are displayed on a screen that is connected to a terminal. Once a request is made, a computer program working in much the same way as the earlier program retrieves the necessary information and produces a similar output. An example of what an operator might see displayed on a screen using the previous example is shown in Fig. 3. The advantage of a menu-type selection is that a more complex dialogue is possible, with faster input than would normally be possible with a question-and-answer type dialogue. A light pen can be moved swiftly over a screen, and the operator is free to select whatever items he wishes. For multiple entries as, for instance, in selecting NZMS 1 map sheets in Canterbury, the operator merely points to the square labelled S for each map sheet and then points to the sheet number. Any mistake committed while making a selection can be deleted by pointing the light pen to the square labelled DEL LST ENTRY. If more than one mistake has been made, the light pen is pointed at the square labelled RESTART which would enable the operator to begin again. When all selections have been made without any mistakes, the operator points to the square labelled END. This initiates the retrieval component of the computer program, and results are produced in a similar fashion to those in Fig. 2. The disadvantage of this type of dialogue is that a greater programming effort is required, and more than likely greater telecommunication costs would be involved.

We consider finally what would be the ideal man–computer dialogue. It is the one which would allow the operator to converse in natural English (ideal at least for English-speaking persons). While this is theoretically the most natural man–machine dialogue, it is also the most difficult to program. An oft-quoted classic of the failure to date of machine translation of the English language is "The spirit is willing, but the flesh is weak" which is rendered by the computer as "The liquor is prepared, though the meat is not tough". The English language is simply too rich in word meanings for artificial-intelligence machines to be relied upon for error-free translations. Within a specific retrieval application, however, it is reasonable to assume that the questions will be asked by an investigator with an interest in obtaining information, and that they will be stated in a direct and straightforward manner. Some form of English would therefore seem possible.

Two years ago, the final report for the Lunar Sciences Natural Language Information System (LSNLIS) was issued as a U.S. Government document by Woods *et al.* (1972). LSNLIS is a research prototype of a computer system to allow English-language access to a large data base of lunar sample material. It allows a lunar geologist, for instance, to ask questions, compute averages and ratios, make selective listings and so forth in a file containing some 13 000 chemical analyses of the lunar samples. LSNLIS operates by translating input English requests into formal requests for answering them. The following example was taken from Woods *et al.* (1972: p. 19) for a request which a geologist made to the LSNLIS system:

(WHAT IS THE AVERAGE CONCENTRATION OF ALUMINIUM IN HIGH ALKALI ROCKS)

(8.134996 . PCT)

In the above example the user typed the question, beginning and ending with parentheses, and the system typed the result. It is easy to see that a similar system could be devised for retrieving information from stored water-well record data. For example, a question might be:

(GIVE ME ALL WELLS IN NZMS 1 S84 WHICH HAVE A DRILLER'S LOG AND WHICH YIELDED AT LEAST 1000 M3/DAY OF WATER)

The answer might be:

(THERE ARE 30 WELLS WHICH MATCH THIS DESCRIPTION. DO YOU WISH TO SEE THEM?)

While the programming costs of developing such a system would be high, the ultimate benefits in terms of greater usage of such a system by geologists, hydrologists and engineers would more than compensate for the initial cost.

A PERSONAL VIEW

It is not too soon for geologists, hydrologists, engineers and regional water board authorities to begin thinking seriously about computer-based information-retrieval systems for groundwater data. Already there are over 20 000 water well records on file in field offices throughout the country (L. J. Brown, pers. comm.). With growing public concern over the quality of groundwater in different parts of the country, chemical analysis data from water wells are likely also to accumulate in much larger number. Data, once gathered are a resource. As with any resource, there should be proper management. The computer offers in this respect a most reliable, efficient and effective means for making the best possible use of such information.

The design of any computer-based information system for groundwater data must involve potential users of the system at all stages of development. Professionals engaged in groundwater studies should not expect to be handed a working system by computer specialists; rather, they should insist on a system designed to meet their needs and requirements. A key factor in the design of such a system is the type of dialogue between man and computer. As touched on briefly in this paper, a range of options is open.

Finally, it should be recognized by all concerned that the development of any computer-based system for information rerieval is likely to take place in evolutionary steps. Flexibility and therefore change must be accepted as a natural course of events.

REFERENCES

Martin, J. 1973: *Design of Man–Computer Dialogues.* Prentice-Hall, New York. 559 p.

Woods, W. A.; Kaplin, R. M.; Nash-Webber, B. 1972: *The Lunar Sciences Natural Language Information System: Final Report.* NTISN72-28984. U.S. Dept. Commerce, Springfield. 387 p.

APPENDIX 1 — Listing of ALGOL computer program for retrieval of water-well records using a question-and-answer dialogue.

```
#FILE SEARCH
BEGIN
FILE CARD(KIND=REMOTE),LP(KIND=REMOTE);
INTEGER ARRAY        E[1:2],N[1:2];
ALPHA ARRAY ANSWER[0:11],BUFF[0:11],S[0:3];
INTEGER M,I,SUBAREA,YIELD,LOG;
LABEL START,NEXT;
POINTER ANS,PA,PB;
REAL UNITS,NSHEET;
REAL X;
INTEGER K,KK,DPH,YLD,DAT,EST,NRH,T,ESTNRH;
DEFINE RX = RANDOM(X) #;
TRUTHSET NUMBER ("0123456789");
TRUTHSET COMMA (",");
PROCEDURE GETYESORNO;
DO BEGIN ANS:=POINTER(ANSWER);
                        READ(CARD,<12A6>,ANSWER[*]);
SCAN ANS:ANS FOR I:72 UNTIL IN ALPHA;
IF I EQL 0 THEN
WRITE(LP,<"PLEASE ENTER YES OR NO">);
END UNTIL I NEQ 0;
START: M:=0;
WRITE(LP,< /,"WHICH ONE-MILE SHEETS DO YOU WISH TO SEARCH?(I.E. S75,S76,
ETC.)">);
PA:=POINTER(BUFF),
READ(CARD,  12  ,BUFF[*]);
K:=72,
NEXT: SCAN PA:PA FOR I:K UNTIL IN ALPHA;
IF I NEQ 0 THEN BEGIN
K:=I;
PB:= POINTER(S[M]),
M:=M+1,
REPLACE PB BY PA:PA FOR K:K WHILE IN ALPHA,
END;
IF M LSS 4 THEN IF I NEQ 0 THEN GO TO NEXT,
IF M EQL 0 THEN BEGIN
WRITE(LP,<"PLEASE ENTER THE ONE-MILE SHEETS YOU WISH TO SEARCH">);
PA:=POINTER(BUFF),
READ(CARD,<12A6>,BUFF[*]);
K:=72;
GO TO NEXT END;
WRITE(LP,< /,"DO YOU WISH TO SEARCH A PORTION OF THIS AREA? (ENTER YES O
R NO)">);
SUBAREA:=0;
GETYESORNO;
IF ANS = "Y" THEN
BEGIN
  SUBAREA :=1;
  WRITE(LP,< /,"FOR THE SUBAREA,ENTER EASTINGS BOUNDS, THE WESTERNMOST F
IRST",/,"(I.E. 20,22)">,);
  READ(CARD,/,E[1],E[2]);
  WRITE(LP,< /,"ENTER NORTHINGS BOUNDS, THE SOUTHERNMOST FIRST",/,"(I.E.
 72,75)">,),
  READ(CARD,/,N[1],N[2]);
END;
WRITE(LP,< /,"WHAT IS THE MINIMUM YIELD FOR A WELL YOU WILL ACCEPT?",/,"
ENTER THE APPROPRIATE UNITS OF MEASUREMENT(I.E. L/MIN OR M3/DAY)",/,"(FO
R EXAMPLE, 400 L/MIN)">,);
PA:=PB:=POINTER(BUFF);
READ(CARD,<12A6>,BUFF[*]);
SCAN PA:PA UNTIL IN ALPHA;
```

```
SCAN PB:PA WHILE IN NUMBER;
YIELD := INTEGER(PA,DELTA(PA,PB));
SCAN PB:PB UNTIL IN ALPHA;
IF PB = "L" THEN UNITS :="L/MIN ";
IF PB = "M" THEN UNITS :="M3/DAY";
WRITE(LP,< /,"DO YOU WISH ONLY WELLS WHICH HAVE A DRILLER'S LOG? (ENTER
YES OR NO)">);
LOG:=0;
GETYESORNO;
IF ANS = "Y" THEN LOG:=1;
WRITE(LP,< /,"IS THIS YOUR REQUEST?">);
NSHEET:="SHEET";
IF M GTR 1 THEN NSHEET:="SHEETS";
WRITE(LP,< /,"YOU WISH TO LOCATE WELLS ON MAP ",A6,X1,4(C3,",")>,NSHEET,
FOR I :=1 STEP 1 UNTIL M DO S[I-1]);
IF SUBAREA = 1 THEN
WRITE(LP,<"WITHIN EASTINGS ",I2," TO ",I2," AND NORTHINGS ",I2," TO ",I2
>,E[1],E[2],N[1],N[2]);
WRITE(LP,<"WHICH YIELD AT LEAST ",I7,X2,A6>,YIELD,UNITS);
IF LOG = 1 THEN
WRITE(LP,<"AND WHICH HAVE A DRILLER'S LOG">);
WRITE(LP,< /,"(ENTER YES OR NO)">);
GETYESORNO;
IF ANS = "N" THEN
BEGIN
WRITE(LP,< /,"TRY AGAIN. ">);
GO TO START;
END;
WRITE(LP,</,"THE WELLS WITH THESE ATTRIBUTES ARE:",/>);
WRITE(LP,<"--",X3,6("-"),X3,6("-"),X3,5("-"),X3,12("-"),X3,8("-"),/>);
WRITE(LP,<" #",X4,"WELL",X5,"GRID",X4,"DEPTH",X3,"YIELD(UNITS)",
X4,"YEAR">);
WRITE(LP,<X7,"NO. ",X6,"REF",X5,"(M)",X19,"DRILLED",/>);
PA:= POINTER(S);
X:= INTEGER(PA+1,2);
T:= 20*RX+1;
FOR I:= 1 STEP 1 UNTIL T DO
BEGIN
K:= ENTIER(M*RX);
IF K GTR M THEN K:=M;
KK:=1000*RX;
DPH:= 100*RX+20;
YLD:= YIELD+RX*YIELD;
DAT:= 1964 +10*RX;
IF SUBAREA = 1 THEN
BEGIN
   IF E[2] GTR E[1] THEN
   EST:=(E[1]+(E[2]-E[1])*RX)*10+10*RX  ELSE
   EST:=((E[1]+(E[2]+100-E[1])*RX) MOD  99)*10+10*RX;
   IF N[2] GTR N[1] THEN
   NRH:=(N[1]+(N[2]-N[1])*RX)*10+10*RX ELSE
   NRH:=((N[1]+(N[2]+100-N[1])*RX)  MOD  99)*10+10*RX;
   END ELSE
BEGIN
   EST:= 1000*RX;
   NRH:= 1000*RX;
END;
ESTNRH:= 1000*EST+NRH;
WRITE(LP,<I2,X3,C3,"/",I3,X2, I6,X3,I4,I8,X1,A6,X5,I4>,
I,S[K],KK, ESTNRH,DPH,YLD,UNITS,DAT );
END;
WRITE(LP,< /,"DO YOU WANT A COPY OF THESE RESULTS?",/,"(ENTER YES OR NO)
">);
GETYESORNO;
IF ANS  ="Y" THEN
WRITE(LP,< /,"DONE. ">);
WRITE(LP,< /,"DO YOU WISH TO MAKE ANOTHER SEARCH? (YES OR NO)">);
GETYESORNO;
IF ANS = "Y" THEN GO TO START;
WRITE(LP,< /,"HAVE A GOOD DAY THEN.  SEE YOU LATER,  TIGER. ">);
END.
#
```