DEVELOPMENT OF A COMPUTERIZED DISTRIBUTION SYSTEM MODEL OF THE MOEN ISLAND WATER DISTRIBUTION SYSTEM

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Project No. 04 Grant No. 14-08-002-G1012
Principal Investigator: Leroy F. Heitz
Project Period: July 1, 1985 to June 30, 1986

The research on which this report is based was financed in part by the United States Department of the Interior, Geological Survey, through the State Water Resources Research Institute.

Contents of this publication do not necessarily reflect the views and policies of the United States Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the U. S. Government.

ABSTRACT

The purpose of this project was to develop a model of the water distribution system for Moen Island in Truk Lagoon. The water distribution system on Moen Island is one that has been plagued with operating problems for years. Even though there appears to be an adequate supply of water, the system is not operated on a 24 hour a day delivery basis and there are also problems with leakage, over use and back flows into the system.

System data was gathered and two system models were developed for the water distribution system. The first model was of the Southfield area on the south end of the island. This model is a comprehensive model and can be used to study individual use rates and the operation of an adequately constructed system. The second model is of the entire island water distribution system, but all the individual services have not been identified. Although this second model is not as comprehensive as the Southfield model it is still valuable in that various operating schemes can be investigated to optimize the coordination of available supplies, storage and demands. A complete listing of raw and annotated data for each model is contained in the appendices to this report.

Development of a water distribution model is only the first phase of solving the many problems with the Moen Island distribution system. This report describes in detail a series of five follow up studies that will use the system models. These follow up studies should be useful in determing solutions that are both sound in engineering concepts and also feasible in both a political and social sense.

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INTRODUCTION

The water distribution system serving Moen, the district center island in Truk State in Micronesia, generally does not provide water to the populations it serves for 24 hours per day in spite of the fact that adequate sources of supply are generally available. This situation leads to great inconvenience and can contribute to sanitation related diseases.

Aside from occasional droughts which exacerbate the situation, sometimes to crisis proportions, there are continuing debates concerning the causes of these water supply shortcomings. Some suggested causes are leakage, waste by consumers (taps left on), and improper operation of or lack of understanding of the distribution system.

Computerized water distribution system models are used to predict flows and pressures at different points in an actual water supply system in response to flow and pressure demands and flow pressure inputs at various points in the system. A fully developed system model can be used to identify areas of leakage or overuse, to define new operating criteria for more efficient system operation, and to easily explore different schemes for improving the system. These model applications could lead to an improvement in performance of the water distribution system on Moen Island. These studies could also help to identify similar water distribution problems that may be occurring in other district center water systems in Micronesia.

In order to construct a model, it is necessary to have an accurate physical description of the piping system and a knowledge of performance characteristics of pumps and storage tanks in the system. The purpose of this study was to gather the data required to construct a computerized water distribution system model and then to actually develop the model.

OBJECTIVES

The primary scope of this project was to develop a computerized model of the water distribution system serving Moen, the district center islands in Truk State, Micronesia.

The primary objectives of this project was to:

1. Gather the hydraulic data required to develop the system model. In order to accomplish this, information on the following was gathered:

    a. Piping system layout, including such items as size, location and roughness of all pipes in the system.

    b. Characteristics of pumping stations and storage reservoirs.

    c. Timing and quantities of demands on the system.

    d. Nature and availability of the water supply.

2. Develop the actual system model. This step involved the following two stages:

    a. Coding the input data for the computer model.

    b. Testing and debugging the data in order to make the model operational.

RELATED RESEARCH

A number of studies have been carried out in the past to define the water consumption patterns and customs of the people of Micronesia, (Stephenson, 1979 and 1980). There have also been some efforts to adopt the use of a fairly simple distribution system model to a single distribution system on Guam (Winter, 1978). It appears that state-of-the-art computerized models have not been applied to island water distribution systems in Micronesia. Studies by B. Reichert, of the U.S. Navy on Truk (Reichert, 1985), indicated that adequate data might be available to develop a state-of-the-art model of the Truk district center water distribution system on Moen Island. Because of this the Moen Island water system was chosen as the district center system to be used in this study.

Although it appears that direct application of a computerized distribution model has not been accomplished in Micronesia, that does not mean that it has not been accomplished elsewhere. Sophisticated distribution models have been available for a number of years and have been widely adopted by engineering consultants and researchers (Walski, 1983). Literally thousands of small and large distributions systems have been analyzed and designed using these sophisticated tools. The key to the use of these models is the availability of the required system description data.

DESCRIPTION OF COMPUTER MODEL USED

The computer program used in this project is one of a series of computerized pipe network programs developed by Dr. Donald J. Wood of the University of Kentucky at Lexington, Kentucky. The program that was used is operational on an IBM personal computer and title EPS84. The particular program has been superceded by a new program called KYPIPE. Complete program manuals and program documentation for all of the pipe network programs developed by Dr. Wood are available through the Civil Engineering Software Center at the University of Kentucky (Wood, 1980 and 1985).

General Description of Pipe Network Flow Equations

All pipe network models are required to solve a system of simultaneous non linear and linear equations with flow in each pipe as the unknown variable. The linear equations are developed by applying the continuity equation (inflow must equal outflow) to the pipe junctions in the system. The non linear equations are developed when the head losses due to pipe friction are analyzed around the closed loops in the system. The sum of losses around each closed loop must sum algebraically to zero. Since head losses in pipes are a non linear function of flow in the pipe the loop equations are non linear in nature. The system of linear and non linear equations cannot be solved by conventional methods of solving linear equations. The two most popular techniques for solution of these equations is the Hardy Cross and the linearization methods.

The Hardy Cross method requires that flows be assumed for each pipe that satisfy the continuity equation at each junction point. A set of corrector equations are developed for each loop in the system. These corrector values are the change in flow required to force the non linear loop head loss equations to go to zero. Adjacent loops contain common pipes and computed correctors for one loop would not normally be appropriate for the adjacent loop. To handle this problem, an iterative technique is developed and a series of correctors are computed and applied to previously used flow values in an iterative fashion until the corrector value is very small compared to the actual flow value computed. The computed correctors are applied in such a fashion to maintain continuity of flow at each junction so that the final corrected flows satisfy both the continuity equation and the loop head loss requirements.

The linearization scheme is slightly different than the Hardy Cross technique. In the linearization scheme the non loop equations are linearized in the following fashion. The loop equations take the form:

$$k_1(Q_1)^n + k_2(Q_2)^n + k_3(Q_3)^n + \ldots.k_m(Q_m)^n = 0$$

(ONE EQUATION FOR EACH CLOSED LOOP)

where

k = head loss coefficient involving diameter, roughness and length of pipe

$k= f*L*.02517/D^5$ Darcy Weisback equation

$k= L*4.7495/D^{4.869}/CH^{1.85}$ Hazen Williams equation

where

f= Darcy Weisbach Friction Factor

L= Length of pipe (feet)

D= Diameter of pipe (feet)

CH= Hazen Williams roughness coefficient

Q = Flow in each individual pipe

n = power term depending on the head loss equation used (1.85 for Hazen Williams, 2.0 Darcy Weisbach method)

m = Pipe number

The junction continuity equations take the form:

$$\Sigma Q_i = 0$$

(One equation for each of (N-1) junctions)

where

ΣQ_i = flow i into or out of the junction. May be a pipe flow or external demand or supply.

N = Total number of junctions in the system

The next step in the process is to linearize the non linear loop equation. This is accomplished by rewriting the loop equations in the following form in order to get each unknown pipe flow value to be to the power of unity:

$$k_1*(Qtrial_1)^{n-1}*Q_1 + k_2*(Qtrial_2)^{n-1}*Q_2+\ldots..+k_m*(Qtrial_m)^{n-1}Q_m = 0$$

(ONE EQUATION FOR EACH CLOSED LOOP)

The above linearized loop equations are combined with the linear junction equations to form a set of simultaneous linear equations that can be solved by conventional matrix means. An iterative technique is required though, because the values of Qtrial are not known for each pipe. The Qtrial values must be equal (or very close to equal) to the Q values resulting from the solution of the simultaneous equations before the correct solution to the flow system is obtained.

The iterative technique involves first assuming pipe flows in the systems. Some schemes call for using a flow value of 1 where other schemes compute flow values in each pipe based on a reasonable value of velocity say 4 ft/sec (1 m/sec). Using these trial values, the simultaneous equations are solved resulting in a set of Q values for each pipe. These values are compared to the previously assumed trail Q values. If the change in Q is very small in each pipe then the correct solution has been obtained. If the change of Q is above some preset limit then another iteration is required. For the next iteration, new trail Qs are computed by averaging the previous trial Q for each pipe with the Q just computed and calling this the new trial Q. The iteration procedure is repeated until the required accuracy between trial and computed Q is obtained.

The program used in this study uses the linearization technique describe above. The program has methods for inputting minor loss coefficients (losses due to pipe fittings) and also methods for establishing tanks and pumps in the system. The procedure for adding these features follows much the same methods as those used for linearization of the loop equations for pipe friction. The manual for the program covers these options in detail (Woods, 1980).

MODEL INPUT DATA

The computer model handles all the linearization procedures internally and all that is required is an adequate geometric description of the pipe system and an accurate list of demands and supplies to the system. The data requirements can be broken down into physical description data and flow data. Physical description data includes the following:

1. Number of pipes

2. Number of junction points

3. Pipe data for each pipe including:

    a. Length

    b. Diameter

    c. Roughness

    d. Minor losses in the pipe

    e. Pump type in the line

    f. Junction numbers connected by the pipe

4. Pump characteristic data input such as head vs. flow data or effective power data

5. Elevation of each junction point

6. Storage tank data including:

    a. Diameter of tanks (program assumes round tanks)

    b. Height of tanks

    c. Maximum and minimum water elevations in the tanks

    d. Pipe numbers of pipe connecting the tanks to the system

Available supply and demand are input to the program through the following data types.

1. Flow demands on the system concentrated at each junction point

2. Supply flows available at each junction point

3. Elevation of water in wells and starting elevations of water in storage tanks.

The model has the capability of doing one time hydraulic simulations to find the flows for a single set of hydraulic conditions or to do time simulations to investigate the long time effects of various operation schemes. Models using both modes of operation were developed in this study.

METHODS OF DATA GATHERING

The principle investigation methods employed in this project were direct on site inspections of the Moen water distribution system and in depth studies of as built drawings of the system. Upon arrival on the island a complete inspection of all above ground visual components of the water system was made. Mr. Dan Patterson of the U.S. Navy Officer in Charge of Construction (OICC) office helped to arrange for this tour and was also invaluable in supplying information on the system. The OICC office was in charge of construction of all the water system improvement construction over the past 10 years. Their files proved to be a wealth of information on all aspects of the water system. Interviews with officials from the Public Works department and with other public officials were also made to gather information on the system. Governor Erhart Aten was also interviewed in order to get a better feel for the political and social aspects of the water system operation.

After first establishing a feel for the complexity of the system and the availability of data to establish a model, it was determined that two models would be developed. The first model developed is of the Southfield area on the south end of the island. This model extends from the L.D.S. church past The Continental Hotel and on out to the Wichap water tank just past the Neauo school. This part of the system is fairly easy to isolate from the rest of the system, and the users are fairly well defined. Also there are several new wells being constructed in this area, and if the well development goes as expected, this part of the system could easily operate as a separate entity and probably have a 24 hour dependable water supply. This system is shown in Figure 1 which is contained in the back pocket of this report.

The second model that was developed is a model of the entire system. This full system model was developed to be used to help in predicting how the system should be operated to take advantage of the available storage capabilities. This model is not a complete system model because all of the individual connections were not identified, but the model still will be useful in identifying operating schemes for using the tank storage that is available in the system. This system is shown in Figure 2 which is contained in the back pocket of this report.

An accurate account of the number of individual connections to the water system in areas other than the Southfield area was impossible to obtain. It may never be possible to get an accurate count since it is suspicioned that there are many illegal connections plus many legal connections that were made by the public works department are not recorded in any written record. The OICC office has a count of the total number of original connections plus the connections installed under later construction projects, but due to time constraints it was impossible to completely piece together the total number of connections recorded even on the OICC drawings.

Appendix I contains a complete listing for the actual data in the Southfield Model. This listing could be used to reproduce the data required to run EPS84. There is also an annotated listing which has description of the input data. Appendix II contains similar listings for the model for the entire system. A 5¼ inch IBM compatible disk containing the above described data is available from the Water and Energy Research Institute of the Western Pacific at the University of Guam.

The models shown have not been calibrated against existing conditions in the field. Because of time limitations and lack of adequate flow measuring equipment it was impossible to do any actual calibration runs. One major use of calibration of a water flow model is to fix the friction coefficients for the piping system. Because most major lines in the system are designed for very low velocities the friction losses in these lines are very small compared to the pumping requirements needed to overcome elevation changes in the system so it is felt that calibration of friction loss coefficients is not needed.

The big calibration problems comes in designating how much water is being supplied to users and how much leakage is taking place in the system. As was mentioned earlier it may be impossible to determine all the system users without a house by house check to see who is being supplied by the system. Future studies could be made to determine those connected to the system. Another factor besides how many user there are is what quantities of water conservation is nearly unheard of, estimating individual water use is nearly impossible. One can make some assumptions as to individual use then let the model determine how known supplies tend to respond to various use patterns. Again further studies are warranted in the area of relating water consumption, leakage and available supplies.

System water supplies are from numerous wells scattered throughout the island and from a surface diversion from the Pou River Basin. Average diversions from the Pou river have been estimated at 174 gpm (Austin, Tsutsumi, 1980). Of course these values vary with season, Table 1 shows estimated diversions from the Pou drainage. These estimates were made by distributing the average of 174 gpm over the entire twelve month period in the same ratio as the average monthly rainfall amount would be distributed over the same period. Rain fall data was obtained from the same source as the average flow data mentioned earlier in this paragraph.

The other major source of water supply is ground water. Table 2 is a listing of the ground water sources as of August 1985. A project in which several new wells were being drilled was underway at the time of the August visit so information on all wells developed during this new project is not available in the table. Because of poor record keeping the data on many of the existing wells could be erroneous. Many pumps have been replaced. The data shown is the best available information.

Table 1. Distribution of inflows to Pou River Catchment

Month	Rainfall Inches	Percent In Month %	Monthly Inflow gpm
Jan	7.6	5.33%	111.36
Feb	7.6	5.33%	111.36
Mar	7.6	5.33%	111.36
Apr	13.3	9.33%	194.88
May	13.3	9.33%	194.88
Jun	13.3	9.33%	194.88
Jul	13.3	9.33%	194.88
Aug	13.3	9.33%	194.88
Sep	13.3	9.33%	194.88
Oct	13.3	9.33%	194.88
Nov	13.3	9.33%	194.88
Dec	13.3	9.33%	194.88

TOTAL 142.5 1946-1983 Average rainfall at airport

Table 2. Well and Pump data at Moen Island Water System as of August 1985.

Well ID#	Ground Elv. feet	Static W.S. Elv. feet	Desired Pumping Rate gpm	W.S. Elv. At Desired Rate feet	Pump Type	Pump Number	Motor hp
1	76				Berkley	6AL15	7.5
2	77				Berkley	6AL15	7.5
3	110				Berkley	4CL17-3	3
4	108						
5	Abandoned						
6	Abandoned						
7	22			-18	Berkley	6AL9	5
8	39						
9	28				Berkley	6AL9	7.5
10	12				Berkley	6AL9	5
11					Berkley	4CL17-3	3
12	22			-4.75	Berkley	6AL9	5
13	38				Berkley	6AL9	5
14	12				Berkley	6AL9	5
15	15				Berkley	6AL9	5
16	Abandoned						
17	24				Berkley	4CL17-3	3
18	9				Berkley	4CL17-3	3
Booster					Paco	16-3075	10
TH-1 No Well							
TH-2	25		30	-5			
TH-3	25	21	34	0	Berkley	22MG11-20	
TH-4 No Well							
TH-5	25	21	22	-14	Berkley	15MG09-10	
TH-6 No Well							
TH-9	40	8	40	-2	Berkley	4CL17-3	
83-1							
2							
* 3	17		50	-17			
4							
5							
6							
7	25		30	-3			
* 8	20		15	-5			
9							
*10	10		30	-20			
11							
12							
13							
14							
15							

Table 2. Continued.

Well ID#	Ground Elv. feet	Static W.S. Elv. feet	Desired Pumping Rate gpm	W.S. Elv. At Desired Rate feet	Pump Type	Pump Number	Motor hp
16							
17							
18							
*19	15						
20							
21							
22							
23							
*24	20						
*25	18						
*26	20						
*27	20						
*28	12						
*29	27						
*30	15						

These wells are in varying stages of development elevations shown are based on preliminary testing all pumps will most likely be Berkley 4CL17-3 wells marked with * are probable as of August 1985.

COORDINATION WITH LOCAL OFFICIALS

In addition to gathering data to develop a pipe system model, some time was spent talking to local officials concerning the many different kinds of problems that the present water system is experiencing. The major areas that were discussed were: 1) high water consumption rates, 2) possible line leakage, 3) over production from existing wells, 4) improper maintenance of chlorinators, and 5) poor maintenance of pumps and auxiliary electrical equipment.

A good deal of time was spent with the water system operators in order to understand just how the system was being operated. Because demands far exceeded available sources the system is presently operated on water hours. This means that fairly complex operating scheme is required to move water to various parts of the system at various times of the day. The possibility of using an operation system model such as EPS84 was suggested, but presently there is no one employed by the department who is proficient enough in computer usage or hydraulics to make use of the model.

Some time was also spent helping to choose proper pumps for the new wells that were being develop. Simple hydraulic calculations were performed to insure that the hydraulic characteristics of the chosen pumps matched the requirements of flow and head placed on the pump by the water distribution system.

FUTURE STUDIES

The development of a system simulation model of the Moen water supply system is really only the first step in helping to solve the many problems that presently exist in the water supply system. Future studies are needed to identify why the system is not working and to identify some solutions to the problems that are both feasible in an engineering sense and also in a political and social sense. Any future studies could include any of the following components.

I. Set up the portion of Southfield as a model of how a water distribution system on Moen or in fact anywhere in Micronesia could be operated.

II. Make operation studies using the entire system model to identify various schemes for better utilizing the storage available in the system and continue gathering information on all connections to the entire water system.

III. Help set up a program where portions of the water system can be tested for leaks and or illegal connections.

IV. Identify some means to cope with the social and political problems such as extensive water overuse and poor system maintenance.

V. Develop a manual to be used by system designers and water system maintenance personnel so that the systems are designed to fit the social and political climate of Micronesia and so those maintaining the system have some idea how to operate and maintain the components of the system once installed.

Any or all of the first three items could probably be accomplished with some degree of confidence given adequate on island time. Item 4 would be the most difficult to accomplish but this item is probably the key to any really measurable improvement of the Moen system. The Moen system is probably representative enough of other Micronesian systems that if these problems could be solved on Moen the systems of other Micronesian Islands could be improved with similar methods. Poor maintenance and the lack of any individual water conservation practices are the major problem with the system. These two problems are difficult problems to solve and it is essential that the problems are solved within the political and social structure of the island if the solutions are to be a long term success. Item 5 would be most helpful for those who will be working on any new water system designs in Micronesia or for those who are trying to maintain the present systems.

A short description for each of the projects described above is contained in the following pages. The most effective project would be project IV dealing with social and political aspects. Project I would require extensive cooperation from the public works department and if their cooperation could not be guaranteed the project would fail. This project would do much to illustrate how a system could be operated and would go a long away in educating the people on the positive aspects of water conservation. Projects II and III are probably next on the priority list. These would require extensive on island time to be fruitful. Project IV could be started even without any more on island studies. If the results of Project I, II and especially IV could be used in this project the resulting manual would be something that could have a real impact on the design and operation of water systems in Micronesia.

PROJECT I

SOUTHFIELD MODEL
WATER DISTRIBUTION SYSTEM

The portion of the Moen water distribution system that is located in the Southfield area is constructed in such a manner that is can be easily isolated from the rest of the Moen Island water distribution system. This system, which extends from the L.D.S. church on around past the Continental Hotel to the Wichap Tank is all of relatively new construction and it is fairly easy to identify all users. This part of the system also contains the sites of several new well projects for the water system. Because this part of the system has a good water supply and an easily identifiable group of users it is felt that this part of the system could be targeted to show how an island water system could be successfully operated.

The idea for this project was originally conceived by Dan Patterson of OICC. This project was discussed with Governor Erhart Aten. He was much impressed with the idea and pledged his support of the project. The key point to this project is that water use at each water connection in the Southfield area will be closely monitored. Each connection will be provided with a meter and a control valve to regulate the flow of water to each individual connection. The valve boxes will be locked to prevent any tampering with the valves by unauthorized persons.

The first stage in the project will be to simply monitor the water use patterns of all of the users. Flows would be checked at least three times a day to get an accurate record of total use and the time distribution of this use. This data will be evaluated and some goal consumption figures will be developed.

The second stage of this project will be to track down those users who are using more than their fair share of water, and to restrict their use by closing their supply valves. In this way the water metering will not be used for billing (which failed in the past) but only as a means of determing use patterns and to identify high use areas. The existing Southfield computer model will be operated in long time simulation mode to help in obtaining the desirable use levels needed for the successful completion of the first stage of this project.

Once the system is operating properly the third stage of the project will begin. This will be primarily a public relations effort. Radio announcement would be made describing how and why the Southfield area is able to have a dependable 24 hour water supply. Water conservation practices would be advertised as a goal for all in the system. It is believed that if success can be shown in this area it may lead to the possibility of success in conservation practice on the rest of the island.

The success of this project will depend on whether the public works department will be willing to do the required work to provide the metered and valved connections at each hookup. It is believed that there is an adequate number of meters and valves available and only labor will be required to carry out the project. Ideally the project should be initiated in cooperation with Truk state. The meters and valves should be installed before anyone making the actual study arrives. Actual time on Island would probably range form 3 to 5 weeks depending how much time is spent on the public relat- ns stage of the project.

PROJECT II

OPERATION STUDIED OF MOEN ISLAND WATER DISTRIBUTION SYSTEM AND CONTINUED GATHERING OF WATER SYSTEM CONNECTION DATA

This project is simply a continuation of the work that was begun in August 1985. The total system model will be operated in long time simulation mode in order to study various schemes for operating the system. At present the capabilities of the entire storage available are not used. The long time simulations will be used to identify how the system could be operated to best take advantage of the existing wells, pumps and storage tanks so that the system can be operated with a minimum number of no water use hours during the day.

Inadequate time was available to gather all the required information on connections for the entire system. The continuation of this work would involve extensive use of the water system as builts that are currently in the possession of OICC. Contacts with Truk State Public Works would also be necessary to find any connections that were made after the water supply projects were completed. An essential part to this work would be the availability of the water system as builts. These as builts will be mover from Truk when OICC office on Truk is closed. It is essential for this or any other project involving the water system that the as built drawings are not lost. This particular projects would be a good justification for researchers to gain access to the as builts so that copies could be made thus preventing the loss of these valuable drawings. Depending of where the as built drawings finally end up, a trip to the Trust Territory Offices in Saipan might be required. The entire project would probably take 3 to 4 weeks depending on the cooperation of the public works department.

Upon completion of this project the entire system could be modeled and various schemes of water conservation and operation could be studied to find practical solutions to the problems being experienced by the present water distribution system. This project could easily be combined with one to the other projects in the list.

PROJECT III

LEAK AND ILLEGAL OR UNKNOWN CONNECTION DIRECTION

One common reason given failure of the water distribution is leakage. In some places it is rather obvious that leakage is occurring, but no one has really substantiated all the leakage problems that have been reported. What is needed is a methodical means of determining when and where leakage is occurring in the system. The entire system is well equipped with valves and it would be fairly easy to isolated individual sections of the system. After each section is isolated it could be charged with one of the local fire trucks. By connecting the fire truck output to the line through a water meter any flow after the initial charging could be accounted for as leakage. For this method to work all house connections would have to be shut off. Sonic leak detectors could be used to pinpoint actual leakage locations. This method would also work well in uncovering any illegal or unknown connections to the system. Again this project would require full cooperation of the Public Works Department. I think this cooperation could be obtained if proper coordination of the project was made with the Governor's office. In order to test the entire system properly several weeks of work would be required. This project would be a good one to combine with project II above if adequate funding were available.

PROJECT IV

POLITICAL AND SOCIAL SOLUTION TO WATER SUPPLY DISTRIBUTION ON TRUK

The biggest factor effecting the inadequacy of the present water supply system was the designers failure to adequately design the system in regard to the social and political climate which the system must operate. At this point in time there are probably several engineering solutions that need to be explored. These have been mentioned in Project I thru III. The political and social ramifications of any engineering solutions that are developed need to be explored to be sure that any particular solution has some chance for success. Experience has shown that what appears to be obvious engineering solution may fail miserably due to the social and political structure of the Island.

It is proposed that a study be made that would involve both an engineer and a sociologist and or political scientist. The engineer must be familiar with the water distribution system and with possible solutions to the water distribution system's shortcomings. The sociologist and or political scientist must be familiar with Micronesia and the Micronesian customs, cultures and political attitudes.

A study would have to be made of water use patterns on Truk. This study would look at both quantities of water and people's attitude toward water consumption. Next the affect of different regulation schemes would have to be explored. If water use must be regulated then a system of regulation must be developed that will fit in with the social and political structure of the island. A close working relationship between the sociologist and or political scientist and an engineer would be necessary to insure that the solution would be feasible in both the engineering and the socia and political senses.

The last phase of this project would involve working with government officials to actually implement the plans developed. Just providing a report suggesting possible changes would probably be much less effective than actually working with governmental officials in making the water system a viable efficient water supply system.

PROJECT V

A MANUAL FOR DESIGN AND MAINTENANCE OF MICRONESIAN WATER SUPPLY AND DISTRIBUTION SYSTEMS

This work is seen to be the culmination of the four previously described projects. The data collected, and the results of the modeling effects, model system demonstration project, and social and political concerns projects would all be integrated together in this final project. A comprehensive manual for design and maintenance of water supply and distribution systems would be developed.

This manual would make those designing water distribution systems in Micronesia aware of the very unique conditions that occur in Micronesia so that they can do a better job of designing new systems or in renovating existing systems. The manual would also be helpful to those maintaining existing systems.

SUMMARY AND CONCLUSIONS

The Moen Island water distribution system is one plagued with many problems. The water system does not serve it users on a regular 24 hour basis in spite of what appears to be an adequate supply. There are problems of low pressures, water leakage, user overuse, and the inability of the system to take advantage of existing storage capability. Because water delivery is not continuous some parts of the system undergo negative pressure which can lead to various sanitation type problems within the system. Water distribution models can be used as planning tools to locate areas of high consumption or leakage and to develop schemes for system operation that might alleviated some of the problem with the existing Moen Island water system.

The results of this study was the development of two water system models of the Moen water distribution system. The first model is of the Southfield area on the southern end of the island. The model is very comprehensive including all individual water services and all the major components of the southern end of the water distribution system. Because of time constraints, it was impossible to develop a completely comprehensive model of the entire island water distribution system, so a simplified model of the entire system was developed. This model would be useful in determing which strategies to use to best utilize the available storage and water supplies.

This report contains a brief description of the EPS84 water distribution system model that was used to simulate the Moen Island water system. A description of the mathematical procedure used to solve the complex system of equations and a description of the required data to develop the model is presented. Both a raw and annotated listing of the data required to run the two models developed is contained in the appendices of this report. Sketches of both the Southfield and entire system model are also provided.

Development of the two water distribution models is only the first step in solving the many problems experienced by the Moen water system. The report contains detailed description of five studies which would do much to solve the many problems presently being experienced. Future studies include operational studies using both the Southfield and total system models. Studies to identify leakage in the system and studies to investigate the social and political aspects of water system operation in Micronesia are also suggested. The culmination of these future studies would be a manual for designers, operators, and governmental officials who deal with the design, construction and operation of water distribution systems in Micronesia. This manual would help to cure problems in existing systems and to alleviate future problems through proper design, construction and operation techniques.

ACKNOWLEDGMENTS

I wish to express my appreciation to the University of Guam, Water and Energy Research Institute and the Department of Interior for financial support for this project. I would like to express a special vote of thanks to Dr. Stephen Winter, past director of the Institute, who provided the momentum to make the project a reality. I would also like to express my appreciation to Mr. Dan Patterson of the U.S. Navy Officer in Charge of Construction Office on Truk for his valuable assistance in obtaining the data required to complete the project successfully. I am also appreciative of Governor Erhart Aten and Deputy Director of Public Works Season Paul of Truk State for their cooperation on this study.

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APPENDIX B

SOUTHFIELD WATER DISTRIBUTION SYSTEM MODEL

SOUTHFIELD WATER DISTRIBUTION SYSTEM MODEL ANNOTATED DATA FOR ESP84 MODEL

NUMBER OF PIPES = 31
NUMBER OF JUNCTION NODES = 21
FLOW UNITS = GALLONS / MINUTE
PRESSURE UNITS = PSI

**** SUMMARY OF INPUT DATA ***

PIPE NO.	NODE #1	NODE #2	LENGTH (FT.)	DIAM. (IN.)	HW-C VALUE	SUM M FACT.	PUMP LINE	ON GRADE
1	1	2	360.0	12.0	130.0	5.0	0.0	
2	[illegible]	[illegible]	490.0	12.0	130.0	5.0	0.0	
3	[illegible]	3	80.0	[illegible]	110.0	450.0	1.0	[illegible]
4	3	4	1160.0	12.0	130.0	5.0	0.0	
5	4	21	90.0	12.0	130.0	1.0	0.0	
6	0	21	70.0	2.0	110.0	460.0	1.0	-2[illegible]
7	21	5	350.0	12.0	130.0	5.0	0.0	
8	0	5	60.0	2.0	110.0	460.0	1.0	1[illegible]
9	5	6	210.0	12.0	130.0	4.0	0.0	
10	0	6	90.0	2.0	110.0	460.0	1.0	-[illegible]
11	6	7	240.0	12.0	130.0	4.0	0.0	
12	0	7	80.0	2.0	110.0	460.0	1.0	-2[illegible]
13	7	8	200.0	12.0	130.0	7.0	0.0	
14	8	9	350.0	12.0	130.0	5.0	0.0	
15	0	9	110.0	2.0	110.0	450.0	1.0	-[illegible]
16	9	10	250.0	12.0	130.0	4.0	0.0	
17	0	10	60.0	2.0	110.0	280.0	1.0	32.0
18	10	11	285.0	12.0	130.0	4.0	0.0	
19	0	11	80.0	2.0	110.0	460.0	1.0	[illegible]
20	11	12	295.0	12.0	130.0	4.0	0.0	
21	0	12	60.0	2.0	110.0	460.0	1.0	[illegible]
22	12	13	200.0	12.0	130.0	4.0	0.0	
23	0	13	80.0	2.0	110.0	460.0	1.0	[illegible]
24	13	14	78.0	12.0	130.0	6.0	0.0	
25	14	15	662.0	12.0	130.0	5.0	0.0	
26	15	16	450.0	12.0	130.0	5.0	0.0	
27	16	17	370.0	12.0	130.0	5.0	0.0	
28	17	18	480.0	12.0	130.0	5.0	0.0	
29	18	19	259.0	12.0	130.0	4.0	0.0	
30	19	20	3174.0	12.0	130.0	6.0	0.0	
31	20	0	2000.0	12.0	130.0	5.0	0.0	1[illegible]

SOUTHFIELD WATER DISTRIBUTION SYSTEM MODEL ANNOTATED DATA FOR ESP84 MODEL (continued)

*** DATA FOR PUMPS FOR THIS SYSTEM ***

PUMP TYPE # 1 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
370	0
285	25
110	50

JUNCT. NO.	DEMAND	ELEVATION
1	0.0	10.0
2	9.0	22.0
3	0.0	8.5
4	9.0	11.5
21	0.0	10.0
5	0.0	14.5
6	4.5	12.5
7	0.0	9.0
8	4.5	5.5
9	4.5	6.0
10	4.5	7.0
11	9.0	9.0
12	9.0	8.5
13	0.0	6.5
14	44.0	6.5
15	9.0	7.0
16	9.0	3.5
17	9.0	2.0
18	4.5	2.5
19	4.5	2.0
20	0.0	76.5

SOUTHFIELD WATER
DISTRIBUTION SYSTEM MODEL
RAW DATA FOR INPUT TO
EPS84 MODEL

31	2	21	1	0	0	0	0	0	0
1	1	2	360	12	130	5	0		
2	2	3	490	12	130	5	0		
3	0	3	80	2	110	460	1	-20	
4	3	4	1160	12	130	5	0		
5	4	21	90	12	130	1	0		
6	0	21	70	2	110	460	1	-20	
7	21	5	350	12	130	5	0		
8	0	5	60	2	110	460	1	-18	
9	5	6	210	12	130	4	0		
10	0	6	90	2	110	460	1	-20	
11	6	7	240	12	130	4	0		
12	0	7	80	2	110	460	1	-20	
13	7	8	200	12	130	4	0		
14	8	9	350	12	130	5	0		
15	0	9	110	2	110	460	1	-20	
16	9	10	250	12	130	4	0		
17	0	10	60	2	110	780	1	-32	
18	10	11	285	12	130	4	0		
19	0	11	80	2	110	460	1	-20	
20	11	12	225	12	130	4	0		
21	0	12	60	2	110	460	1	-20	
22	12	13	200	12	130	4	0		
23	0	13	80	2	110	460	1	-20	
24	13	14	38	12	130	0	0		
25	14	15	662	12	130	5	0		
26	15	16	450	12	130	5	0		
27	16	17	370	12	130	5	0		
28	17	18	480	12	130	5	0		
29	18	19	259	12	130	4	0		
30	19	20	3176	12	130	6	0		
31	20	0	2000	12	130	6	0	157.5	
1	2	370	0	285	25	110	50		
1	10.0	0							
2	22.0	9							
3	8.5	0							
4	11.5	9							
21	10.0	0							
5	14.5	0							
6	12.5	4.5							
7	9.0	0							
8	5.5	4.5							
9	6.0	4.5							

SOUTHFIELD WATER DISTRIBUTION
SYSTEM MODEL RAW DATA
(CONTINUED)

10	7.0	4.5		
11	7.0	9		
12	8.5	9		
13	6.5	0		
14	6.5	44		
15	7.0	9		
16	3.5	9		
17	2.0	9		
18	2.5	4.5		
19	2.0	4.5		
20	76.5	0		
0	0	888	0	-9999

APPENDIX II

Entire Water Distribution
System Model

ENTIRE WATER DISTRIBUTION SYSTEM MODEL ANNOTATED DATA FOR EPS84 MODEL

NUMBER OF PIPES = 77
NUMBER OF JUNCTION NODES = 41
FLOW UNITS = GALLONS / MINUTE
PRESSURE UNITS = PSI

CLOSED LINES - 41 70

*** SUMMARY OF INPUT DATA ***

PIPE NO.	NODE #1	NODE #2	LENGTH (FT.)	DIAM. (IN.)	HW-C VALUE	SUM-M FACT.	PUMP TYPE	GRD GRADE
1	0	1	2000.0	12.0	130.0	5.0	0.0	[illegible]
2	1	2	4285.0	12.0	130.0	5.0	0.0	
3	2	3	630.0	12.0	130.0	4.0	0.0	
4	3	4	370.0	12.0	130.0	3.0	0.0	
5	4	5	450.0	12.0	130.0	3.0	0.0	
6	5	6	662.0	12.0	130.0	3.0	0.0	
7	6	7	738.0	12.0	130.0	3.0	0.0	
8	0	7	80.0	2.0	110.0	460.0	1.0	-20.0
9	0	7	60.0	2.0	110.0	460.0	1.0	20.0
10	7	8	510.0	12.0	130.0	4.0	0.0	
11	0	8	80.0	2.0	110.0	460.0	1.0	20.0
12	0	8	60.0	2.0	110.0	780.0	1.0	30.0
13	0	8	110.0	2.0	110.0	460.0	1.0	-21.0
14	8	9	1040.0	12.0	130.0	5.0	0.0	
15	0	9	80.0	2.0	110.0	460.0	1.0	-20.0
16	0	9	90.0	2.0	110.0	460.0	1.0	-20.0
17	0	9	60.0	2.0	220.0	460.0	1.0	19.0
18	9	10	560.0	12.0	130.0	4.0	0.0	
19	0	10	70.0	2.0	110.0	460.0	1.0	20.0
20	10	11	1250.0	12.0	130.0	5.0	0.0	
21	0	11	80.0	2.0	110.0	460.0	1.0	-20.0
22	11	12	850.0	12.0	130.0	4.0	0.0	
23	12	13	1515.0	12.0	130.0	5.0	0.0	
24	13	14	1780.0	12.0	140.0	5.0	0.0	
25	0	14	125.0	2.0	110.0	460.0	1.0	-5.0
26	0	14	50.0	2.0	110.0	460.0	2.0	0.0
27	0	14	60.0	2.0	110.0	460.0	3.0	14.0
28	14	15	3137.0	12.0	140.0	5.0	0.0	
29	0	15	40.0	2.0	110.0	460.0	1.0	-3.0
30	0	15	50.0	2.0	110.0	470.0	1.0	-5.0
31	15	16	4098.0	12.0	140.0	5.0	0.0	
32	16	17	400.0	12.0	130.0	4.0	0.0	
33	0	17	50.0	2.0	110.0	460.0	1.0	17.0
34	0	17	25.0	2.0	110.0	460.0	1.0	5.0
67	0	17	150.0	4.0	110.0	1000.0	1.0	-5.0
35	17	18	250.0	12.0	130.0	4.0	0.0	
64	0	18	50.0	2.0	110.0	460.0	1.0	[illegible]

ENTIRE WATER DISTRIBUTION SYSTEM MODEL ANNOTATED DATA FOR EPS84 MODEL

[illegible]	[illegible]	[illegible]	[illegible]	2.0	[illegible]	460.0	[illegible]	[illegible]
[illegible]	[illegible]	31	120.0	[illegible]	130.0	3.0	[illegible]	
[illegible]	31	[illegible]	540.0	[illegible]	110.0	[illegible]	[illegible]	
[illegible]	32	34	250.0	8.0	110.0	2.0	0.0	
[illegible]	[illegible]	[illegible]	75.0	4.0	[illegible]	1.0	[illegible]	
[illegible]	[illegible]	[illegible]	40.0	[illegible]	110.0	1.0	0.0	-11.0
54	31	35	290.0	12.0	130.0	[illegible]	0.0	
[illegible]	[illegible]	36	[illegible]	6.0	110.0	2.0	0.0	
[illegible]	[illegible]	[illegible]	150.0	4.0	[illegible]	1000.0	4.0	[illegible]
[illegible]	[illegible]	[illegible]	70.0	4.0	110.0	1000.0	4.0	-36.0
[illegible]	35	37	306.0	12.0	130.0	[illegible]	0.0	
59	37	[illegible]	1095.0	[illegible]	140.0	3.0	0.0	156.0
[illegible]	[illegible]	38	3700.0	12.0	170.0	5.0	0.0	
[illegible]	38	39	3300.0	12.0	130.0	5.0	0.0	
[illegible]	39	[illegible]	1290.0	12.0	170.0	3.0	0.0	157.2
[illegible]	19	23	710.0	12.0	110.0	3.0	0.0	
[illegible]	23	4	[illegible]	12.0	110.0	3.0	0.0	
[illegible]	[illegible]	24	50.0	6.0	110.0	3.0	0.0	
[illegible]	[illegible]	25	280.0	4.0	110.0	1000.0	6.0	54.0
70	[illegible]	25	70.0	4.0	110.0	1000.0	6.0	52.0
71	24	26	300.0	12.0	110.0	3.0	0.0	
72	26	27	70.0	12.0	110.0	1.0	0.0	
73	16	27	70.0	12.0	110.0	23.1	5.0	
74	27	28	1100.0	12.0	110.0	4.0	0.0	
75	28	29	100.0	12.0	120.0	4.0	0.0	
76	29	[illegible]	15.0	12.0	110.0	4.0	0.0	231.0
77	[illegible]	[illegible]	100.0	2.0	110.0	460.0	1.0	[illegible]
[illegible]	15	19	1130.0	12.0	130.0	5.0	0.0	
[illegible]	19	20	720.0	12.0	130.0	[illegible]	0.0	
[illegible]	20	21	150.0	12.0	130.0	[illegible]	0.0	
39	21	40	200.0	6.0	110.0	3.0	0.0	
40	40	41	200.0	6.0	110.0	3.0	0.0	
[illegible]	0	41	70.0	4.0	110.0	1000.0	0.0	[illegible]
42	[illegible]	41	30.0	2.0	110.0	460.0	[illegible]	[illegible]
43	[illegible]	40	70.0	[illegible]	110.0	460.0	[illegible]	14.0
44	[illegible]	22	370.0	[illegible]	130.0	[illegible]	0.0	
45	[illegible]	[illegible]	100.0	[illegible]	110.0	1000.0	1.0	15.0
46	22	[illegible]	250.0	12.0	120.0	[illegible]	0.0	[illegible]
47	[illegible]	[illegible]	470.0	12.0	130.0	[illegible]	[illegible]	
48	0	[illegible]	30.0	7.0	110.0	460.0	4.0	[illegible]

ENTIRE WATER DISTRIBUTION SYSTEM MODEL ANNOTATED DATA FOR EPSA4 MODEL

*** DATA FOR PUMPS FOR THIS SYSTEM ***

PUMP TYPE # 1 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
250	10
280	25
1[illegible]	45

PUMP TYPE # 2 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
365	15
150	25
100	30

PUMP TYPE # 3 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
280	10
200	15
120	20

PUMP TYPE # 4 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
350	10
300	30
130	70

PUMP TYPE # 5 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
120	25
100	200
[illegible]	[illegible]

PUMP TYPE # 6 IS DESCRIBED BY THE FOLLOWING DATA:

HEAD	DISCHARGE
[illegible]	10
210	[illegible]
150	20

ENTIRE WATER DISTRIBUTION SYSTEM MODEL ANNOTATED DATA FOR EPS84 MODEL

JUNCTION NO.	DEMAND	ELEVATION
1	0.0	[illegible].5
2	0.0	4.5
3	0.0	[illegible].3
4	0.0	[illegible].5
5	0.0	7.0
6	0.0	6.5
7	0.0	8.5
8	0.0	7.0
9	0.0	12.5
10	0.0	10.0
11	0.0	8.5
12	0.0	10.0
13	0.0	4.0
14	0.0	19.0
15	0.0	14.0
16	0.0	16.0
17	0.0	14.0
18	0.0	9.0
19	0.0	46.0
20	0.0	38.5
21	0.0	39.0
22	0.0	66.0
23	0.0	57.0
24	0.0	71.2
25	0.0	71.2
26	0.0	104.5
27	0.0	119.0
28	0.0	219.5
29	174.0	231.0
30	0.0	23.0
31	0.0	13.5
32	0.0	13.0
33	0.0	13.0
34	0.0	20.0
35	0.0	11.5
36	0.0	11.5
37	0.0	26.0
38	0.0	15.0
39	0.0	3.5
40	0.0	39.0
41	0.0	39.0

ENTIRE WATER DISTRIBUTION
SYSTEM MODEL
RAW DATA FOR INPUT TO
EPSB4 MODEL

```
77  2  41  6  0  0  2  0  0  0
41      70
1       0       1       2000    12      130     5       0
151.6
2       1       2       3285    12      130     5       0
3       2       3       630     12      130     4       0
4       3       4       370     12      130     3       0
5       4       5       450     12      130     3       0
6       5       6       662     12      130     3       0
7       6       7       239     12      130     3       0
8       0       7       80      2       110     460     1
-20
9       0       7       60      2       110     460     1
-20
10      7       8       510     12      130     4       0
11      0       8       80      2       110     460     1
-20
12      0       8       60      2       110     780     1
-32
13      0       8       110     2       110     460     1
-20
14      8       9       1040    12      130     5       0
15      0       9       90      2       110     460     1
-20
16      0       9       90      2       110     460     1
-20
17      0       9       60      2       220     460     1
-19
18      9       10      560     12      130     4       0
19      0       10      70      2       110     460     1
-20
20      10      11      1250    12      130     5       0
21      0       11      80      2       110     460     1
-20
22      11      12      850     12      130     4       0
23      12      13      1515    12      130     5       0
24      13      14      1780    12      140     5       0
25      0       14      125     2       110     460     1               -5
26      0       14      50      2       110     460     2               0
27      0       14      60      2       110     460     1
-14
28      14      15      2137    12      140     5       0
29      0       15      40      2       110     460     1               -3
```

ENTIRE WATER DISTRIBUTION
SYSTEM MODEL RAW DATA
CONTINUED)

30	0	15	50	2	110	460	1	-5
31	15	16	4098	12	140	5	0	
32	16	17	400	12	130	4	0	
33	0	17	50	2	110	460	1	
-17								
34	0	17	25	2	110	460	1	-5
67	0	17	150	4	110	1000	1	-5
35	17	18	250	12	130	4	0	
64	0	16	50	2	110	460	4	
-19								
36	16	19	830	12	130	5	0	
37	19	20	220	12	130	3	0	
38	20	21	150	12	130	2	0	
39	21	40	200	6	110	3	0	
40	40	41	200	6	110	3	0	
41	0	41	320	4	110	1000	0	
-20								
42	0	41	30	2	110	460	4	4
43	0	40	20	2	110	460	4	14
44	21	22	330	12	130	3	0	
45	0	22	100	4	110	1000	1	15
46	22	0	250	12	110	3	0	
157.6								
47	20	30	470	12	130	3	0	
48	0	30	80	2	110	460	4	7
49	0	30	90	2	110	460	4	
-51.5								
65	30	31	120	12	130	3	0	
50	31	32	540	8	110	2	0	
51	32	34	250	8	110	2	0	
52	32	33	75	4	110	1	0	
53	0	33	40	2	110	1	0	
-11								
54	31	35	290	12	130	3	0	
55	35	36	270	6	110	2	0	
56	0	36	250	4	110	1000	4	-3
57	0	36	20	4	110	1000	4	
-36								
58	35	37	306	12	130	3	0	
59	37	0	1092	12	140	2	0	
156								
60	37	38	3300	12	130	5	0	
61	38	39	3300	12	130	5	0	
62	39	0	1290	12	130	3	0	
157.2								
66	19	23	310	12	110	3	0	

ENTIRE WATER DISTRIBUTION
SYSTEM MODEL RAW DATA
(CONTINUED)

67	23	24	130	12	110	[illegible]	[illegible]	
68	25	24	50	6	110	2	0	
69	0	25	280	4	110	[illegible]	[illegible]	54
70	0	25	20	4	110	1000	[illegible]	52
71	24	26	380	12	110	3	0	
72	26	27	70	12	110	1	0	
73	26	27	70	12	110	23.1	5	
74	27	28	1100	12	110	4	0	
75	28	29	100	12	110	4	0	
76	29	0	25	12	110	4	0	
231								
77	0	15	100	2	110	460	1	
-2								
1	2	350	10	280	25	125	45	
2	2	365	15	250	25	100	70	
3	2	280	10	220	15	120	20	
4	2	350	10	300	30	130	70	
5	2	120	25	100	200	76	325	
6	2	580	10	510	35	250	70	
1	7.5	0						
2	4.5	0						
3	2.3	0						
4	3.5	0						
5	7.0	0						
6	6.5	0						
7	8.5	0						
8	7.0	0						
9	12.5	0						
10	10.0	0						
11	8.5	0						
12	10.0	0						
13	4.0	0						
14	19.0	0						
15	14	0						
16	16	0						
17	14	0						
18	9	0						
19	46	0						
20	38.5	0						
21	39.0	0						
22	66.0	0						
23	57	0						
24	71.2	0						
25	71.2	0						
26	104.5	0						
27	119.0	0						

ENTIRE WATER DISTRIBUTION
SYSTEM MODEL RAW DATA
(CONTINUED)

28	219.5	0		
29	233	174		
30	23	0		
31	13.5	0		
32	13.0	0		
33	13.0	0		
34	20	0		
35	11.5	0		
36	11.5	0		
37	26	0		
38	15	0		
39	3.5	0		
40	39	0		
41	39	0		
0	0	888	0	-9999

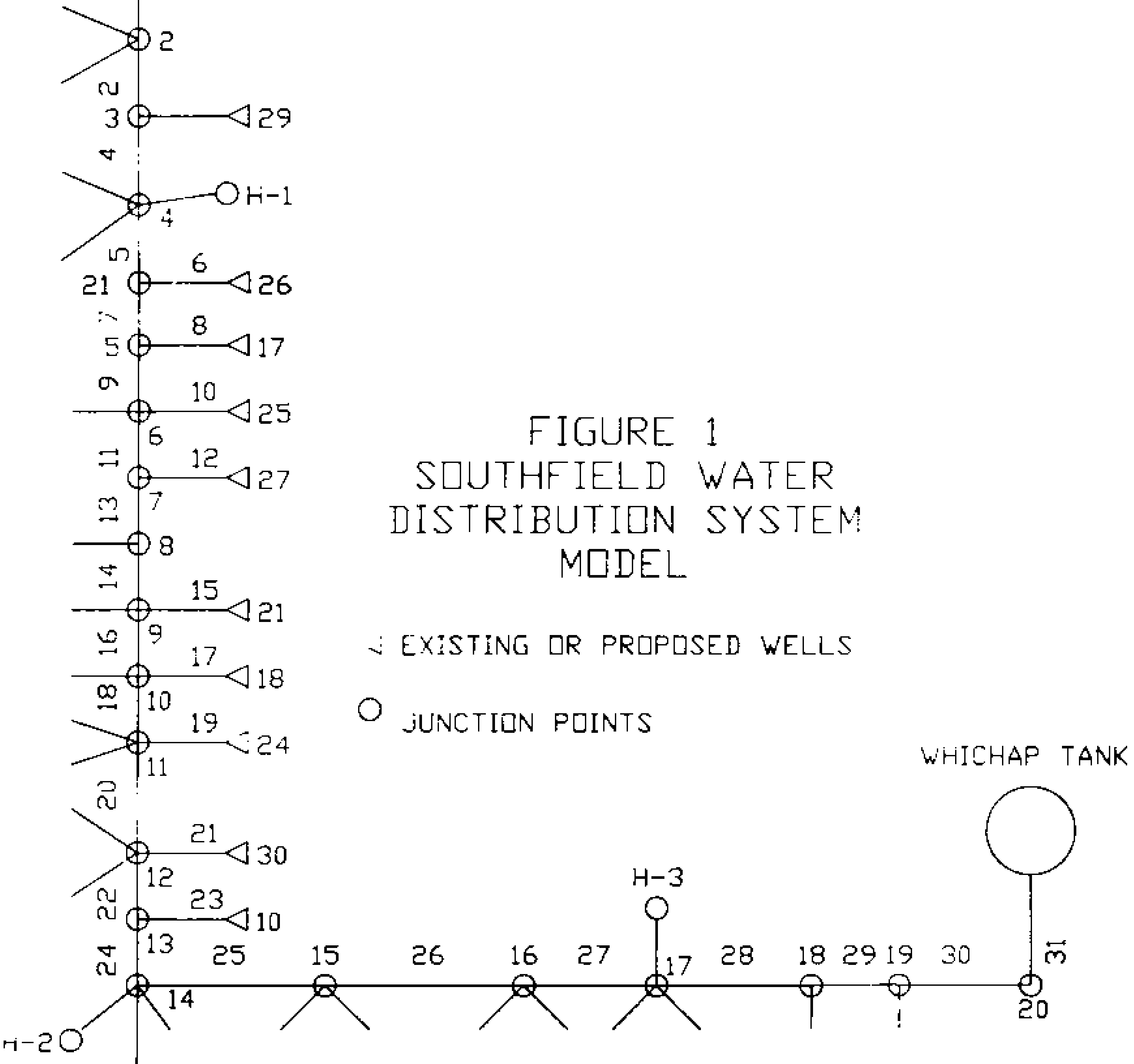

FIGURE 1
SOUTHFIELD WATER
DISTRIBUTION SYSTEM
MODEL

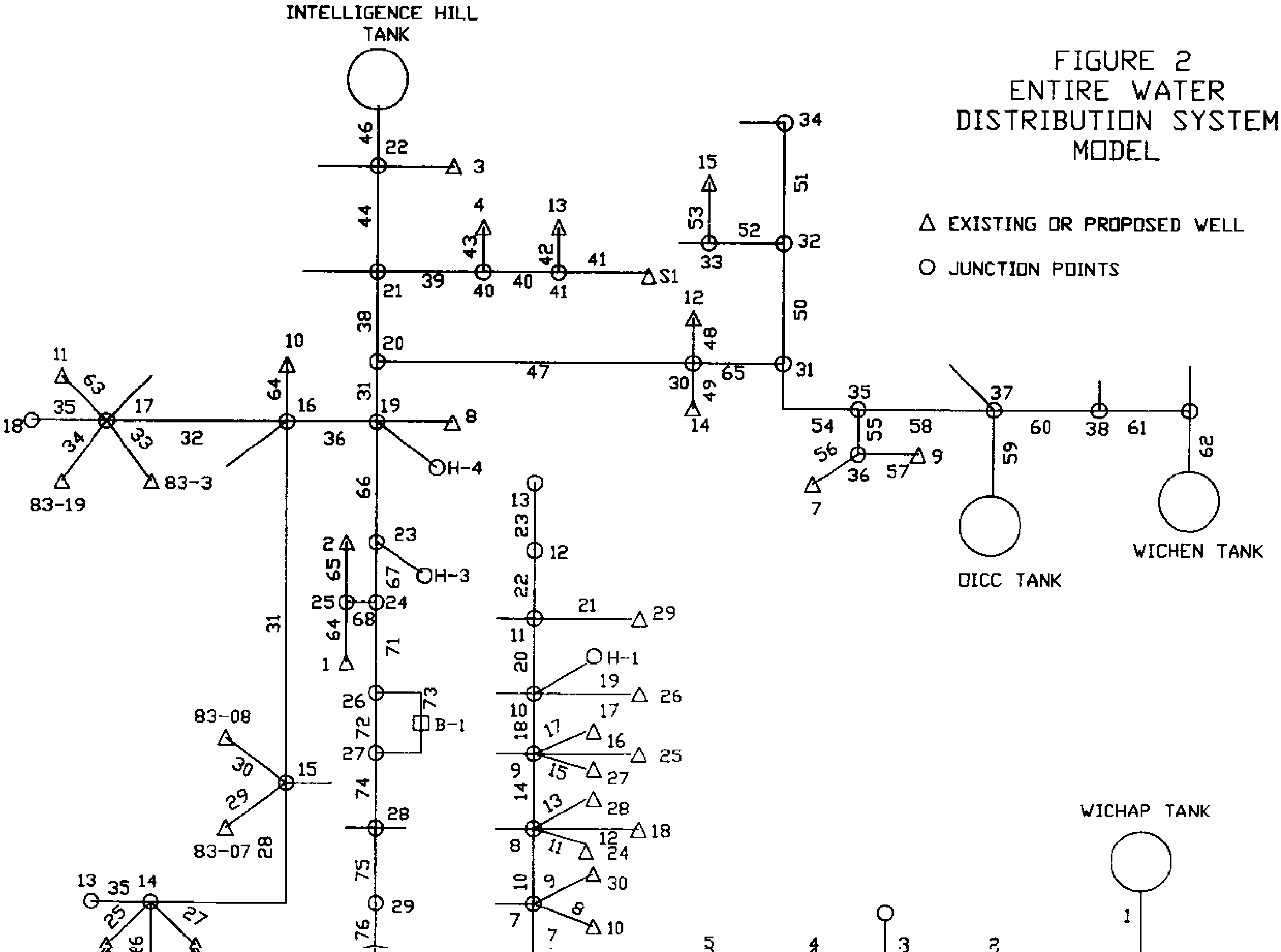

FIGURE 2
ENTIRE WATER DISTRIBUTION SYSTEM MODEL