DEMOCRATIC REPUBLIC OF MADAGASCAR
MINISTRY OF INDUSTRIES, ENERGY AND MINES

GROUNDWATER DEVELOPMENT STUDY

IN

SOUTH-WESTERN REGION

OF

THE DEMOCRATIC REPUBLIC OF MADAGASCAR

VOLUME 4
SUPPORTING REPORT(2)

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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Volume 4 :
Supporting Report (2)

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1. DATA BASE

1. Introduction

This Manual is prepared to operate "Hydrogeological Database System" which is constructed for "GROUNDWATER DEVELOPMENT STUDY IN SOUTH-WESTERN REGION OF THE DEMOCRATIC REPUBLIC OF MADAGASCAR".
The objective of this database system is to manage meteorological , hydrological and hydrogeological data and information for contributing groundwater development.
This program is developed on condition of following soft and hard tools;

        -Toshiba model J3100 (IBM compatible type)
            GX021(32 bits, 40 M bite hard disk)
            SL021(16 bits, 20 M bite hard disk)
        -Dual mood printer

        -Word perfect (French)
        -Word Star   (English)
        -Lotus 123
        -Database 3 plus

1.2 Outline

This system is composed of following functions.

(1) Data entry function

To entry following information and records

        a) Information of monitoring unit

        - Meteorological station
        - Gauging station
        - Well (borehole, dug well)

        b) Collected records (monthly and/or daily)

          - Rainfall
          - Discharge
          - Groundwater level
          - Temperature
          - Evaporation
          - Humidity
          - Sunshine hours
          - Wind velocity

        c) Water quality analysis

        d) Results of pumping test

        e) Groundwater level

(2) Search function

(2) Search function

To search entried information and records by required range

(3) Display and print function

To display on a screen and output to a printer

(4) Location map function

To show the Study Area with locations of entried wells and moni-
toring units

(5) Assist function

To arrange entried with graphic style on the screen

```
MAIN MENU ── APPEND/MODIFY ──┬── INFORMATION OF ──────────┬── METEOROLOGICAL STATION       PRINT
                             │   STATION/BOREHOLE          ├── GAUGING STATION   APPEND/ MODIFY
                             │                             ├── WELL/BOREHOLE
                             ├── DAILY DATA                ├── PRECIPITATION
                             │                             ├── DISCHARGE
                             │                             ├── WATER LEVEL
                             ├── MONTHLY DATA              ├── PRECIPITATION
                             │                             ├── DISCHARGE
                             │                             ├── WATER LEVEL
                             │                             ├── TEMPERATURE:MAX,MEAN,MIN
                             │                             ├── EVAPORATION
                             │                             ├── HUMIDITY 9:00, 15:00
                             │                             ├── SUNSHINE HOUR
                             │                             └── WIND VELOCITY: MAX,MEAN,AVG
                             │
                             ├── DISCHARGE OBSERVATION
                             ├── CHEMICAL QUALITY
                             ├── PUMPING TEST
                             └── GROUNDWATER LEVELING


         ── SEARCH ─────────┬── DESIGNATE AN EXTENT
                            ├── OF LAT. & LONG. ─────────┬── DAILY PRECIPITATION
                            │                            ├── MONTHLY PRECIPITATION
                            │                            ├── DAILY DISCHARGE
                            │                            ├── MONTHLY DISCHARGE
                            │                            ├── WATER LEVEL
                            │                            ├── TEMPERATURE:MAX,MIN,AVG
                            │                            ├── EVAPORATION
                            │                            ├── HUMIDITY: 9:00,15:00
                            │                            ├── SUNSHINE
                            │                            ├── WIND VELOCITY:MAX,MIN,AVG
                            │                            ├── SIMULTANEOUS DISCHARGE OBSERVATION
                            │                            └── ALL
                            └── ALL DATA


         ── DISPLAY & PRINT─┬── INFORMATION OF STATION
                            ├── DAILY DATA
                            ├── MONTHLY DATA
                            ├── DISCHARGE OBSERVATION
                            ├── CHEMICAL QUALITY OF WATER
                            ├── PUMPING TEST
                            └── GROUNDWATER LEVEL


         ── LOCATION MAP ───┬── METEOROLOGICAL STATION
                            ├── HYDROLOGICAL STATION
                            └── WELL & BOREHOLE


         ── ASSIST FUNCTION─┬── APPEND & MODIFY INDEX
                            ├── CODE
                            └── GRAPH
```
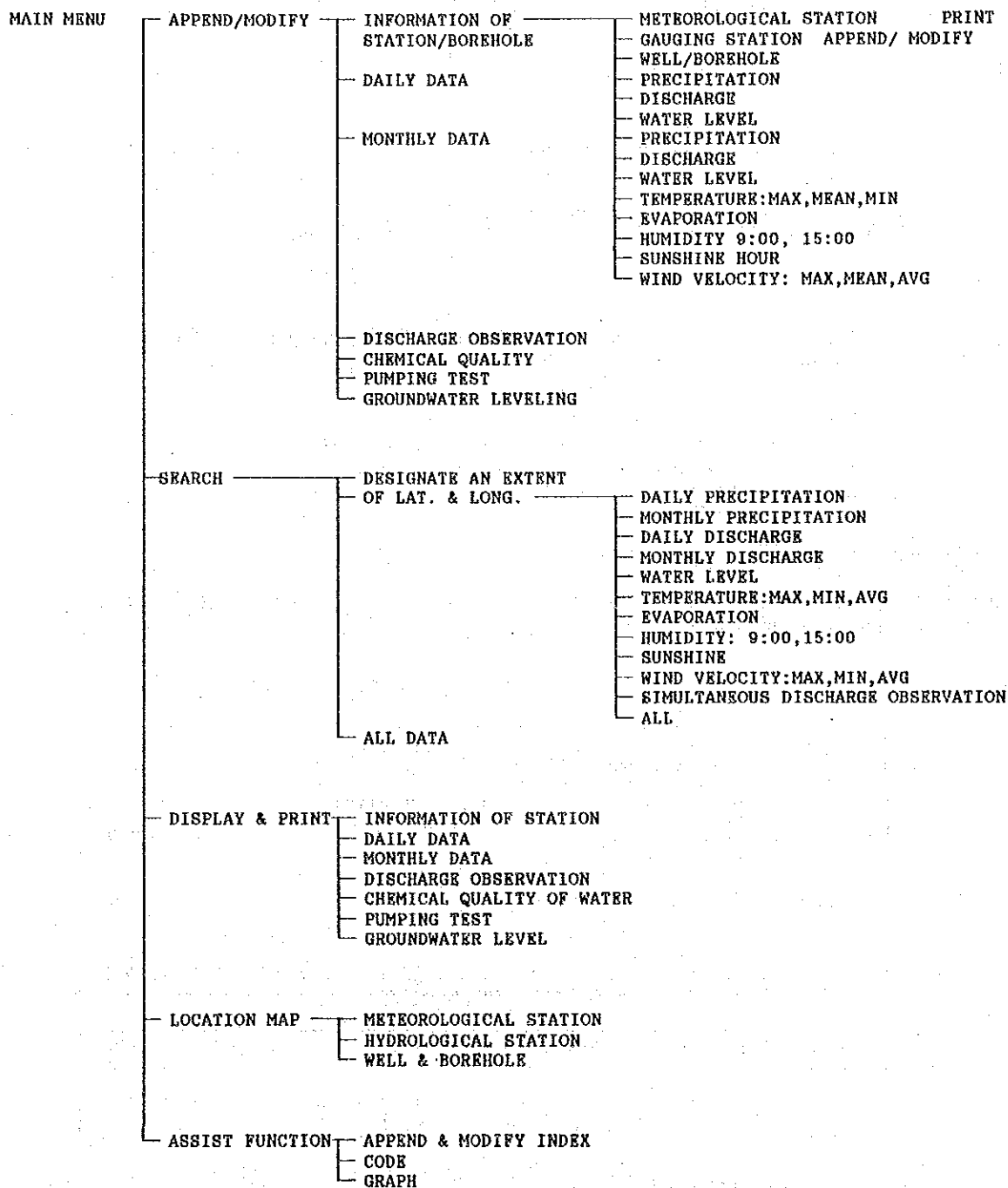
Fig. 4.3.2 Flow of Hydrogeological Database

2. Getting Started

2.1 Installation

Starting up of your computer

        (1) Turn on your computer
        (2) Enter the date (if necessary) and press RETURN
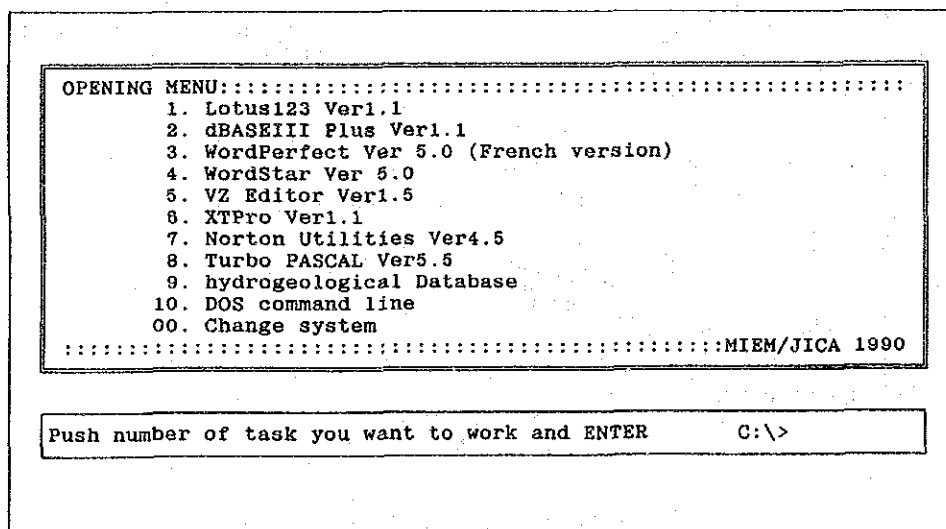   (3) enter the time (if necessary) and press RETURN

If you have a DOS in your hard disk, the prompt is

C >

        (4) Insert a Hydrological D.B. disk(No.1) in drive A
        (5) Type copy "a: inst.bat c:" and press RETURN
        (6) Type "inst" and RETURN
        (7) Follow a message on the display
            Inst.bat copies all directories and files which
            need for database program.
        (8) Remove disk from drive A.

2.2 Opening Menu

When you turn on a computer power switch, following "opening menu
will be appeared automatically;

```
OPENING MENU:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
            1. Lotus123 Ver1.1
            2. dBASEIII Plus Ver1.1
            3. WordPerfect Ver 5.0 (French version)
            4. WordStar Ver 5.0
            5. VZ Editor Ver1.5
            6. XTPro Ver1.1
            7. Norton Utilities Ver4.5
            8. Turbo PASCAL Ver5.5
            9. hydrogeological Database
           10. DOS command line
           00. Change system
    :::::::::::::::::::::::::::::::::::::::::::::::::::::MIEM/JICA 1990

    Push number of task you want to work and ENTER        C:\>
```

Then, type 9 and RETURN.
General menu of Hydrogeological Database will be appeared.
Follow the message on the screen.

3. General Skills

3.1 Command (menu) selection

There are three ways to send a command to the CPU.

(1) Select a command with the cursor keys and push RETURN

This way is generally applicable. When a menu appears on the screen, a command highlighted is called the current command. The current command is sent to the CPU upon pushing RETURN. You can select the current command with the cursor keys. When a cursor key is pushed, highlighted position moves among your choice of commands.

(2) Push a command number

This way is also generally applicable. Commands shown on a menu are generally given command numbers. Upon pushing a command number, the command is sent to the CPU. You do not have to push RETURN.

(3) Push a function key

If an instruction says "Select by function keys", upon pushing the function key corresponding to the command will send that command to the CPU. You do not have to push RETURN.

3.2 Data entry

(1) Data entry field

When you are required to enter data, data entry fields, where data are supposed to be given, appear on the screen. The fields are highlighted for easy identification. The field where the cursor is located is called the current entry field. If there are two or more entry fields on the screen, you can change the current entry field with the cursor keys.

(2) Data entry

Numerical keys and general keys are used to type in data. Typed characters appear in the current entry field on the screen. When finished typing in data, push RETURN. The next field will become the current entry field, or an instruction for the next operation will appear. (Under certain circumstances, the next field will become the current entry field without pushing RETURN.)

(3) Modification

The delete key, Back-space key, and cursor keys are used to erase characters or shift the cursor. If two or more entry fields exist, you can change the current entry field with a cursor key to modify data entered earlier or to skip forward to another

entry field. However, once the next instruction appears, or a system process (such as the computer's automatic supplying of an organization name or an aquifer name upon your entry of a code number) takes place, you can not use these means to modify data. In such a case, answer "N" to the query "OK? (Y/N)". You will be brought back to the very first data entry field of the data entry mode. The entries you have made will still be in each field. You can now move forward to make any corrections necessary.

3.3 Code numbers

(1) Station code and borehole code

Every meteorological and hydrological station and borehole is given a code number when registered in the systems. Since the code number is used in all operations to specify a station or borehole, the station or borehole code number must be registered prior to any other operation. If an operation is attempted with non-registered code number, one of the following messages will appear and the operation will be rejected.

        – Bad code number, or
        – The code does not exist

A code number can be chosen at your will, providing that the number is of four digits between 0000 and 9999. In order to classify a category of data, the letter "M" is given to the head of the code number of a meteorological station (ex. M0011), "H" is given to a hydrological station (ex. H8167), and "W" to a borehole (ex. W0123). These letters are given automatically by the program and do not have to be typed in.

The table of code numbers and their corresponding station or borehole names must be prepared for reference. You should update the table regularly.

(2) Index codes

There are four index codes: organization code, river code, aquifer code, and water use code Organizations, who own or are responsible for a station or borehole, are given a code number.
River names, aquifer names and water use of a borehole are given code numbers as well.
These code numbers and corresponding contents can be modified or appended by use of the assist menu of the data base.

3.4 General instructions

Instructions will often appear on the screen to help you. General rules and necessary responses to the instructions are:

(1) "Enter" "Push"

        In selecting a command, the term "enter" requires you to type in one or more characters and then press RETURN. The

term "push" only requires you to press a single key.

(2) Enter station code

Since the system is managed with code numbers, entering a station, borehole, or literature code number is the most frequent command.
In the Hydrogeological Data Base, when you are required to enter a code number, one of the following statements appear:

- Enter METEOROLOGICAL STATION code M_____
- Enter HYDROLOGICAL STATION code H_____
- Enter Well code W_____

You must type in the code number correctly. If the number is M0015, type in 0015. Do not type in 15, or M15, for the system will interpret these as different code numbers.

(3) Query

A query which asks you to confirm your intention will appear upon entry of a command or completion of data entry. *Enter Y to confirm. Enter N to modify or cancel the command* or data. Queries include:

- OK? (Y/N)

Generally used after completion of data entry.

- Enter this data? (Y/N),   - This data? (Y/N),
- Modify this data? (Y/N), - Print this data? (Y/N)

Upon entering a station or borehole code number, these statements, along with the station or borehole name corresponding to the code number, will appear on the screen for your confirmation
   - Append new data? (Y/N)

This statement appears when you are about to enter a new station code or new data.

- Continue to edit? (Y/N),
- Continue to next month? (Y/N),
- Enter another data? (Y/N)

These statements ask you whether you wish to continue *to enter the data or not.*

(4) Cancellation

When the following statements appear, you can quit the operation by entering E, O, or OO in accordance with an instruction. The preceding menu will appear on the screen.

```
- Enter (E) to quit,    - Enter (0) to quit,
- Enter (00) to quit,   - Enter (00) - (00) to quit
```

(5) Printer

The following statement will appear when data is to be printed out by the printer.

```
- Set Printer, and Hit RETURN key!
```

Follow the following procedures

    1. Make sure the printer power switch is on.
    2. Make sure the green light on the SEL button is on.

If not, push the SEL button to turn on the light.

    If you want to feed paper
    1. Turn off the light on the SEL button.
    2. Push the T.O.F button to feed one page, or
       push the L.F button to feed one line.

4. Hydrogeological DataBase

Main menu of the hydrogeological database is as follows;

```
        >>>>  MAIN  MENU  <<<<

        1. APPEND or MODIFY DATA

        2. SEARCH STATION NAME

        3. DISPLAY and PRINT OUT

        4. LOCATION MAP

        5. ASSIST FUNCTIONS

        0. END




                                        M1000
```

The functions of the commands shown in the M1000 menu are:

(1) APPEND or MODIFY DATA

- To register a new station or borehole code number
- To enter information about a station or borehole
- To enter daily data, monthly data, and other data
- To modify data already stored in the database

(2) SEARCH STATION NAME

- To find stations according to specified data
- To find out stations located in specified ranges
- To print out information about such stations

(3) DISPLAY and PRINT OUT

- To print out information about stations and boreholes
- To print out monthly and daily data
- To print out other data stored in the database

(4) LOCATION MAP

- To display the locations of stations and boreholes
- To give the coordinates of stations and boreholes

(5) ASSIST FUNCTIONS

- To append or modify index (organization, aquifer, river, and water-use) code numbers and their contents
- To draw graphs of monthly or daily data

Two ways are commonly available to select commands:

    (a) Push the number of the command, or
    (b) Push the cursor keys to select the command and then
        push RETURN

4.1 APPEND OR MODIFY

The sub-menu M1100 appears when 1 is chosen from the M1000 menu.

```
>>>>>>>>      APPEND  OR  MODIFY  DATA      <<<<<<<<

        1. INFORMATION of STATION / BOREHOLE

        2. DAILY DATA

        3. MONTHLY DATA

        4. DISCHARGE OBSERVATION DATA

        5. CHEMICAL QUALITY of WATER

        6. PUMPING TEST

        7. G/W LEVEL SIMULTANEOUS OBSERVATION

        0. END


                                          M1100
```

The functions of the commands are:
    (1) INFORMATION of STATION / BOREHOLE

      - To register a new station or borehole code number.
      - To enter information about a station or borehole.

    (2) DAILY DATA

      - To enter daily records. The following data can be
       precipitation, discharge, and water level

    (3) MONTHLY DATA

      - To enter monthly records. The following data can be
       entered:

      precipitation, evaporation, discharge, water level
      temperature (min., max., ave.)
      humidity (min., max., 9:00, 15:00), sunshine duration
      wind velocity (min., max., ave.)

    (4) DISCHARGE OBSERVATION DATA

      - To enter records of discharge measurement. This includes
       date of observation, water level, and discharge.

(5) CHEMICAL QUALITY OF WATER

 - To enter records of chemical quality tests. This
   includes date of sampling and principal ion
   concentration.

(6) PUMPING TEST

 - To enter records of pumping tests. This includes date
   of test, static and dynamic water levels, yield
   specific capacity, transmissibility, permeability,
   coefficient of storage, and pumping duration.

(7) G/W LEVEL SIMULTANEOUS OBSERVATION

 - To enter records of groundwater level simultaneous
   observation.
   These are duration of observation and water level.

4.1.1 INFORMATION OF STATION / BOREHOLE

The sub-menu M1110 appears when 1 is chosen from the M1100 menu.

```
┌─────────────────────────────────────────────────────────────┐
│                                                              │
│     <<<< INFORMATION DATA --- APPEND and MODIFY ---  MENU >>>> │
│                                                              │
│             1. METEOROLOGICAL STATION DATA                   │
│                                                              │
│             2. GAUGING STATION DATA                          │
│                                                              │
│             3. WELL and BOREHOLE DATA                        │
│                                                              │
│             0. END                              M1110        │
│                                                              │
└─────────────────────────────────────────────────────────────┘
```

4.1.1.1 Sub-menus

The sub-menus M1111, M1112, and M1113 appear upon selection of a command in the sub-menu (M1110). In each, the functions of the commands are:

    (1) PRINT

       - To print out a table of code numbers and their correlation ponding station names and other information
       Note: This command should be selected when you need the latest table.

    (2) APPEND OR MODIFY DATA

      - To register a station code number if the station is new.
      - To enter information about a station.

```
┌─────────────────────────────────────────────────────────────┐
│                                                              │
│    <<<< METEOROLOGICAL STATION DATA  APPEND, MODIFY and PRINT MENU >>>> │
│                                                              │
│           1. PRINT                                           │
│                                                              │
│           2. APPEND or MODIFY DATA                           │
│                                                              │
│           0. END                                             │
│                                                 M1111        │
│                                                              │
└─────────────────────────────────────────────────────────────┘
```

4.1.1.2 Entry of Information

(1) Station or borehole code

Upon selection of the command "APPEND OR MODIFY DATA", you will be asked the code number of the station. If the code number has been registered in the system, the name of the station or borehole corresponding to the code number will appear on the screen. If not, you will be asked whether you wish to append a new station or borehole with the code number.

(2) Data entry fields

Upon entry of a station or borehole code number, the screen displays a data entry mode. Data entry modes consist of statements and data entry fields. Data entry fields are painted blue. Existing data is displayed in respective data entry fields. If the station or borehole is new, all data entry fields are empty.

(3) Meteorological station data entry mode

```
METEOROLOGICAL STATION CODE:M_____    <- code number appears
                       NAME:          <- enter station name
AGENCY CODE:<-  enter code number of responsible agency
        NAME:<-  agency name appears upon agency code entry
VILLAGE    :   <-  enter village
DISTRICT   :   <-  enter district
PREFECTURE :   <-  enter prefecture
PROVINCE   :   <-  enter province
RIVER BASIN OR RIVER CODE: <- enter river code number
                     NAME: <- river name appears
ALTITUDE :                 <- enter altitude in M.S.L. m
MAP SHEET No. :            <- enter 1/250000 map No.
SECTOR(NE,NW,SE,SW) :      <- enter location on the map
LATITUDE :, LONGITUDE :    <- enter coordinates
```

Note: 1. You do not have to fill in all of the data entry
         fields.
      2. The RIVER BASIN OR RIVER CODE for meteorological
         stations is 1 (one), which indicates "Mangoky
         BASIN".

```
          ----------   METEROGIGCAL  STATION  DATA   ----------

    METEOROLOGICAL STATION CODE: M0001
                          NAME: Toliara

    AGENCY CODE:      0
          NAME:

    VILLAGE:
    DISTRICT:
    PREFECTURE:
    PROVINCE:
    RIVER BASIN or RIVER CODE:
                       NAME:

    ALTITUDE:        9.0 m

    MAP SHEET No.: 2e          SECTOR(NE,NW,SE,SW): NE

    LATITUDE:     23° 23'
    LONGITUDE:    43° 44'

            Modify this data? (Y/N)
```

(4) Hydrological station data entry mode

```
HYDROLOGICAL STATION CODE:H----    <- code number appears
                    NAME:          <- enter station name
AGENCY CODE: <-  enter code number of responsible agency
        NAME: <-  agency name appears upon agency code entry
VILLAGE     :    <-  enter village
DISTRICT    :    <-  enter district
PREFECTURE  :    <-  enter prefecture
PROVINCE    :    <-  enter province
RIVER BASIN OR RIVER CODE: <- enter river code number
                    NAME:  <- river name appears
ALTITUDE :                      <- enter altitude in M.S.L m
MAP SHEET No. :                 <- enter 1/250000 map No.
SECTOR(NE,NW,SE,SW) :           <- enter location on the map
LATITUDE :, LONGITUDE :         <- enter coordinates
```

Note: You do not have to fill in all of the entry fields.
      But the river code must be given for all station
      information.

```
 ----------- ----------     GAUGING  STATION  DATA     ----------

  GAUGING STATION CODE:      H0001
                  NAME:      Ihosy

  AGENCY CODE:       1
         NAME:    Directorate of Meteorology

  VILLAGE:
  DISTRICT:
  PREFECTURE:
  PROVINCE:
  RIVER BASIN or RIVER CODE:
                    NAME:

  ALTITUDE:        96.3 m

  MAP SHEET No.:               SECTOR(NE,NW,SE,SW): 4

  LATITUDE:        22° 23'
  LONGITUDE:       46°  6'

            Modify this data? (Y/N)
```

(5) Borehole record data entry modes

Four borehole record data entry modes are presented in succession. The four deal, respectively, with general data, borehole specifications, lithology, and pumping test data.

a) First data entry mode: general data

Upon entry of the borehole code, the first data entry mode appears.

```
WELL CODE:W----   <- code number appears
      NAME:       <- enter borehole name
AGENCY CODE:    <-  enter code number of responsible agency
        NAME:    <-  agency name appears upon agency code
entry
VILLAGE    :    <- enter village
DISTRICT   :    <- enter district
PREFECTURE :    <- enter prefecture
PROVINCE   :    <- enter province
RIVER BASIN OR RIVER CODE: <- enter river code number
                     NAME: <- river name appears
ALTITUDE :                 <- enter altitude in M.S.L. m
MAP SHEET No. :            <- enter 1/250000 map No.
SECTOR(NE,NW,SE,SW) :      <- enter location on the map
LATITUDE :, LONGITUDE :    <- enter coordinates
```

Note: 1. You do not have to fill in all of the entry fields.
2. The RIVER BASIN OR RIVER CODE for every borehole record is 1 (one), which indicates "Mangoky BASIN".

```
---------     BOREHOLE  LOCATION     ----------

WELL CODE:     W5001
     NAME:     Manoy

AGENCY CODE:      3
      NAME:    Ministry of Industries, Energy and Mines

VILLAGE:       Manoy
DISTRICT:
PREFECTURE:    5
PROVINCE:
RIVER BASIN or RIVER CODE: 10
                   NAME: Lake Ihotry

ALTITUDE:      84.0 m

MAP SHEET No.: E57        SECTOR(NE,NW,SE,SW):

LATITUDE:      22° 1'
LONGITUDE:     43° 48'

                OK? (Y/N)
```

b) Second data entry mode: borehole specifications

Upon completion of the first data entry mode, the second data entry mode appears.

WELL CODE:W----,   NAME:---------- <- borehole name and code appear
DATE(dd/mm/yy) : <- enter date of borehole completion
DEPTH OF BORE : <- enter depth of borehole
DIAMETER AT TOP : <- enter diameter of casing top
DIAMETER AT BOTTOM :   <- enter diameter of casing bottom
PERMANENT LINING TUBES :<- enter casing and screen position
                                and their material
WATER STRUCK AT DEPTH OF:<- enter water struck depth
AQUIFER CODE :<- enter code number of aquifer borehole taps
       NAME :<- aquifer name appears upon aquifer code
                 entry
USE WELL FOR : <- enter code number of water use
CONTENT :<- water use appears upon water use code entry
REM. : <- enter remarks regarding borehole or its record

Note: - The aquifer code should be given for every borehole
        record.
      - In giving DATE, if the number of the day or month
        is less than 10, put 0 in front of the number.
        (ex. 05)

```
====           BOREHOLE  SPESIFICATION              ====

WELL;     CODE: W6001        NAME: Manoy
DATE(dd/mm/yy):29/08/90      TOTAL DEPTH  :    38.4 m
DIAMETER AT TOP:  100.0 mm  AT BOTTOM:  100.0 mm


PERMANENT LINING TUBES:
        TOP(m)    BOTTOM(m)       MATERIAL
   1)    0.0        18.4     Blank casing
   2)   18.4        38.4     FRP screen
   3)     .           .
   4)     .           .
   5)     .           .
WATER STRUCK at DEPTH of:   1)       . m to       . m
                            2)       . m to       . m
                            3)       . m to       . m

   AQUIFER;     CODE:    NAME:
   USE WELL FOR; CODE: 1  CONTENT:DOMESTIC

REM.:
```

c) Third data entry mode: lithology

Upon completion of the second data entry mode, the third data entry mode appears. The data entry mode to append new borehole information and that to modify existing information differ.

- APPEND MODE -

CODE W----   <- borehole code number appears
Stratum No.   <- stratum numbers appear in numerical order
Nature of Strata <- enter lithology
Bottom Depth   <- enter depth to the bottom of stratum

- MODIFICATION MODE -

The existing table of lithology will appear along with the following instructions:

MODIFY->(M) APPEND->(A) END->(E) DELETE->(D) SCROLL->

These commands mean:

- Push M to modify lithology of specified stratum.
- Push A to append new stratum after the last stratum.
- Push D to delete specified stratum.
- Push E to quit the process
- Use the cursor keys to move within the table of lithology.

Procedures to enter date are the same as those in the APPEND MODE.

```
                    DETAILES of  STRATA

   CODE    W5001

   Stratum No.

   Nature of Strata


   Bottom Depth          m

No.  Nature of Strata                                      Depth(m)
  2  DARK,BROWN,SANDY,SILT,-,CLAY                              7.0
  3  SANDSTONE,(,BROWN,MEDIUM,-,COARSE,SAND,+,MUD            11.0
  4  SANDSTONE,(,RED,BROWN,MEDIUM,-,COARSE,SAND,+            18.0
  5  *,MUD,)                                                 18.1
  6  SANDSTONE,(,LIGHT,BROWN,MEDIUM,-,COARSE,-,VERY          35.0
  7  *,COARSE,SAND,)                                         36.1
  8  LIGHT,BROWN,-,BROWN,SANDY,GRAVEL,(,COARSE,-             41.0
  9  *,SMALL,PEBBLE,LIMESTONE,GNEISS,&,QUARTZ,)              41.1
 10  BROWN,GRAVEL,MARL                                       42.0

  /
```

Attention:

- Terms available to describe lithology are given in Tab.1.
- Type in a term and push RETURN.
- If the term is not listed in the table, the following message appears. Push RETURN and correct the term, or push the HELP key to view the table.
  Error! No such name [RETURN] to continue [HELP] to show
  ──

- A maximum of nine terms can be given to one stratum.
- If the number of terms is less than nine, push RETURN a second time after the last term entered to complete the entry.
- The table of lithology will appear line by line below the entry fields as each line is entered.

```
                          STRATA  NAME

          &                 /                  (                 )
          -                 *                  +                 L/C
          BASALT            BASALTIC           BASEMENT          BIG
          BLACK             BLUE               BOULDER
          BRECCIA           BROWN
          CALCALIOUS        CALCITE            CHALKY            CLAY
          CLAYER            CLEAN              COARSE            COPMPACT
          COMPACTED         COMPLEX            CREAM             CONGLOMERATE
          DIORITIC          DARK
          FINE              FISSURED           FOSSIL
          FRACTURED         GNEISS             GRAIN             GRANITIC
          GRAVEL            GRAVELIC           GREEN
          GREY              GRANULE            HARD
          LARGE             LATERITE           LATERITIC         LAVA
          LIGHT             LIMESTONE
          MARL              MARLY              MASSIVE           MATERIAL
          MEDIUM            METAMORPHICS       MICA              MIDDLE
          MUD               MUDSTONE           ORANGE            PALE
          PEBBLE            PINK               PLASTIC           POOR
          PORUS             PURPLE             PYRITE            QUARTZ

                       HIT RETURN TO return
```

In order to simplify a strata condition, following symbols is given as these meaning;

& ─── and, / ─── alternation, + ─── with
* ─── continued, L/C ─── Lost circulation

Following figure show a example of drilling log and description by symbols.

No.	Nature of Strata	Depth(m)
1	RED,BROWN,SANDY,MARL,(,WEATHERED,)	4.0
2	RED,BROWN,MARL,+,SAND,(,WEATHERED,)	7.0
3	GREEN,BROWN,SANDY,MARL	11.0
4	LIGHT,BROWN,-,BROWN,/,SANDY,MARL,SANDY,LIMESTONE	26.0
5	*,&,TENDER,LIMESTONE	26.1
6	LIGHT,BROWN,-,BROWN,/,SANDY,MARL,SANDY,LIMESTONE	27.0
7	*,&,TENDER,LIMESTONE,+,(,L/C,)	27.1
8	LIGHT,BROWN,-,BROWN,/,SANDY,MARL,SANDY,LIMESTONE	32.0
9	*,&,TENDER,LIMESTONE	32.1
10	LIGHT,BROWN,-,BROWN,/,SANDY,MARL,SANDY,LIMESTONE	33.0
11	*,&,TENDER,LIMESTONE,+,(,L/C,)	33.1
12	LIGHT,BROWN,-,BROWN,/,SANDY,MARL,SANDY,LIMESTONE	35.0
13	*,&,TENDER,LIMESTONE	35.1
/		

1-19

d) Fourth data entry mode : pumping test data

Upon completion of the third data entry mode, the following query will appear.

- Enter PUMPING TEST DATA ? (Y/N)
  The fourth data entry mode appears when Y is chosen.

```
WELL CODE :W-----    <- code number of borehole appears
      NAME :          <- name of borehole appears
DATE(dd/mm/yy):        <- enter date test was performed
STATIC WATER LEVEL :   <- enter static water level
DYNAMIC WATER LEVEL:   <- enter dynamic water level
YIELD :                <- enter yield of the borehole
SPECIFIC CAPACITY:     <- enter specific capacity
TRANSMISSIBILITY:      <- enter transmissibility
PERMEABILITY:          <- enter permeability
COEFFICIENT OF STORAGE:<- enter storativity
PUMPING DURATION:      <- enter duration of pumping test
```

Note: In giving DATE, if the number of day or month is less than 10, put 0 in front of the number. (ex. 13/01/86)

```
========  PUMPING  TEST  DATA    ========

WELL;      CODE: W5005      NAME: ANALATELO

           DATE(dd/mm/yy):   /  /

           STATIC  WATER LEBEL:         .  m
           DYNAMIC WATER LEBEL:         .  m

           YIELD:                       .  m^3/day
           SPECIFIC CAPACITY:           .  m^3/day/m

           TRANSMISSIBILITY:            .  m^2/day
           PERMEABILITY:                .  m/day
           COEFFICIENT of STORAGE:      .

           PUMPING DURATION:      hours
```

4.1.2 DAILY DATA

The sub-menu M1120 appears when 2 is chosen from the M1100 menu.

```
┌─────────────────────────────────────────────────────────┐
│                                                         │
│         <<<<<    DATA APPEND OR MODIFY    >>>>>          │
│                                                         │
│             1. PRECIPITATION                            │
│                                                         │
│             2. DISCHARGE                                │
│                                                         │
│             3. WATER LEVEL                              │
│                                                         │
│             0. END                                      │
│                                                         │
│                                              M1120      │
└─────────────────────────────────────────────────────────┘
```

(1) Station or borehole code

Upon selection of a command, you will be asked the station or borehole (well) code number as follows:

Enter METEOROLOGICAL STATION code. M____ <-For 1. PRECIPI-
TATION
Enter HYDROLOGICAL STATION code. H____   <-For 2. DISCHARGE
Enter WELL code. W____   <-For 3. WATER
LEVEL

Upon entry of the code number, its corresponding station or borehole name appears as in this example:

Enter METEOROLOGICAL STATION code. M____ <-- Enter code.
    METEOROLOGICAL STATION name ____ <-- Name appears.

If the code number does not exist, an error message appears.

(2) Entry of year and month

Upon confirming the code number, you will be asked the year and month as follows:

  Enter year   0
  Enter month   0

Reply as follows:
  Enter year 1965 <- Four digits are required.
                                   (e.q. not" 65")

If daily data for the specified month and year already exists in the database, the first daily data entry mode appears.

    Append new data ? (Y/N)

If no data already exists for the specified year and month, the following message first appears. Upon confirming, the first daily data entry mode appears.

(3) Daily data entry modes

For each of three data entry modes, data entry fields corresponding to the days of the specified month appear on the screen. You can shift the current data entry field among these days with the cursor keys. To calculate total and complete your entry of data, use the cursor keys to move the cursor beyond the last entry field. The three data entry modes are:

CAUTION-- Never use the RETURN key to move the cursor among the data fields except when intentionally entering data. Without keying a value in, pressing the RETURN key will enter a 0 for the field in which the cursor is located.

a) Precipitation

```
        Unit:        mm
        Data type:   Integer
        Total: Monthly precipitation (mm) is calculated
               upon completion of data entry.
```

```
            DAILY  PRECIPITATION  DATA              ** EDIT

    METEOROLOGICAL STATION CODE: M0001
                          NAME: Toliara

    YEAR: 1969      MONTH:  1

    DAY    1     2     3     4     5     6     7     8     9    10
           0     0     0     0     0     0     0     0     0     0

          11    12    13    14    15    16    17    18    19    20
           0     0     0     0     0     0     0     0     0     0

          21    22    23    24    25    26    27    28    29    30
           0     0     0     0     0     0     0     0     0     0

          31
           0                              Unit: mm/day

      TOTAL     0


                      OK? (Y/N)
```

b) Discharge

      Unit: m^3 (cubic meters)/sec. (daily average
           discharge)
      Data type: Number with two decimal places (ex. 1.23)
      Total: Monthly total discharge (m^3/month) is
           calculated upon completion of data entry.

c) Water level

      Unit:m (M.S.L.) (daily average groundwater level)
      Data type: Number with two decimal places (ex. 3.45)
      Average: Monthly average water level (m) is
           calculated upon completion of data entry.

Note:
  – Enter –1 for missing values
  – Monthly total or average value will not be calculated
    if daily data includes missing value(s).

4.1.3 MONTHLY DATA

The sub-menu M1130 appears when 3 is chosen from the M1100 menu.

```
┌─────────────────────────────────────────────────────────────┐
│                                                             │
│                                                             │
│                << MONTHLY DATA APPEND OR MODIFY >>          │
│                                                             │
│        1. PRECIPITATION          9. HUMIDITY at 12:00       │
│                                                             │
│        2. DISCHARGE              a. HUMIDITY at 17:00       │
│                                                             │
│        3. WATER LEVEL            b. AVERAGE HUMIDITY        │
│                                                             │
│        4. MINIMUM TEMPERATURE    c. SUNSHINE DURATION       │
│                                                             │
│        5. MAXIMUM TEMPERATURE    d. MINIMUM WIND VELOCITY   │
│                                                             │
│        6. AVERAGE TEMPERATURE    e. MAXIMUM WIND VELOCITY   │
│                                                             │
│        7. EVAPORATION            f. AVERAGE WIND VELOCITY   │
│                                                             │
│        8. HUMIDITY at 7:00       0. END                     │
│                                                             │
│                                                             │
│                                              M1130          │
│                                                             │
└─────────────────────────────────────────────────────────────┘
```

(1) Station or borehole code

Upon selection of a command, you will be asked the station or borehole (well) code number as follows:

                                        Command characters
Enter METEOROLOGICAL STATION code. M____   <-   1,4,5,6,7,8,9,
                                                a,b,c,d,e,f
Enter HYDROLOGICAL STATION code. H____   <-   2
Enter WELL code. W____   <-   3

Upon entry of the code number, its corresponding station or borehole name appears as in this example:

Enter HYDROLOGICAL STATION code. M‐‐‐‐‐   <‐‐‐ Enter code.
      HYDROLOGICAL STATION name   ‐‐‐‐‐‐   <‐‐‐ Name appears.

If the code number does not exist, an error message appears.

(2) Entry of year

Upon confirming the code number, you will be asked the year as follows:

 Enter year   0

Reply as follows:

Enter year 1965 <- Four digits are required.(e.g.not "65")
If monthly data for the specified year already exists in
the database, the first monthly data entry mode appears.
If no data already exists for the specified year, following
message appears.

    Append new data ? (Y/N)

Upon confirming, the first monthly data entry mode appears.

(3) Monthly data entry modes

For each of eight data entry modes, data entry fields
corresponding to the months of the specified year appear on
the screen. You can shift the current data entry field
among these months with the cursor keys. To calculate total
and complete your entry of data, use the cursor keys to
move the cursor beyond the last entry field. The eight data
entry modes are:

a) Precipitation

        Unit: mm
        Data type: Integer
        Total: Annual total value (mm) will be calculated
                   upon completion of data entry.

```
┌─────────────────────────────────────────────────────────────┐
│                                                               │
│          MONTHLY  PRECIPITATION  DATA            ** EDIT      │
│                                                               │
│  METEOROLOGICAL STATION CODE: M0001                           │
│                       NAME: Toliara                           │
│                                                               │
│                                                               │
│   YEAR   1969                                                 │
│                                                               │
│   MONTH    1        2        3        4        5        6     │
│           73       40        2       32       41       18     │
│                                                               │
│            7        8        9       10       11       12     │
│            2        0        0        0        9       86     │
│                                                               │
│                                                               │
│   TOTAL        303            Unit: mm/month                  │
│                                                               │
│                                                               │
│                                                               │
│             Modify this data? (Y/N)   Y                       │
│                                                               │
└─────────────────────────────────────────────────────────────┘
```

b) Evaporation

    Unit: mm
    Data type: Integer
    Total: Annual total value (mm) will be calculated
                upon completion of data entry.

c) Discharge

    Unit: 10000m^3(cubic meters)/month (monthly total)
    Data type: Integer
    Total: Annual total discharge (10000m^3/year) is
           calculated upon completion of data entry.

d) Water level

    Unit: m (M.S.L.) (monthly average water level)
    Data type: Number with two decimal places (ex. 4.56)
    Average:Annual average water level (m) is calculated
           upon completion of data entry.

e) Temperature (Minimum, Maximum, Average)

    Unit: degree C (monthly average temperature)
    Data type: Number with one decimal place (ex. 27.8)
    Average: Annual average temperature is calculated
           upon completion of data entry.

f) Humidity (Minimum, Maximum, at 9:00, at 15:00)

    Unit: % (monthly average humidity)
    Data type: Number with one decimal place (ex. 27.8)
    Average: Annual average humidity is calculated
           upon completion of data entry.

g) Sunshine duration

    Unit: hour/day (monthly average daily duration)
    Data type: Number with one decimal place (ex. 7.8)
    Average: Annual average daily sunshine duration is
           calculated upon completion of data entry.

h) Wind velocity (Minimum, Maximum, Average)

    Unit: m/sec. (monthly average wind velocity)
    Data type: Number with one decimal place (ex. 10.8)
    Average: Annual average wind velocity is calculated
           upon completion of data entry.

Note:
    - Enter -1 for missing values
    - Annual total or average value will not be calculated
      if monthly data includes missing value(s).

4.1.4 DISCHARGE OBSERVATION DATA

The following will occur when 4 is chosen from the M1100 menu.

(1) Station code

You will be asked the code number of the station where the discharge observation was carried out.

Enter HYDROLOGICAL STATION code. H_____

Upon entry of the code number, its corresponding station name appears as follows:

Enter HYDROLOGICAL STATION code. M----   <--- Enter code.
      HYDROLOGICAL STATION name ------- <--- Name appears.

If the code number does not exist, an error message appears.

(2) Date

Upon confirmation, you will be asked the date when the observation was carried out.

Enter Date (dd/mm/yy):   /   /   <- day, month, year

Note. If the number of day or month is less than 10, put 0
      in front of the number. (ex. 01/09/89 1st. Sept.
      1989)

(3) Water level, discharge

Water level (gauge height of the station) and observed discharge are entered next.

WATER LEVEL :   <- enter water level
DISCHARGE   :   <- enter observed discharge

4.1.5 CHEMICAL QUALITY OF WATER

The following will occur when 5 is chosen from the M1100 menu.

(1) Station or borehole code

You will be asked the code number of the station or bore-hole where the water sample was taken.

Enter HYDROLOGICAL STATION or WELL code.

$$\text{HYDROLOGICAL STATION} \text{ --- (H)}$$
$$\text{WELL} \text{ --- (W)}$$

In order to distinguish between hydrological station and borehole, H and W must be put in front of the code number of hydrological station and borehole, respectively.

(2) Date

Upon confirmation, you will be asked the date when the water sample was taken.

Enter Date of sampling   /   /   <- day, month, year
    (dd/mm/yy)

Note: If the number of day or month is less than 10, put 0 in front of the number. (ex. 09/05/89 9th May 1989)

(3) Data entry mode

Upon entry of the date, the data entry mode for the chemical quality of water appears. Abbreviations used in the mode to indicate principle ion concentration and the unit of concentration are:

Ca:	Calcium	(++)	mg/l	Mg:	Magnesium	(++)	mg/l
Na:	Sodium	(+)	mg/l	K:	Potassium	(+)	mg/l
HCO3:	Bicarbonate	(-)	mg/l	SO4:	Sulfate	(--)	mg/l
Cl:	Chloride	(-)	mg/l	NO3:	Nitrate	(-)	mg/l
F:	Fluoride	(-)	mg/l	TDS:	Dissolved solids		mg/l
Fe:	Iron	(++,+++)	mg/l				

```
          CHEMICAL  QUALITY  of  WATER  DATA            ** EDIT

     WELL CODE: W6007
     WELL NAME: BEFANDRIANA

     DATE(dd/mm/yy): 25/09/90


     Ca     53.0 mg/L     Mg    31.0mg/L     Na  14.8mg/L     K     2.10 mg/L

         HCO3   4.9 mg/L   SO4       mg/L   Cl  16.0 mg/L   NO3-   0.0  mg/L
     Variable not found.
         F      0.53mg/L   TDS  283  mg/L   PH   7.1        Fe    0.00 mg/L
```

4.1.6 PUMPING TEST

The following will occur when 6 is chosen from the M1100 menu.

(1) Borehole code

You will be asked the code number of the borehole where the pumping test was carried out.

Enter WELL code. W____

(2) Data entry mode

Upon entry of the borehole (well) code, the data entry mode to enter pumping test data appears.

```
        WELL CODE :W----     <- code number of borehole appears
             NAME :          <- name of borehole appears
DATE(dd/mm/yy):              <- enter date test was performed
STATIC WATER LEVEL :         <- enter static water level
DYNAMIC WATER LEVEL:         <- enter dynamic water level
YIELD :                      <- enter yield of the borehole
SPECIFIC CAPACITY:           <- enter specific capacity
TRANSMISSIBILITY:            <- enter transmissibility
PERMEABILITY:                <- enter permeability
COEFFICIENT OF STORAGE:      <- enter storativity
PUMPING DURATION:            <- enter duration of pumping test
```

Note: In giving DATE, if the number of day or month is less than 10, put 0 in front of the number. (ex. 13/01/86)

4.1.7 G/W LEVEL SIMULTANEOUS OBSERVATION

The following will occur when 7 is chosen from the M1100 menu.

(1) Duration of the observation

You will be asked the duration of the observation (beginning and ending date of the observation).

Enter date of beginning and end   (dd/mm/yy)
      /   /   -   /   /

(ex. 19/07/88 - 01/08/88 <- The observation was carried out
from Jul. 19th to Aug. 1st,1988)

(2) Borehole code

You will be asked the borehole (well) code number of the borehole where the water level was measured.

Enter WELL code: W_____

(3) Water level

Upon confirmation, you will be asked the water level.

WATER LEVEL: <- enter water level of the borehole

4.2 SEARCH STATION NAME

The sub-menu M1200 appears when 2 is chosen from the M1000 menu. The functions of the commands are:

1. Designate an extent of LATITUDE and LONGITUDE

Specify the range within which the station search is to be made.

2. Search from all data

The station search is made from among all data.

```
          <<<<    SEARCH  DATA      >>>>

    1. Designate an extent of LATITUDE and LONGITUDE

    2. Search  from   all  DATA

    0. END


                                        M1200
```

If you select the first command, you will be asked the range of the search.

Enter range of Latitude and Longitude
    LATITUDE   −
    LONGITUDE   −

Upon entry of the coordinates, sub-menu M1210 appears. If you select the second command, sub-menu M1210 appears immediately.

```
    <<<<<  SEARCH  MENU  >>>>>   Move cursor key and RETURN, or Push number
    1. DAILY   PRECIPITATION        d. HUMIDITY at 17:00

    2. MONTHLY PRECIPITATION        e. AVERAGE HUMIDITY

    3. DAILY   DISCHARGE            f. SUNSHINE DURATION

    4. MONTHLY DISCHARGE            g. MINIMUM WIND VELOCITY

    5. DAILY   WATER LEVEL          h. MAXIMUM WIND VELOCITY

    6. MONTHLY WATER LEVEL          i. AVERAGE WIND VELOCITY

    7. MINIMUM TEMPERATURE          j. SIMULTANEOUS OBSERVATION

    8. MAXIMUM TEMPERATURE          k. PUMPING TEST

    9. AVERAGE TEMPERATURE          l. CHEMICAL QUALITY of WATER

    a. EVAPORATION                  m. DISCHARGE OBSERVATION

    b. HUMIDITY at 7:00             n. ALL

    c. HUMIDITY at 12:00            o. END
                                             M1210
```

(1) Select item

You will be asked to select an item of observation from the
menu. Stations which have record of carrying out that item
of observation will be found and their names displayed.

Note: If you choose n from sub-menu M1210, the system will
search for files which have any one of the items of
observation, 1 through m.

(2) Print out

Upon selection of the item of observation, sub-menu M1211
appears, from which you can select information on the
stations or boreholes to be printed out.

```
  <<<<        SEARCH  AND  PRINT        >>>> 1. DAILY    PRECIPITATION

      1.   CODE,NAME,AGENCY NAME

      2.   CODE,PLACE NAME,LOCAL-GOVER.,STATE,RIVER BASIN or RIVER

      3.   CODE,NAME,ALTITUDE,MAP SHEET No.,SECTOR,LATITUDE,LONGITUDE

      4.   CODE,ITEMS of OBSERVATION

      5.   CODE,NAME,TERM of OBSERVATIONAL DATA

      0.   END                                               M1211
```

Note:

- 4. CODE, ITEMS OF OBSERVATION will print out station
code numbers and all items of observation carried out
at those stations.

- 5. CODE,NAME, TERM OF OBSERVATIONAL DATA will print out
station code numbers and period of observation for the item
chosen from sub-menu M1210. This command can only be used
when the selected item of observation is daily or monthly
data and cannot be used for items j through n sub-menu
M1210.

4.3 PRINT OUT

The sub-menu M1300 appears when 3 is chosen from the M1000 menu.

```
>>>>>>>>      DISPLAY AND PRINT MENU        <<<<<<<<

        1. INFORMATION of STATION / BOREHOLE

        2. DAILY DATA

        3. MONTHLY DATA

        4. DISCHARGE OBSERVATION DATA

        5. CHEMICAL QUALITY of WATER

        6. PUMPING TEST

        7. G/W LEVEL SIMULTANEOUS OBSERVATION

        0. END


                                              M1300
```

4.3.1 INFORMATION OF STATION / BOREHOLE

The sub-menu M1310 appears when 1 is chosen from the M1300 menu.

```
    <<<< INFORMATION DATA --- DISPLAY and PRINT --- MENU >>>>

            1. METEOROLOGICAL STATION DATA

            2. GAUGING STATION DATA

            3. WELL and BOREHOLE DATA

            0. END

                                              M1310
```

4.3.1.1 METEOROLOGICAL STATION AND HYDROLOGICAL STATION

```
          <<<<METEOROLOGICAL STATION-----DISPLAY and PRINT MENU>>>>

                    1. PRINT INFORMATIONS BY CODE

                    2. PRINT BY RIVER BASIN OR RIVER-NAME

                    3. PRINT INFORMATIONS OF EVERY STATION

                    0.  END

                                                        M1311
```

Sub-menus for meteorological or hydrological stations appear, respectively, when either 1 or 2 is chosen from the M1310 menu. Sub-menu M1311 is an example. In both sub-menus, the functions of the commands are:

(1) PRINT INFORMATION BY CODE

Choose this to print out all information on a particular station. You will be asked the code number of the station. If the code you enter does not exist, an error message will appear.

(2) PRINT BY RIVER BASIN OR RIVER-NAME

Choose this to print out data on every station which belongs to a particular river or river-basin.
The sub-menu M1311R appears upon selection of this command. You will be asked to select river or river basin.

```
           <<<<      RIVER  BASIN  or  RIVER  NAME  LIST      >>>>
                              SELECT NAME.

   Mangoky        Onilahy        Fiherenana    Manombo        Malio

   Isahena        Sakanavaka     Taheza        Sakondry       Lake Ihotry

   END



                                                        M1311R
```

The sub-menu M1311P appears upon selection of the river or river-basin. You will be asked to select the information to be printed out (ex. If you need names and locations, select 3).

```
┌──────────────────────────────────────────────────────────────────┐
│                                                                    │
│        <<<       SEARCH AND PRINTOUT        >>>   Onilahy          │
│                                                                    │
│     1.  CODE,NAME,AGENCY NAME                                      │
│                                                                    │
│     2.  CODE,PLACE NAME,LOCAL-GOVER.,STATE,RIVER BASIN or RIVER    │
│                                                                    │
│     3.  CODE,NAME,ALTITUDE,MAP SHEET No.,SECTOR,LATITUDE,LONGITUDE │
│                                                                    │
│     4.  CODE,ITEMS of OBSERVATION                                  │
│                                                                    │
│     0.  END                                                        │
│                                                     M1311P         │
│                                                                    │
└──────────────────────────────────────────────────────────────────┘
```

(3) PRINT INFORMATION OF EVERY STATION

The sub-menu M1311P appears upon selection of this command. You will be asked to select the information to be printed out.

4.3.1.2 WELL AND BOREHOLE DATA

Sub-menu M1312 appears when 3 is chosen from the M1310 menu. The functions of the commands are:

```
┌──────────────────────────────────────────────────────────────────┐
│                                                                    │
│                                                                    │
│            <<<<WELL----DISPLAY and PRINT MENU>>>>                  │
│                                                                    │
│         1. PRINT INFORMATIONS BY CODE                              │
│                                                                    │
│         2. PRINT BY EACH AQUIFER                                   │
│                                                                    │
│         3. PRINT INFORMATIONS OF EVERY BOREHOLE                    │
│                                                                    │
│         0.  END                                                    │
│                                                     M1312          │
│                                                                    │
└──────────────────────────────────────────────────────────────────┘
```

(1) PRINT INFORMATION BY CODE

Choose this to print out all information on a particular borehole. You will be asked the code number of the borehole.
If the code you enter does not exist, an error message will appear.

(2) PRINT BY AQUIFER

Choose this to print out data on every borehole which taps a particular aquifer.
The sub-menu M1312A appears upon selection of this

command. You will be asked to select the aquifer.

```
          <<<<   AQUIFER  NAME  LIST      >>>>
                        SELECT NAME.

          A/M-U/E        B/M-U/E

          B/M-U/E        Ls/L-M/E

          CD/M/J         CD/L/J

          END
                                        M1312A
```

The sub-menu M1312P appears upon selection of the aquifer
er. You will be asked to select information to be print
out (ex. If you need depth of borehole, water level,
and yield, select 4).

(3) PRINT INFORMATIONS OF EVERY BOREHOLE

The sub-menu M1312P appears upon selection of this
command. You will be asked to select the information to
be printed out.

```
       <<<<       SEARCH AND  PRINTOUT     >>>>  B/M-U/E

   1.  CODE,NAME,AGENCY NAME,USE FOR

   2.  CODE,AQUIFER-NAME,PLACE-NAME,LOCAL-GOVER.,STATE

   3.  CODE,NAME,ALTITUDE,MAP SHEET No.,SECTOR,LATITUDE,LONGITUDE

   4.  CODE,AQUIFER,DEPTH,DIAMETER,STATIC W.L.,DYNAMIC W.L.,YIELD

   0.  END
                                              M1312P
```

4.3.2 DAILY DATA

The sub-menu M1320 appears when 2 is chosen from the M1300
menu.

```
       <<<<<   DAILY DATA      PRINT     >>>>>

          1. PRECIPITATION

          2. DISCHARGE

          3. WATER LEVEL

          0. END
                                        M1320
```

Upon entry of a command, you are asked to enter the code number of a station or borehole. Upon entry of the code number, you are asked to enter the period to be covered by the data to be printed out.

            Enter beginning year   ---- - ----
            and ending year to print

4.3.3 MONTHLY DATA

The sub-menu M1330 appears when 3 is chosen from the M1300 menu.

```
          <<  MONTHLY  DATA            PPRINT  >>

    1. PRECIPITATION              9. HUMIDITY at 12:00

    2. DISCHARGE                  a. HUMIDITY at 17:00

    3. WATER LEVEL                b. AVERAGE HUMIDITY

    4. MINIMUM TEMPERATURE        c. SUNSHINE DURATION

    5. MAXIMUM TEMPERATURE        d. MINIMUM WIND VELOCITY

    6. AVERAGE TEMPERATURE        e. MAXIMUM WIND VELOCITY

    7. EVAPORATION                f. AVERAGE WIND VELOCITY

    8. HUMIDITY at 7:00           0. END


                                         M1330
```

Upon entry of a command, you are asked to enter the code number of a station or borehole. Upon entry of the code number, you are asked to enter the period to be covered by the data to be printed out.

            Enter beginning year   ---- - ----
            and ending year to print

4.3.4 DISCHARGE OBSERVATION DATA

The sub-menu M1340 appears when 4 is chosen from the M1300 menu. The functions of the commands are:

    (1) PRINT BY STATION

    Choose this to print out discharge observation data on a particular station. You will be asked the station code number.

    (2) PRINT ALL DATA

    Choose this to print out discharge observation data on all stations.

```
+----------------------------------------------------------------+
|                                                                |
|   <<<<           DISCHARGE  OVSERVATION  DATA      PRINT        >>>> |
|                                                                |
|                    1.   PRINT BY STATION                       |
|                                                                |
|                    2.   PRINT ALL DATA                         |
|                                                                |
|                    0.   END                                    |
|                                                                |
|                                            M1340               |
|                                                                |
+----------------------------------------------------------------+
```

4.3.5 CHEMICAL QUALITY OF WATER

The sub-menu M1350 appears when 5 is chosen from the M1300 menu.
The functions of the commands are:

(1) PRINT BY AQUIFER

Choose this to print out chemical quality data on a
particular aquifer. You will be asked to select an aquifer.

(2) PRINT BY WELL OR STATION CODE

Choose this to print out data on a particular station or
borehole.

(3) PRINT ALL DATA

Choose this to print out data on all aquifers and all
stations or boreholes.

```
+----------------------------------------------------------------+
|                                                                |
|         <<< CHEMICAL QUALITY of WATER DATA    PRINT >>>         |
|                                                                |
|              1.   PRINT BY EACH AQUIFER                        |
|                                                                |
|              2.   PRINT BY WELL OR STATION CODE                |
|                                                                |
|              3.   PRINT ALL DATA                               |
|                                                                |
|              0.   END                                          |
|                                                                |
|                                        M1350                   |
|                                                                |
+----------------------------------------------------------------+
```

4.3.6 PUMPING TEST

The sub-menu M1360 appears when 6 is chosen from the M1300 menu. The functions of the commands are:

(1) PRINT BY AQUIFER

Choose this to print out pumping test data performed at the boreholes in a particular aquifer. You will be asked to select an aquifer.

(2) PRINT BY WELL

Choose this to print out data on a particular borehole.

(3) PRINT ALL DATA

Choose this to print out data on all aquifers and boreholes.

```
          <<< PUMPING TEST DATA    PRINT >>>

          1.   PRINT BY EACH AQUIFER

          2.   PRINT BY WELL OR STATION CODE

          3.   PRINT ALL DATA

          0.   END




                                          M1360
```

4.3.7 G/W LEVEL SIMULTANEOUS OBSERVATION

When 1 is chosen from the M1300 menu, the peoriod of the periods of the simultaneous observations whose data have been stored in the data base.

The following statements and data entry fields appear at the bottom of the screen.

Type in the number of term to print and RETURN (Within 10 terms)
When complete, RETURN again.

___ ___ ___ ___ ___ ___ ___ ___ ___ ___

Type in the numbers of the periods of observation. You can select up to ten periods, there are only four periods stored.
When your selection is complete, push the RETURN key without typing in any letter to quit the selection and print out the results.

    Ex. To print out the results of the observations carried out from 19/07/88 to 01/08/88 and from 16/05/89 to 21/05/89:

    Type in the number of term to print and RETURN (Within 10 terms)
    When complete, RETURN again.

    _2_ _4_ RET ___ ___ ___ ___ ___ ___ ___

4.4 LOCATION MAP

The sub-menu M1400 appears when 4 is chosen from the M1000 menu.

```
      1. METEOROLOGICAL STATION
      2. HYDROLOGICAL STATION
      3. WELL AND BOREHOLE
      0. END                          M1400
```

For commands 1 through 3, a map of the basin withprincipal
drainages and town names appears on the screen.
Select the map section you want to enlarge with the cursor keys
by moving the painted rectangle among the map sections When the
section you want to enlarge is painted, push RETURN.
An enlarged map with locations of stations and boreholes appears.
If you want to view a list of the coordinates of the stations and
boreholes, push the HELP key.

> Note: If you want to make a hard copy of the screen,
>   hold the GRPH key down and press the COPY key.

1. METEROLOGICAL STATION   SELECT MAP WITH ARROW KEY. PRESS (E)-)MENU.
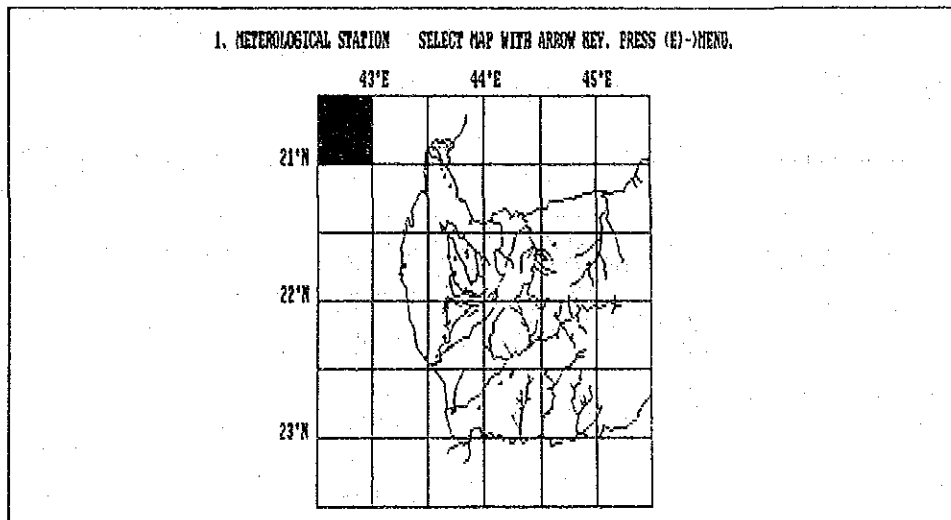
4.5 ASSIST FUNCTIONS

The sub-menu M1500 appears when 5 is chosen from the M1000 menu.
The functions of the commands are:

(1) APPEND AND MODIFY INDEX CODE

Choose this to append and modify index codes. Index codes
include agency code, river code, aquifer code, and water
use code.

```
        <<<<    ASSIST  MENU        >>>>

        1.  APPEND and MODIFY Index code

        2.  GRAPH

        0.  END


                                          M1500
```

(2) GRAPH

Choose this to draw a graph of daily or monthly data.
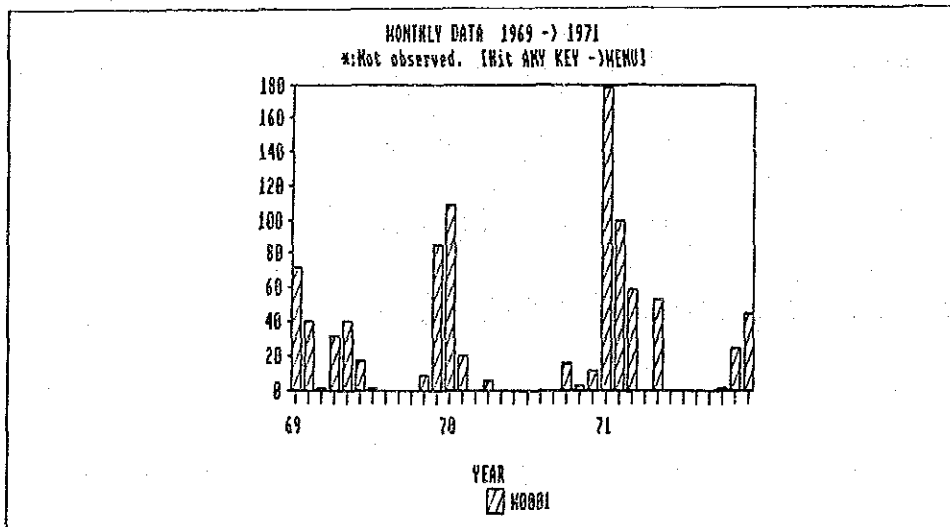
4.5.1 APPEND and MODIFY INDEX CODE

The sub-menu M1510 appears when 1 is chosen from the
M1500 menu. Select 1, 3, 5, or 7 to print out or display an
index code Table. Select 2, 4, 6, or 8 to append or modify
an index code.

```
<<<        APPPEND   AND    MODIFY    ID. CODE          >>>

       1.  AGENCY CODE                    PRINT/DISPLAY

       2.                                 EDIT /APPEND

       3.  RIVER BASIN OR RIVER CODE      PRINT/DISPLAY

       4.                                 EDIT /APPEND

       5.  AQUIFER CODE                   PRINT/DISPLAY

       6.                                 EDIT /APPEND

       7.  USE (WELL) CODE                PRINT/DISPLAY

       8.                                 EDIT /APPEND

       0.  END


                                                  M1510
```

4.5.1.1 PRINT/DISPLAY

When command number 1, 3, 5, or 7 is selected, the follow-
ing instruction appears.

Enter (P) to print out, enter (S) to display on the screen

The index table will be printed out or displayed on the
screen in accordance with your command (P or S).

4.5.1.2 APPEND and MODIFY

When command number 2,4,6, or 8 is selected, the following
instruction appears.

Enter Index code number to edit.   _____

Enter the index code. If the number exists, the following
message appears.

The code indexes below meaning. RETURN to confirm, push E
to quit
   2   S.S.W.B/S.S.M.W.E   <- code number and its
contents

If you need to see the index table, enter 999.

Upon confirmation, you will be asked to type in the con-

Upon completion of typing, push RETURN to quit. The fol-
lowing instruction will appear.

Hit RETURN to confirm. Push (E) to edit again. Push (D) to
delete this Index.
To confirm, push RETURN. If you need to correct your entry,
push E to type in again. If you want to delete the index,
push D.

4.5.2 GRAPH

The sub-menu M1520 appears when 2 is chosen from the M1500
menu. You can make a graph of daily data or monthly data.
Up to
five stations and/or types of data can be drawn in a graph.

```
<<<    GRAPH   MENU        >>>

     1.   DAILY DATA

     2.   MONTHLY DATA


     0.   END


                                        M1520
```

4.5.2.1 Data entry mode

(1) Data type and station code

The sub-menu M1521, for daily data, or M1522, for monthly
data appears when 1 or 2, respectively, is chosen from the
M1520 menu. Data entry procedures are:

(a) Type in the number of the data type (ex. enter 2 to
select discharge).

(b) Type in the code number of the station (ex. enter
0006 to select ARGUNGU). The station name will appear.

(c) Continue (a) and (b).

(d) When you have completed selection of data type and
station, enter 9 (daily data) or 99 (monthly data) in
the entry field for data type.

```
        Enter observation item number and station code number.

        DATA PLACE CODE      PLACE NAME

    1.     1    M0001        Toliara

    2.    99

    3.

    4.

    5.
                  Enter beginning and end year to display graph.
                  Duration must be not more than 30 years.
                  B. Year -->E. Year


                                              M1521
```

(2) Year and month

You will then be asked the beginning and ending month of
the graph.
Enter beginning and end month and year to display graph.
Duration must be within one year (daily data).
Duration must be within thirty years (monthly data).

        YEAR MONTH   ->   YEAR MONTH

Ex. If you want to draw a graph of monthly precipitation
at Toliara station from 1969 to 1971, your data entry
becomes:

```
     DATA   PLACE CODE     PLACE NAME
1.    1       M0001         Toliara
2.   99
3.
4.
```

```
         YEAR   MONTH    ->    YEAR   MONTH
         1969     1            1971    12
```

Enter observation item number and station code number

```
     DATA PLACE CODE       PLACE NAME

1.     1     M0001          Toliara

2.     9

3.

4.

5.

     DATA    1. DAILY PRECIPITATION
             2. DAILY DISCHARGE
             3. DAILY WATER LEVEL
```

4.5.2.2 Graph Mode

The general MENU (M-G) of the data base systems will then appear. Enter G to enter the graph mode, and wait two or three minutes for the following menu to appear.

```
        < TYPE IN THE NUMBER OF THE COMMAND YOU WANT TO SELECT, AND RETURN >

     +---------------------------------------------------------------------+
            1. DATA BASE

                    When ready, Enter 1

            G. DISPLAY GRAPH

                    When ready, Enter G

            0. END
                        Enter 0

     +---------------------------------------------------------------------+
       If you have selected the GRAPH menu in the Hydrogeological Data Base
       and this menu text was shown upon completion of data entry, please
       type in (G) and hit RETURN to display a graph on the screen.

     C:\HDB>
```

Select graph type by cursor or push No.

1 LINE CHART   2 BAR CHART   0 END

Select the desired chart, and the following menu will appear.

Do you want to designate minimum and maximum of graph?

1 AUTO   2 MANUAL

If you select 1, the graph size will be automatically determined by the system. If you select 2, you will be asked the minimum and maximum values for the graph.

MINIMUM ?
MAXIMUM ?

Upon completion of your selections, the graph will appear on the screen. If you want to make a hard copy of the screen, hold the GRPH key down and push the COPY key.

Push the space key to quit the display, and the following menu will appear.

   Do you want to change duration
   1 No   2 Yes

If you select 2, you can change the duration of the graph provided, that the new duration is within the original duration. If you select 1, the following menu appears again.

   Select graph type by cursor or push No.
   1 LINE CHART   2 BAR CHART   0 END

If you want to quit, select 0. The general menu (M-G) of the data base system appears again.
Select 1 to continue in the hydrogeological data base.

```
         < TYPE IN THE NUMBER OF THE COMMAND YOU WANT TO SELECT, AND RETURN >

    +--------------------------------------------------------------------+

          1. DATA BASE

                   When ready, Enter 1

          G. DISPLAY GRAPH

                   When ready, Enter G

          0. END
                       Enter 0

    +--------------------------------------------------------------------+

      If you have selected the GRAPH menu in the Hydrogeological Data Base
      and this menu text was shown upon completion of data entry, please
      type in (G) and hit RETURN to display a graph on the screen.

    C:\HDB>
```

2. GROUNDWATER SIMULATION

INTRODUCTION

Groundwater is increasingly being exploited as both a primary and supplementary source of water supply in a variety of regions and nations. However, groundwater is essentially a hidden resource, the effects of groundwater often causes land subsidence in urban areas and seawater intrusion in coastal areas, which in 1960-1970 become a social problem in Japan. In view of the importance of groundwater and the uncertainties associated with its use, "Simulation" a a mathematical tool is necessary in order to foster more efficient groundwater resource management. The purpose of the report on groundwater simulation is to summarize the state-of-the-art in computer modeling in Japan and its utilization in groundwater basin management studies.

Numerical groundwater models simulate the behavior of groundwater systems and their response to stress, which includes: flow, subsidence, mass transport and heat transport. However, in this report mainly flow and subsidence models are described. Other models are being developed or are undergoing improvements.

2-1 SIMULATION FOR GROUNDWATER BASIN MANAGEMENT

2-1-1 THE ROLE OF GROUNDWATER SIMULATION

Groundwater development is considered similar to the operation of a huge integrated system. Groundwater is exploited as a useful water resource. However, undesirable effects such as sea water intrusion and land subsidence may occur as counteractions.

The behavior of groundwater is subjected not only to the characteristics of the groundwater basin, itself, but also to the activities of human beings, such as pumping, artificial recharging and so on.

The groundwater basin is regarded as a system and characterized by the following three items

a. is of a huge scale
b. is made up of components of a complicated and codependent relation
c. playing an important role in economy of the related region

Thus, the simulation approach to the groundwater basin by using various modeling techniques, has widely been employed in solving management problems of groundwater basins since the mid-1960's.

2-1-2 FUNDAMENTAL PROCEDURE OF GROUNDWATER SIMULATION

The simulation procedure for an artesian groundwater basin is basically same as that which is usually employed, and is described as follows (Figure 2-1).

a. The integrated system of the groundwater basin is comprised of area units and aquifer system units referred to as subsystems. A subsystem is further divided into elements (aquifer constants). The scale and accuracy of these elements are subject to the purpose and complexity of the system.

b. The interrelated nature of the subsystems and elements allows quantification of the groundwater simulation model once the computer program has been written.
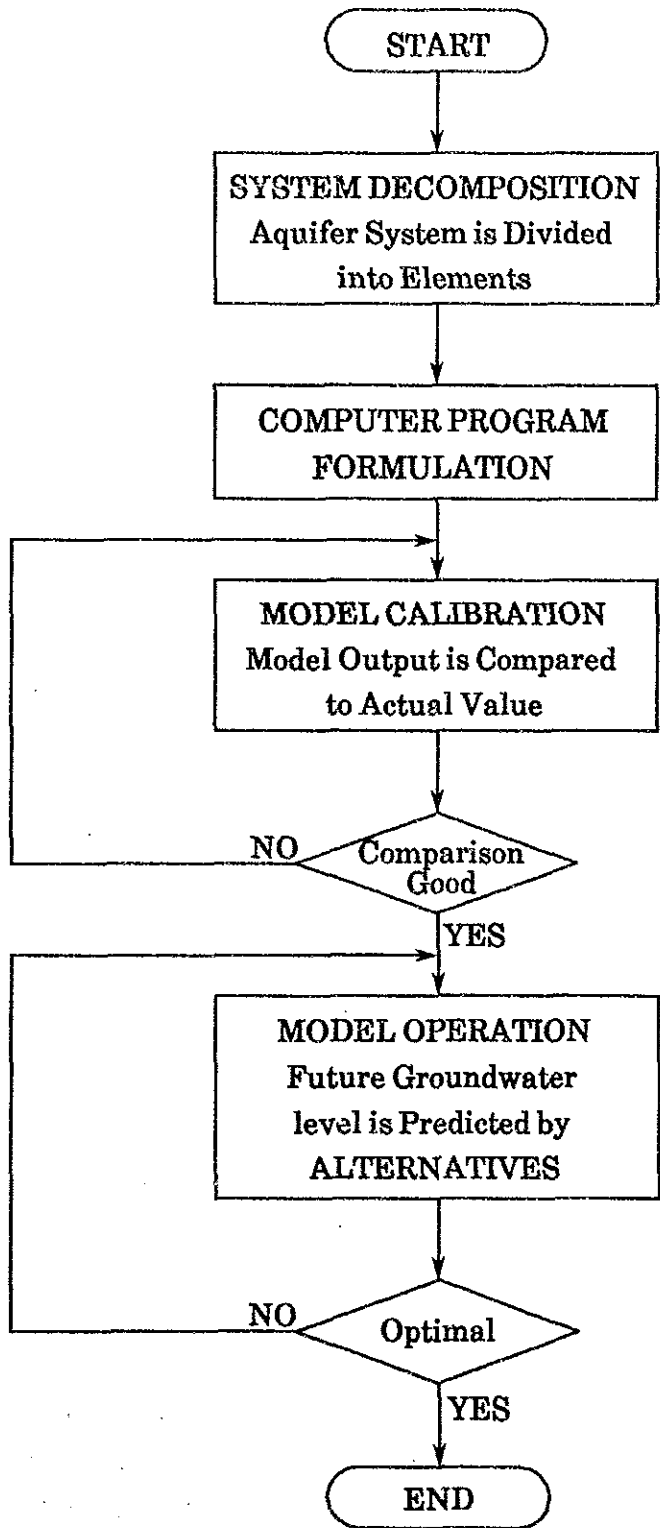
Fig. 2-1 General Procedure of Simulation

c. Initial and boundary conditions, as well as historical data (e.g. withdrawal) are incorporated into the groundwater simulation model. The model is then checked to see whether it represents actual conditions or not. (For example, outputs on groundwater levels are compared with actual observed data). Through this process, boundary conditions and given parameters are identified.

d. By applying future withdrawal of groundwater to the new model, the decline of groundwater levels are predicted.

e. The optimal exploitation plan is determined in consideration of factors for safe yield.

2-2 PRESENT STATUS OF GROUNDWATER SIMULATION

Humans' extensive and varied interference with the groundwater system has fostered the development of formal mathematical tools to aid in simulating groundwater conditions and predicting the response of the system. At the simplest level, these mathematical tools include analytical methods or models which deal with idealized aquifers assumed to exhibit uniform conditions, steady flows, and regular geometrical boundaries. Analytical solutions to groundwater problems can be carried out with the aid of paper and pencil and perhaps a calculator, and generally do not require expensive hardware such as computers.

For more complex aquifer situations where heterogeneous and dynamic conditions including irregular boundaries prevail or where more accurate simulations are desired, the use of more sophisticated techniques and technology becomes necessary. Historically, the first such technique to be developed was the analog model. As its name implies, the analog model is a physical replica of the groundwater system by a medium which is capable of reproducing the processes occurring in an aquifer. For example, analogs which have been employed for groundwater systems include the flow of viscous fluids of the passage of electrical currents through resistance capacitance networks (Figure-2-2).

$$T(h_1 + h_2 + h_3 + h_4 - 4h_5) = S \, \Delta x_\lambda^2 \frac{\partial h_5}{\partial t_A}$$
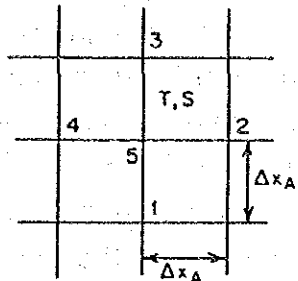
(a)
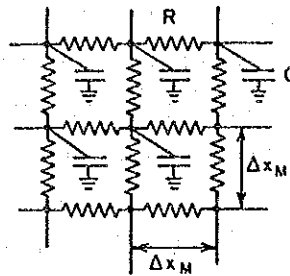
(b)

Small homogeneous portion of discretized aquifer and analogous resistor-capacitor network (after Prickett, 1975).
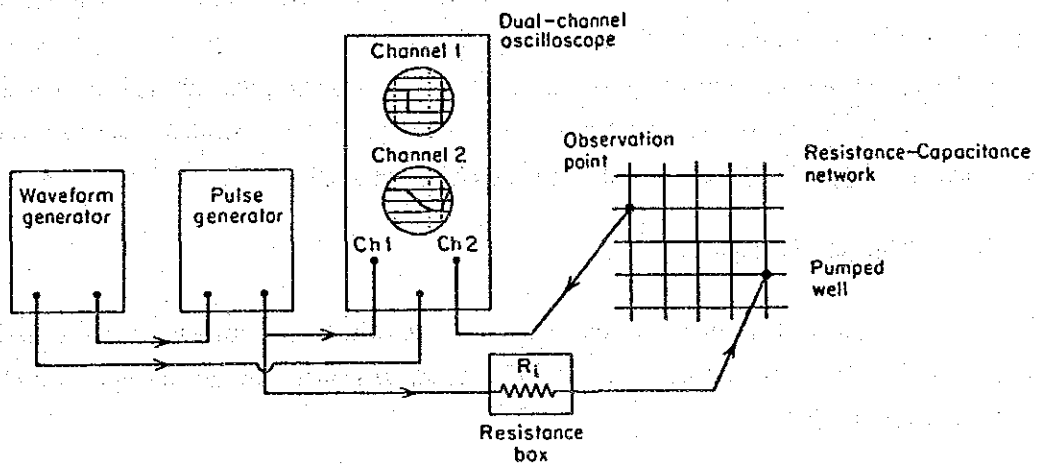
Excitation-response apparatus for electrical-analog simulation using a resistance-capacitance network.

Fig. 2-2 Resistance-capacitance network and Analog model

While the introduction of analog models enabled the analysis of more complex groundwater problems, they proved to be cumbersome, difficult to maintain, and inflexible with regard to application to different problems. Over the past decade, therefore, analog models have been largely replaced by numerical models which depend on the solution of algebraic equations on the digital computer. Numerical models are capable of analyzing more complex situations than are the analog models. In addition, numerical models have proved to be far more versatile than their predecessors. Research in the late 1960's produced hybrid models which attempted to combine the best features of the digital computer with visual display and immediate outputs of the analog model. Hybrid models have not, however, been widely used.

In 1976, SCOPE Groundwater Modeling Steering Committee surveyed the numerical models related to groundwater management. The results of the survey were published in 1980, entitled "Groundwater Management: The Use of Numerical Models". According to their report, among the numerical groundwater models, four different major purposes can be distinguished. These are: 1) prediction models, which simulate the behavior or the groundwater system and its response to stress; 2) resource management models, which integrate prediction with the objectives of water management to indicate appropriate decisions; 3) identification models, which determine input parameters for both of the above; 4) data manipulation models, which process and manage input data for all the above (Figure 2-3).

2-2-1 PREDICTION MODELS

Most of the models produced by data are prediction models which may be subdivided into four major categories: flow, subsidence, mass transport and heat transport.

Flow models utilize information on aquifer parameters, boundary conditions, precipitation, and human-induced development, to solve mathematical equations for determining quantitative aspects of groundwater flow such as direction and rate of flow, change in water level, stream-aquifer interactions and interference effects of wells. While most of these models simulate flow in aquifers, flow models have also been developed for the unsaturated zone, and for coupled saturated-unsaturated-surface system. Flow models are the most commonly used, as well as generally the best developed of the groundwater models

Figure 2-3 TAXONOMY OF SURVEYED MODELS

```
SURVEYED
MODELS
├── PREDICTION (200)
│     ├──── FLOW (138)
│     │       ├──── SINGLE PHASE (127)
│     │       │       ├──── SATURATED (107)
│     │       │       │       ├── Lumped (2)
│     │       │       │       ├── Hydraulic (84)
│     │       │       │       │       ├── single aquifer (64)
│     │       │       │       │       └── multiple aquifer (20)
│     │       │       │       └── Hydrodynamic (21)
│     │       │       │               ├── 2 dimensional (13)
│     │       │       │               └── 3 dimensional (8)
│     │       │       ├── UNSATURATED (3)
│     │       │       ├── SATURATED-       (13)
│     │       │       │   UNSATURATED
│     │       │       └── SUBSURFACE-SURFACE (4)
│     │       └──── MULTIPHASE (11)
│     ├──── MASS TRANSPORT (39)
│     │       ├── LUMPED (5)
│     │       └── DISTRIBUTED (34)
│     │               ├── CONSERVATIVE (17)
│     │               └── NONCONSERVATIVE (17)
│     ├──── HEAT TRANSPORT (9)
│     ├──── DEFORMATION (8)
│     └──── OTHERS (5)
├── MANAGEMENT (29)
│     ├──────── GROUNDWATER (13)
│     │           ├── QUANTITY (10)
│     │           └── QUALITY & QUANTITY (3)
│     └──────── GROUNDWATER AND SURFACE WATER (16)
│                 ├── QUANTITY (13)
│                 └── QUALITY & QUANTITY (3)
├── IDENTIFICATION (16)
└── DATA MANIPULATION (5)
```

(The number in parentheses indicates the number of model reports) Yehuda Bachmat et al. (1977):
The use and Utility of Numerical Models in Groundwater Resource Management, Draft Final
Report, SCOPE.

Subsidence or deformation models attempt to describe the phenomenon of land subsidence which may be caused by excessive withdrawal of groundwater. Groundwater withdrawals lower the fluid pressure in the aquifer, and consequently reduce the aquifer's capability to sustain the load of the ground above it. The result is vertical compression of the land. Subsidence models are needed to predict deformation-related impacts of various pumping schemes in affected areas.

Mass transport models are based on a flow component, but they deal primarily with questions of groundwater quality. They are thus used to predict the movement and concentration in the aquifer of various pollutants including radionuclides, leached solids from landfill and irrigated area, and salt water intruding in coastal areas. To accomplish this, the models incorporated mathematical approximations of the transport, by means of fluid flow (convection), and/or mixing of one or more chemical constituents in the groundwater. Because of these considerations, mass transport models in general tend to be more complicated than flow models. Transport models that describe only the movement of pollutants are called conservative; models that also take into account chemical and biological reactions are termed non conservative. The oil industry has been active in developing transport models for two substances, oil and water, which are immiscible.

Heat transport models attempt to predict the flow of heat or water or steam in situations where thermal effects are important. In practice, these have been applied to problems associated with hot springs, geothermal reservoirs and waters flowing between aquifers under the influence of heat.

2-2-2 RESOURCE MANAGEMENT MODELS

Management models have been developed in an attempt to indicate courses of action which will be consistent with stated management objectives and constraints. The objectives may be, for example, to maximize net economic benefits, to minimize costs, or to ensure adequate water supply at all times for all users. Management models may employ the techniques of both simulation and optimization in deriving their outputs. In contrast to purely physically-based prediction models, management models incorporate economic, technological, political and institutional aspects to the problems or situations

being analyzed.

2-2-3 IDENTIFICATION MODELS

Parameter identification models have been developed in response to the need to calibrate and validate prediction and management models. Although engineering techniques have long existed for calculating parameters through pumping tests, the identification of parameters for regional groundwater systems must be augmented by regular observations of wells throughout the regional system. As a result, parameter identification models are being developed which attempt to derive parameter values for regional groundwater models through the analysis of long-term historical data — technically known as solving the inverse problem. The quality of such parameters is still, of course, only as good as the data from which they are derived.

2-2-4 DATA MANIPULATION MODELS

The difficulties involved in estimating parameters are closely linked with the more general issue of data collection for groundwater models. Models can be run with any amount of available data, but the actual amount of quality of these data directly affect the reliability of the model's results. The task of collecting appropriate amounts of accurate data to ensure model reliability thus implies the need for a fourth class of model — data manipulation model. This model can be used in various ways, including specifying data collection procedures, designing data collection networks, identifying critical data, and storing and processing data for use in other models.

2-3 GROUNDWATER SIMULATION MODEL ON FLOW AND SUBSIDENCE PROBLEM

As mentioned in the opening statement, flow and subsidence models are widely used in Japan and other advanced nations. Other prediction models, such as the mass-transport or heat transport models, are not well developed at present. They are adequate for obtaining first order estimates. However, some major technical and conceptual difficulties will habe to be overcome before they will be as easily applied and useful as the flow and subsidence models.

In this section, simulation models on flow and subsidence are briefly introduced. In particular, land subsidence due to over pumpage and its control are important groundwater management problems in Japan.

Therefore, concept and equation of the motion of flow and the subsidence mechanism are discussed in particular in this report.

The purpose of the simulation study on land subsidence based on groundwater balancing is to forecast the number of centimeters of settlement expected for the number of meters of groundwater level decline caused by a volume of withdrawal in an area.

In order to answer this, it was necessary to reproduce the groundwater balancing and groundwater flow system in a confined groundwater basin by simulation. At the initial stage of this investigation, the simulation of groundwater behavior was executed based on the "unit-basin" model as a lumped parameter system and two dimensional single aquifer models on a horizontal plane which were provided by Tyson and Weber (1964).

As the investigation proceeded, the simulation model was revised to the quasi three-dimensional model and the two-dimensional multi-aquifer model in vertical cross section. They were applied to study groundwater flow and settlement of the multi-aquifer system. The revised models give satisfactory results in actual fields of land subsidence.

2-3-1 QUASI THREE-DIMENSIONAL MODEL

It is well known that land subsidence is caused by the squeezing of water from the confining clayey bed into the confined aquifer due to decline in the groundwater pressure in the main confined aquifer.

Quantitative analysis of squeezing is very important in study on land subsidence.

At the first stage of investigation, it was pointed out that calculated leakage is mutually related to actual subsidence, by the authors (Shibasaki, Kamata and Shindo, 1969). Then, at the middle stage of the investigation, calculated leakage rate was divided into leakage and squeeze by changing the leakage parameter in the study of the land subsidence of the Niigata Lowland (Shibasaki, Kamata and Wada, 1971).

At present, squeeze and leakage can be analyzed by the simultaneous equation of the motion of the groundwater flow in the confined aquifer and the confining clayey beds by a complete three-dimensional model. However, this solution is not easily obtained because the procedure requires a digital computer of huge capacity and a long running time.

2-3-1-1   Single Confined Aquifer Model

The provided quasi three-dimensional single aquifer model is composed of an unconfined aquifer, a confining clayey bed, a main confined aquifer and an impermeable base rock, in descending order, as shown in Figure 2-4.

If each layer is uniform in permeability, the partial differential equation governing the two-dimensional nonsteady flow of groundwater for a horizontal aquifer is

$$T\left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2}\right) = S\frac{\partial h}{\partial t} + w(x, y, t) \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

where h is the head (L), S is the storage coefficient (dimensionless), T is the aquifer transmissivity (L^2/T), t is the time (T), w(x, y, t) is the source or sink (L/T), and x, y are the rectangular coordinate. w(x, y, t) is recharging or discharging rate in a unit area in unit time, in other words. w(x, y, t) is also expressed as

$$w(x, y, t) = L(x, y, t) + Ar(x, y, t) - Qd(x, y, t,) \quad \dots\dots\dots\dots\dots \quad (2)$$
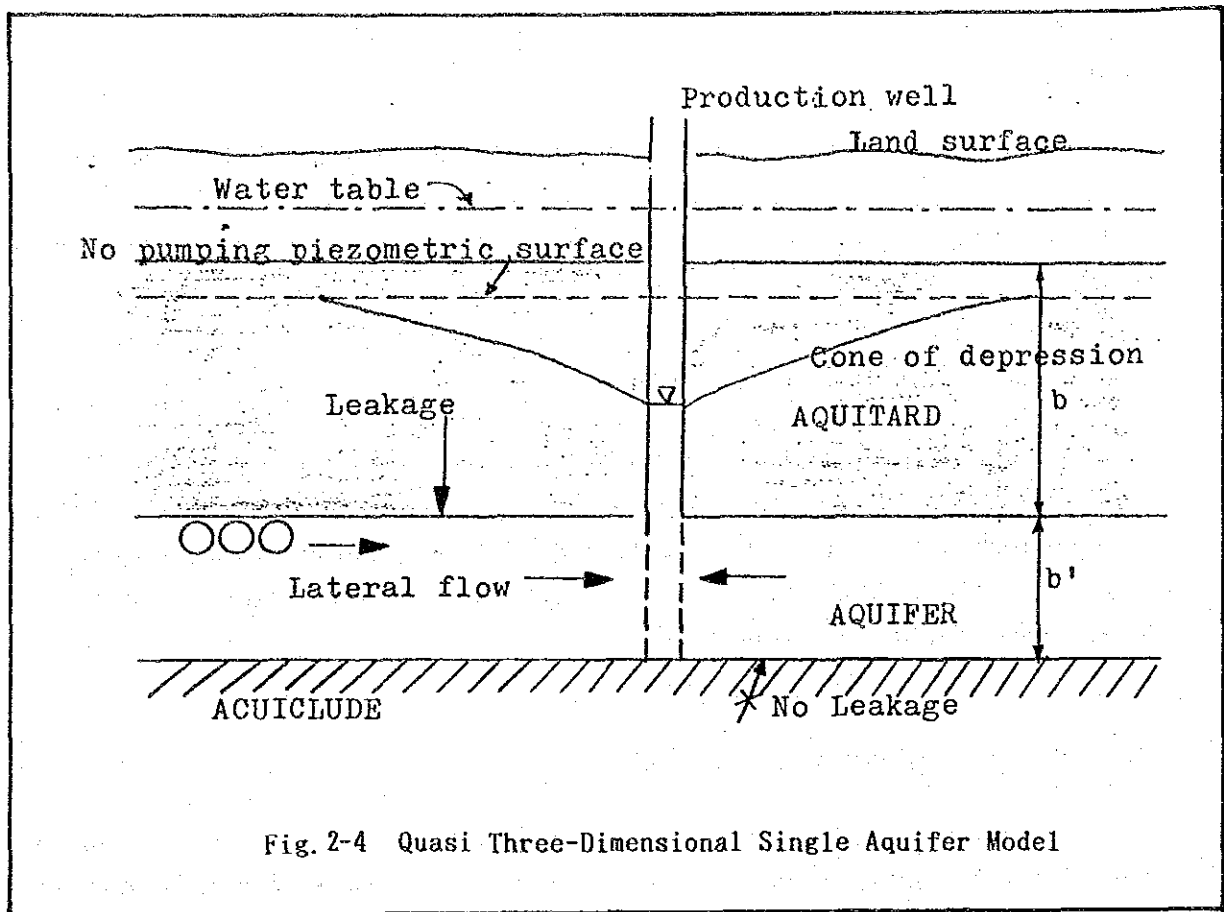
Fig. 2-4   Quasi Three-Dimensional Single Aquifer Model

in which L(x, y, t) is the leakage including squeeze Sq(x, y, t), Ar(x, y, t) is the artificial recharge, and Qd(x, y, t) is the discharge, in a unit area in unit time. The leakage which flows through the confining layer is expressed as

$$L(x, y, t) = \frac{k'}{b'}(h(t) - H(t))$$ .... (3)

where, k' is the permeability coefficient (L/T) of the confining clayey bed, b' is the thickness of the confining clayey bed (L), h(t) is the head of confined aquifer (L) and H(t) is the head of the unconfined aquifer (L).

Beside this, hydrodynamics in the confining clayey bed corresponding to the change of the head of the confined aquifer are shown as

$$\frac{\partial^2 h'}{\partial x^2} + \frac{\partial^2 h'}{\partial y^2} + \frac{\partial^2 h'}{\partial z^2} = \frac{S's}{k'}\frac{\partial h'}{\partial t}$$ .... (4)

in which h' is the excess head (L), S's is the specific storage (1/L) and k' is the permeability coefficient (L/T) of the confining clayey bed.

In such a case, the permeability of the confining clayey bed is far smaller than that of main confined aquifer, the direction of the groundwater flow in the confining bed can be assumed to be vertical. Then Eq. (4) is replaced by

$$\frac{\partial^2 h'}{\partial z^2} = \frac{S's}{k'}\frac{\partial h'}{\partial t}$$ .... (5)

The analytical solution of Eg. (6) was given by Carsraw and Jaeger (1954) as follows.

The initial and boundary conditions are

$$h'(z, o) = 0 \qquad t \leqq o$$

$$h'(o, t) = 0 \qquad t > o$$ .... (6)

$$h'(b', t) = \Delta h \qquad t > o$$

where Δh is the change of groundwater head of the main confined aquifer.

The solution is expressed as

$$h' = \Delta h \sum_{n=0}^{\infty} \text{erf}\left[\frac{(2n+1)+z/b'}{(4k't/S'sb')^{1/2}}\right] - \text{erf}\left[\frac{(2n+1)-z/b'}{(4k't/S'sb')^{1/2}}\right] \quad .. \quad (7)$$

At the boundary between the confining layer and the aquifer, the vertical groundwater flow is calculated as

$$k'\frac{\partial^2 h'}{\partial z^2}\bigg|_{z=b'} = \frac{k'\Delta h}{b'(\pi k't/b'^2 S's)^{1/2}}\{1 + 2\sum_{n=0}^{\infty} \exp(-n^2/(k't/b'^2 S's))\} \quad .. \quad (8)$$

which is composed of leakage and squeeze.

The squeeze rate Sq is derived easily as

$$Sq = \int_0^{b'} S' sh'(z)dz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

This analytical solution is considered as applicable for the model in simple hydrogeological conditions.

2-3-1-2   Squeeze and Land Subsidence

Squeezing from the confining clayey bed has been studied analytically by many hydrogeologists. Hantush (1960, 1967) first developed the Leakage and Squeeze Theory of the coupled two-confined aquifer system. Neuman and Witherspoon (1969) expanded the theory to cover multiple-leaky aquifer systems and derived analytical solutions. In addition, Wadachi (1939) pointed out that land subsidence is caused by squeezing from the confining clayey bed to the main confined aquifer.

The concept in understanding this phenomenon is that groundwater in a clayey bed flows vertically due to the excess head gradient caused by the decline in the groundwater head of the main confined aquifer. This process of squeezing is equal to Tezaghi's Consolidation Theory.

If the squeezing process is governed by Equation (4), the simultaneous solution should be obtained from the three-dimensional equation of flow which, in order to obtain, would require a core-size digital computer of huge capacity.

Therefore, the numerical method based on Equation (5), is provided for practical purpose to obtain approximations.

The squeeze rate is calculated by the excess head change in the clayey bed from the numerical solution of Eq. (5). The squeeze rate is given by the following equation in time increment "Δt".

$$Sq_\ell = S's\ \Delta h'_\ell\ \Delta Z \qquad\qquad \dots\dots\dots\dots\dots \quad (10)$$

where Sq_ℓ is the squeeze rate at node ℓ and $\Delta h'_\ell$ is the change in the excess head at node ℓ. Δz is the thickness of the clayey slice. (Figure 2-5)

Thus, the total squeeze from the clayey confining bed at each node is expressed as

$$Sq = \sum_{\ell=1}^{m} S's.\Delta h'\ \Delta z \qquad\qquad \dots\dots\dots\dots\dots \quad (11)$$

The total squeeze rate is expected to agree with the land subsidence.

2-3-1-3 Multi-Aquifer Model

The provided quasi three-dimensional multi-auqifer model is composed of multi-layered aquifer-aquitard systems.

Neglecting the vertical flow component in aquifers and the horizontal flow component in aquitard, the basic equation of the motion of these systems is expressed as follows. (Figure 2-6)

$$\frac{\partial}{\partial x}\left(Tix\frac{\partial hi}{\partial x}\right)+\frac{\partial}{\partial y}\left(Tix\frac{\partial hi}{\partial y}\right)=Si\frac{\partial hi}{\partial t}+Wi \quad \dots\dots\dots\dots \quad (12)$$

Where hi is the head(L), Si is the storativity (dimensionless), Tix, Tiy are the aquifer transmissivity (L^2/T), t is the time (T), Wi is the source or sink (L/T), and x,y are the spatial coordinates. Suffix i denotes the aquifer in descending order.

Wi is also expressed as

$$W_i = Q_i - (L_{i+1}+L_i) \qquad\qquad \dots\dots\dots\dots\dots \quad (13)$$

Water table

Unconfined Aquifer

Grid

Δz

Confining Layer

.l-1

Hydrostatic Pressure

l

Excess Pressure

l+1

Final Pressure

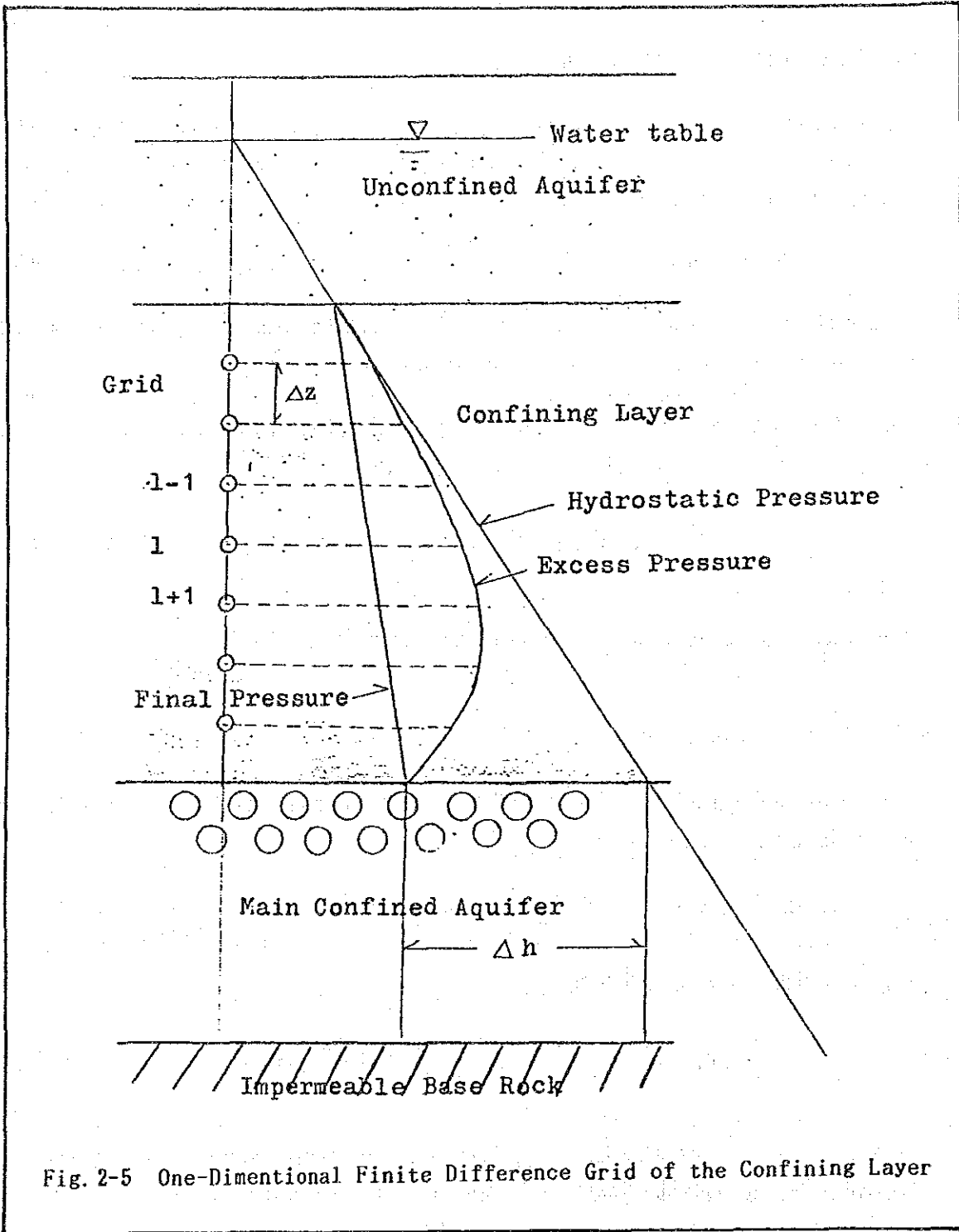Main Confined Aquifer

Δh

Impermeable Base Rock

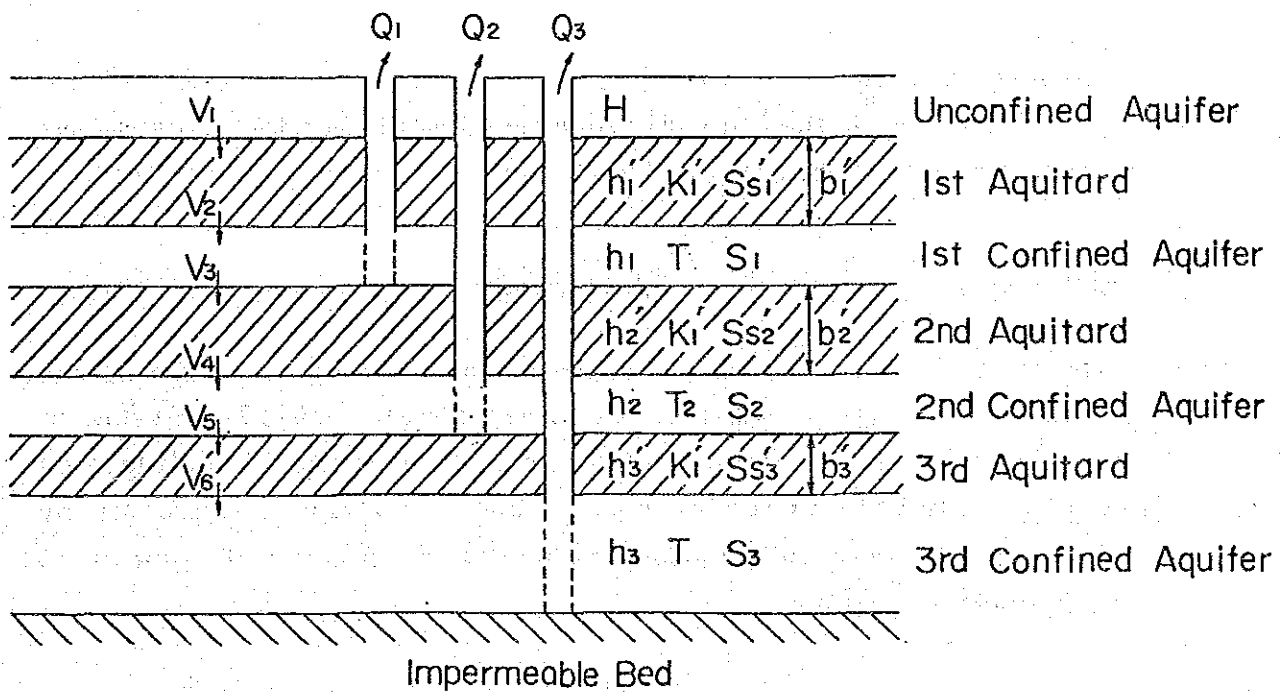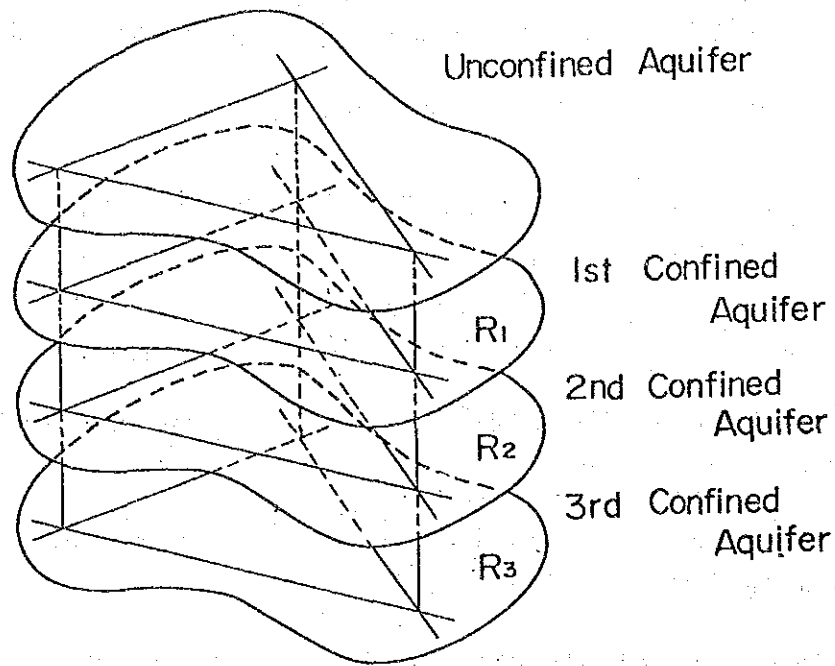Fig. 2-5 One-Dimentional Finite Difference Grid of the Confining Layer

Fig. 2-6   Quasi Three-Dimensional Multi-Aquifer Model

where Qi is the pumping discharge or recharge rate, Li is the leakage which flows into i-th aquifer, Li + 1 is the leakage which flows into i + 1-th aquifer.

Leakage from aquifer to aquifer expressed as

$$Li \quad = \frac{k'i}{b'i}(hi - hi_{-1}) \qquad \dots\dots\dots\dots\dots\dots \quad (14)$$

$$Li_{+1} = \frac{k'i+1}{b'i+1}(hi - hi_{+1}) \qquad \dots\dots\dots\dots\dots\dots \quad (15)$$

where k'i is the permeability coefficient (L/T) of the i-th aquitard and b'i is the thickness of i-th aquitard.

Eq. (12) can be solved simultaneously in conjunction with aquifer and aquitard by the leakage factor.

The squeezing rate is expressed as the following simple formula.

$$\Delta Sqi = \frac{(\Delta hi + \Delta hi_{+1})}{2}b'iS'si \qquad \dots\dots\dots\dots\dots\dots \quad (16)$$

where ΔSqi is the squeezing rate of the i-th aquitard, b'i is the thickness, Ss'i is the specific storage of the i-th aquitard, Δhi and $\Delta hi + 1$ are the change in the groundwater head in the upper and lower aquifers adjacent to i-th aquitard.

2-3-2 TWO-DIMENSIONAL MULTI-AQUIFER MODEL

It was noticed through the study that the rate of vertical groundwater flow to the confined aquifer was considerable as compared to that of lateral flow in heavy developed areas. Due to this fact, the two-dimensional multi-layered aquifer system model in vertical cross section was devised to represent the dynamic groundwater flow and the deformation of aquifers and aquitards in the groundwater basins.

2-3-2-1 Mathematical Basis of the Model

The basic equation governing the three-dimensional groundwater flow is expressed as

$$K_{xx}(\frac{\partial^2 h}{\partial x^2}) + K_{yy}(\frac{\partial^2 h}{\partial y^2}) + K_{zz}(\frac{\partial^2 h}{\partial z^2}) = s\frac{\partial h}{\partial t} + W(x, y, z, t) \quad \dots \quad (17)$$

where K_{xx}, K_{yy}, K_{zz} are the permeability coefficients in the x, y and z directions, respectively, and Ss is the specific storage, $W(x, y, z, t)$ is the source or sink term. Other notations are same as Eq. (1).

If two-dimensional groundwater flow is assumed in a vertical cross section which has the thickness Δy for y direction, Eq. (17) can be written as

$$[K_{xx}\frac{\partial^2 h}{\partial x^2}]_\ell + K_{zz}(\frac{\partial^2 h}{\partial y^2}\ell) = [Ss\frac{\partial h}{\partial t}] + W(x, z, t) \quad \dots\dots\dots \quad (18)$$

in which [ ]$_\ell$ indicates the properties of the ℓ-th member layer in the multi-layered aquifer system. (Figure 2-7)

2-3-2-2 Compression of Deep Aquifers

The settlement in the deep stratum was pointed out and studied by Hayami (1955) and Lohman (1961). According to Lohman, the deformation of an aquifer caused by the lowering of groundwater pressure is shown as

$$\Delta m = (\frac{S}{\rho g} - n\beta m)\Delta p. \quad \dots\dots\dots\dots \quad (19)$$

where Δm is the change in the thickness of the aquifer of an original thickness m(L), Δp is the change in groundwater pressure (M/L^2), and S is the storativity of the aquifer (dimensionless), ρ is the density of water ($M.T^2/L^4$), g is the acceleration due to gravity (L/T^2), n is the porosity of the aquifer (dimensionless), β is the compressibility of the water (L^2/M). The change in the head in the multi-layered aquifer system is obtained by the solution of Eq. (18) at each node of the cell. Then, the change in the groundwater pressure is given by

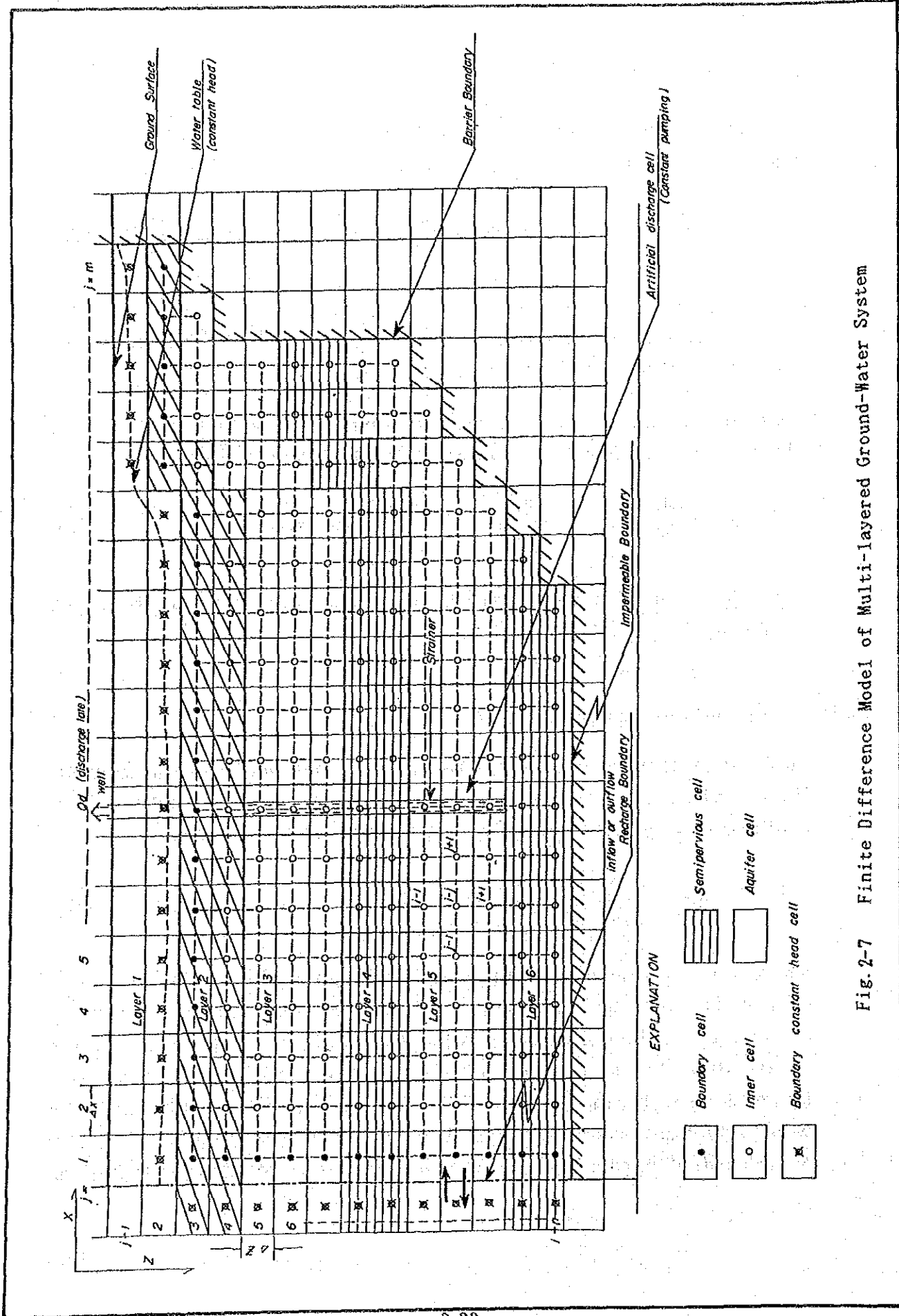$$p = \gamma\omega.\Delta h \quad \dots\dots\dots\dots \quad (20)$$

Fig. 2-7   Finite Difference Model of Multi-layered Ground-Water System