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US Army Corps of Engineers

FORT MONMOUTH, NEW JERSEY WATER DISTRIBUTION SYSTEMS

VOLUME I. PRELIMINARY ASSESSMENT

by

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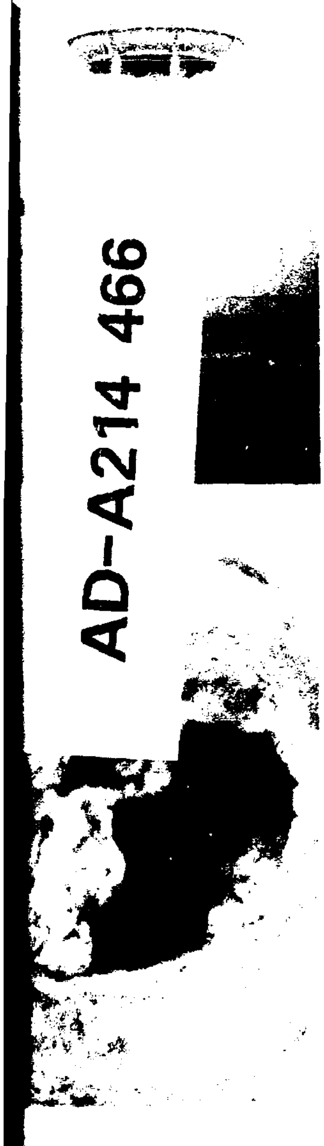

September 1989

Final Report

Approved For Public Release; Distribution Unlimited

Environmental Laboratory

Prepared for DEPARTMENT OF THE ARMY
Directorate of Engineering and Housing
Fort Monmouth, New Jersey 07703-5000

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): Miscellaneous Paper EL-89-10	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: USAEWES Environmental Laboratory; 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code): 3909 Halls Ferry Road, Vicksburg, MS 39180-6199	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION: Directorate of Engineering and Housing; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code): Fort Monmouth, NJ 07703-5000	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

Fort Monmouth, New Jersey, Water Distribution Systems; Volume I: Preliminary Assessment

12 PERSONAL AUTHOR(S)

Sharp, Wayne W.; Chase, Donald V.; Schroeder, Paul R.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final report in 2 vols	FROM ______ TO ______	September 1989	40

16 SUPPLEMENTARY NOTATION

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Fire demand	Water distribution
			Internal roughness	Water quality
			Rehabilitation	Water supply

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This report assesses the present condition of the Fort Monmouth, New Jersey, water distribution systems. A calibrated mathematical model of each system was created using information obtained from field tests and observations.

Rehabilitation alternatives are addressed which will improve the water quality and supply. Hydraulic improvement, reliability, and economic analyses of each alternative were performed. Recommendations to improve each system are discussed in general and will be further analyzed in the final product (Volume II) of this work unit.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code) / 22c OFFICE SYMBOL

DD Form 1473, JUN 86 — Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

This report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), in partial fulfillment of Reimbursable Order No. 88-C4-07 from the Fort Monmouth Directorate of Engineering and Housing (DEH), Fort Monmouth, NJ.

The report was prepared by Mr. Wayne W. Sharp, Mr. Donald V. Chase, and Dr. Paul R. Schroeder of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL.

The work was accomplished under the direct supervision of Dr. John J. Ingram, Chief, WREG, and Dr. Raymond L. Montgomery, Chief, EED, and under the general supervision of Dr. John Keeley, Assistant Chief, EL, and Dr. John Harrison, Chief, EL. The authors gratefully acknowledge the help of Mr. Terry Taylor in the collection of field data as well as data supplied by Mr. Mike Maier, Mr. Jim Ott and Ms. Lori Kam of the Fort Monmouth DEH.

Commander and Director of WES was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Sharp, Wayne W., Chase, Donald V., and Schroeder, Paul R. 1989. "Fort Monmouth, New Jersey, Water Distribution Systems; Volume I: Preliminary Assessment," Miscellaneous Paper EL-89-10, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

FORT MONMOUTH, NEW JERSEY, WATER DISTRIBUTION SYSTEMS

VOLUME I: PRELIMINARY ASSESSMENT

PART I: INTRODUCTION

Background

1\. Fort Monmouth is located in the central portion of Monmouth County, New Jersey, approximately 42 miles* south-southwest of New York City. Fort Monmouth is primarily composed of two distinct regions: the main post and Camp Charles Wood. The main post covers approximately 627 acres with elevations ranging from 5 to 30 feet above sea level. Camp Charles Wood covers an area of approximately 508 acres and has elevations between 20 and 70 feet above sea level.

2\. Fort Monmouth was established in 1917 to meet national emergencies created by World War I. Fort Monmouth, the military post, was founded in 1925. World War II spawned new development, which included the Camp Charles Wood area, and by the mid-1940's, Fort Monmouth had developed into a peacetime training center. The majority of construction in the main post and Camp Charles Wood was completed by the mid-1950's and has remained essentially unchanged since that time (T and M Associates 1982).

3\. Since the early 1980's, Fort Monmouth has experienced problems with its water distribution systems. The systems are old (50+ years) and in need of overall rehabilitation to rectify the existing problems. Rehabilitation efforts have been implemented since that time but provided no long-term success. The US Army Engineer Waterways Experiment Station (WES) (1988) was then contacted to provide a comprehensive rehabilitation plan as well as guidance on implementing the recommendations.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Purpose

4. The purpose of this report is to assess the current condition of the Fort Monmouth water distribution systems and analyze the existing problems. Recommendations based on this assessment will be made in Volume II for the rehabilitation of both systems.

Scope of Report

5. This report includes a calibrated computer model of the distribution systems, field test results for fire flow capacity and internal roughness (head loss), and overall water quality assessment. Rehabilitation alternatives available for the fort are discussed and will be used in Volume II for the selection of one or more rehabilitation schemes. This will be accomplished through communication between Waterways Experiment Station personnel and Fort Monmouth personnel based on economic and practical guidelines.

PART II: SYSTEM DESCRIPTION AND COMPUTER MODEL

Distribution Systems

6. The distribution systems at Fort Monmouth, including both the main post and Camp Charles Wood, contain approximately 30 miles of water mains ranging in diameter from 0.5 in. to 12 in. In the main post, over 94 percent of all pipes are unlined cast iron ranging in diameter from 6 to 12 in. In Camp Charles Wood 42 percent of the mains are 6- to 10-in. unlined cast iron pipe and 52 percent are 6- to 10-in. asbestos cement. The remaining small percentage is steel and PVC (T and M Associates, 1982).

7. There are three water storage tanks within Fort Monmouth. Two tanks, located in the main post, are inactive and provide water for emergency use only. A large ground storage tank (500,000 gal) is flushed periodically with booster pumps but is inactive the majority of the time. An elevated storage tank (250,000 gal) is presently inactive 100 percent of the time. Both tanks in the main fort are valved off. An elevated tank in Camp Charles Wood is the only active tank but provides storage and pressure for the Myer Center only. It is filled by booster pumps within the Myer Center and does not significantly affect system pressures outside the immediate vicinity of the Hexagon. Figures 1 and 2 show the location of these tanks.

System Schematics and Model Development

8. A water distribution system can be represented by a network of nodes and links corresponding to junctions and pipes. A schematic of such a system or network uses line segments and circles to represent pipes and nodes, respectively. A node is defined as either an intersection of two or more pipes or a point where demands are placed upon the system. Schematics are needed to develop a computerized description of the system.

9. When developing a computer model, it is not usually necessary or desirable to include every pipe and node that is actually present in the system. Eliminating smaller mains (and thus nodes) that do not carry much flow, called skeletonizing the system, is common practice in computer modeling. This is desirable because it can reduce computer time as well as make the system easier to work with and visualize without jeopardizing the accuracy of the

model (Walski, 1984). Schematics of both the main post and Camp Charles Wood areas are presented in Figures 1 and 2.

10. The primary reason for developing a calibrated mathematical model of a water distribution system is to enable the user to identify and solve problems and analyze system changes in a reliable manner. Computer models describing the Fort Monmouth systems will be used to evaluate rehabilitation alternatives (Section VI) and provide a basis for common, reliable comparisons of these alternatives (Gessler and Walski, 1985).

Water Source and Supply

11. Fort Monmouth's potable water is supplied entirely by the New Jersey American Water Company (formerly Monmouth Consolidated Water Company) under a purchase agreement. Seven interconnections exist between the New Jersey American Water Company and Fort Monmouth distribution systems; five of them are presently operating and metered. Three interconnections are located in the main post and two in Camp Charles Wood (Figures 1 and 2).

Physical Characteristics

12. Once the system schematic has been developed, a database containing information on the physical characteristics of each component of the system such as pipes, nodes, storage tanks, pumps, check valves and pressure-reducing valves should be assembled. Maps showing the location of all system components were obtained from the Fort Monmouth Directorate of Engineering and Housing (DEH) for this purpose. Pipes used in the computer model were selected from these maps based primarily on diameter, and demand concentrations in a given area. Pipe material, diameter, and length were also taken from the maps. Internal roughness values are also necessary and were determined by field measurements and calibration analysis (Sections IV and V). Tables 1 and 2 list all pipe data for both the main fort and Camp Charles Wood, while Tables 3 and 4 list all node data for both systems.

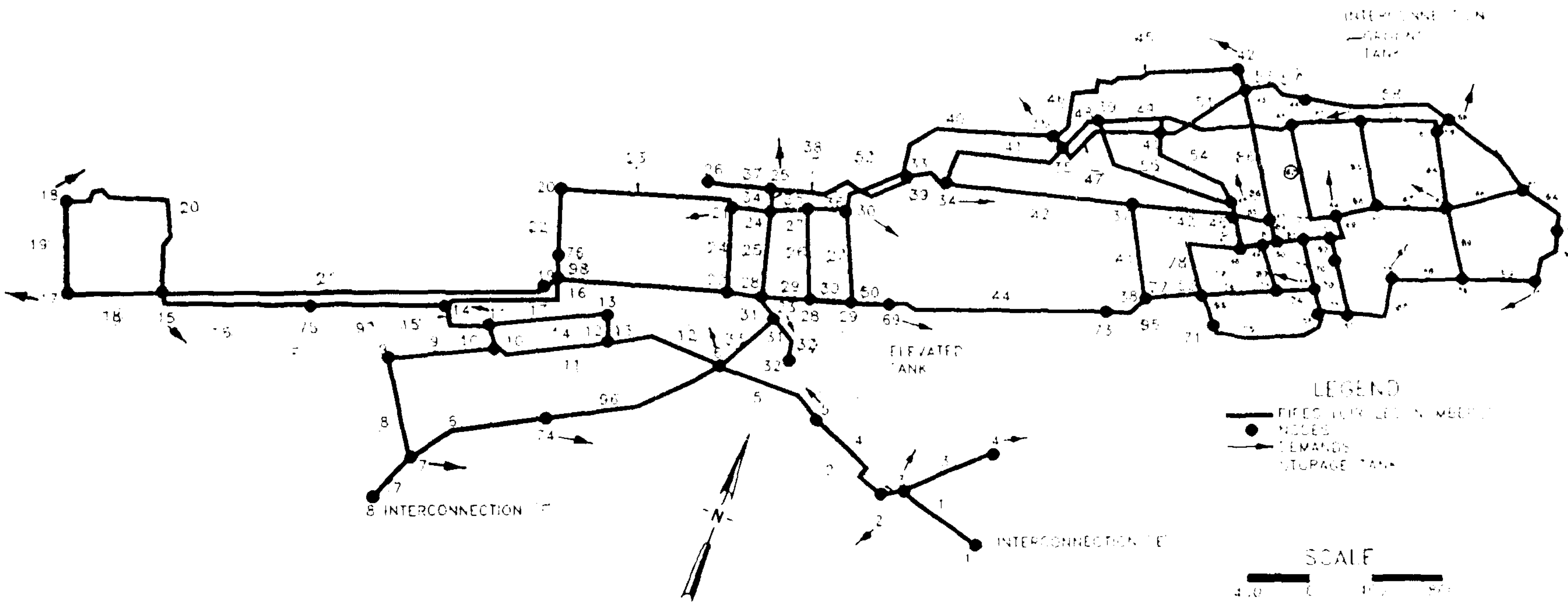

Figure 1. Main post system schematic

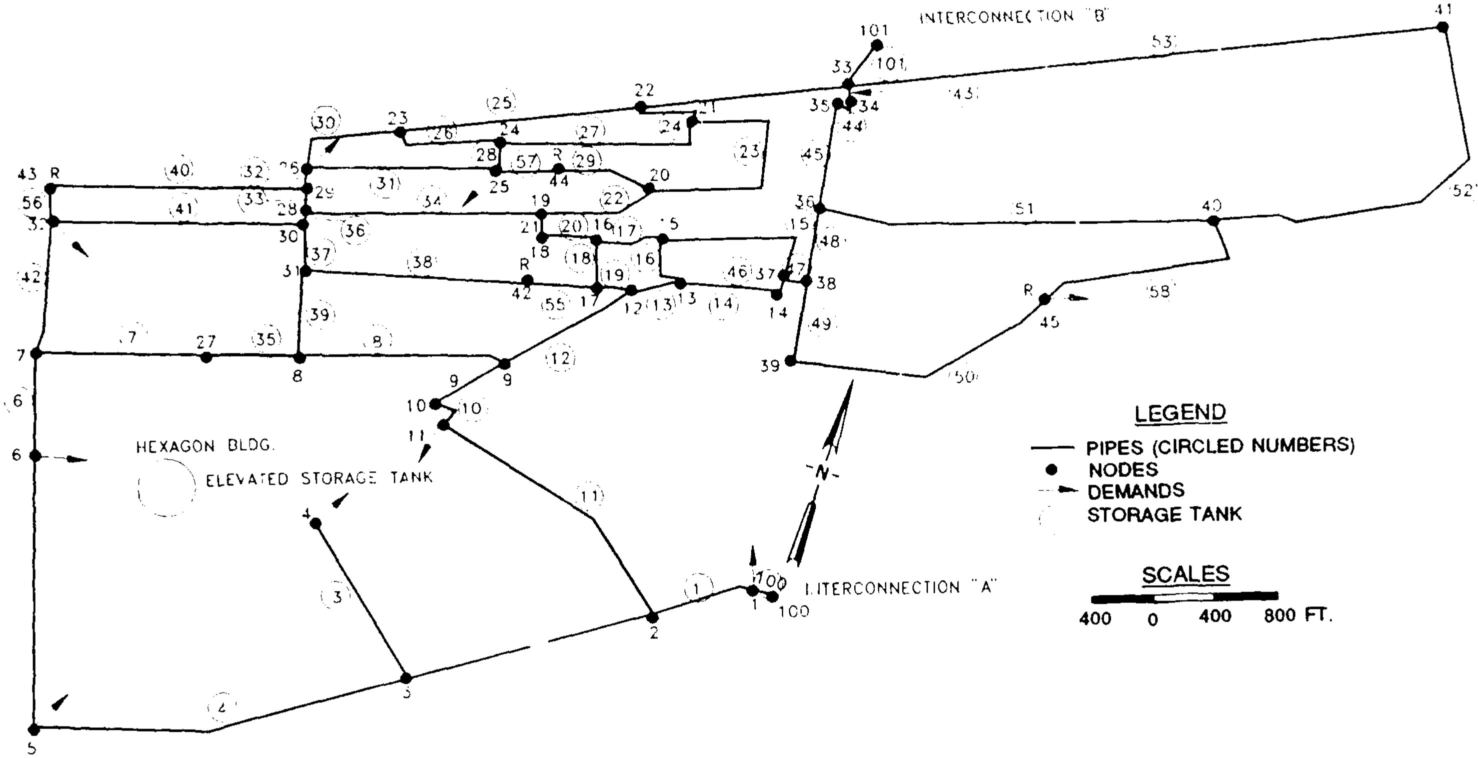

Figure 2. Camp Charles Wood system schematic

Water Demands

13. Water demands at Fort Monmouth were estimated to be 116 gpm for the main post and 130 gpm for Camp Charles Wood based on monthly water bills from the American Water Company over the four-year period of October 1983 through September 1987. This average flowrate was then divided into smaller demands placed at appropriate locations within the distribution system. The placement of these demands at individual nodes as well as a global demand factor to account for seasonal variations of water use was determined during system calibration. System demands are shown in Figures 1 and 2 as arrows placed at nodes. The numerical values for demands are listed in Tables 3 and 4 of this section.

PART III: SYSTEM CONDITION AND PROBLEMS

14. Three main problems have been identified in Fort Monmouth's Water distribution systems: red water, water quality, and water storage facilities. The primary problem is "red water." This is due to corrosion of internal pipe walls of unlined cast iron pipes forming iron and rust deposits (tuberculation). Given the low volume of water consumed at Fort Monmouth, and thus low line velocities during normal operation, these iron and rust deposits settle in the pipe. However, during periods of high demand, these deposits are disturbed and cause discoloration (red water).

15. Tuberculation is present in almost all unlined cast iron pipe, especially those pipes carrying corrosive water. Water quality data taken at Fort Monmouth (T and M Associates, 1982) indicated a Langlier Index between -1.38 and -1.94. The negative indices indicate corrosive water. A review of water quality data provided by fort personnel indicates a corrosive water was being supplied to them through 1985. Data from 1986 to present indicate a noncorrosive water, however. Since Fort Monmouth purchases its water from the New Jersey American Water Company, it has little control over this factor as corrosive water may still meet all water quality standards. However, steps can be taken to control this problem were attempted as a result of a consulting study done in 1982 on the Fort Monmouth water distribution systems (T and M Associates, 1982).

16. Internal cleaning (pigging) of the fort's pipes to remove the rust and tuberculation was recommended. Chemical injection at interconnection sites was also recommended to help control future corrosion. A long-chain linear phosphate called CalciQuest (brand name) was used for this purpose. It is designed to form a protective barrier on metallic surfaces to inhibit corrosion and to capture ionic iron. However, the cleaning (pigging) operation was halted substantially short of its original goal, and chemical injection was never initialized because the source of the problem (tuberculation) was not controlled properly.

17. Overall water quality is another problem at Fort Monmouth. Water quality tests comparing samples taken at the interconnections (supply points) and at locations within Fort Monmouth's distribution systems show a substantial decrease in the quality of water within the fort's distribution systems, especially in the main post. The following deteriorations in water quality

were cited: higher corrosivity, higher suspended solids, drastic increases in iron concentrations, slightly higher manganese levels, dramatic decreases in chlorine residuals (nearly zero), and presence of iron bacteria. At the time of these tests (1980) the potable water within the main post failed to meet the Safe Drinking Water Act water quality standards.

18. A more recent survey of over 600 water quality records (1984-88), supplied by the New Jersey American Water Co. and Fort Monmouth, show the same trends for increased iron concentrations and decreased chlorine residuals within the fort's systems. Sixty percent of all samples failed to meet New Jersey Safe Drinking Water Act secondary standards for chlorine residuals, and 45 percent failed for iron concentrations and total turbidity (see Table 5). Furthermore, these failures showed no spatial trends within the fort as all areas exhibited failures. It is important to note that the quality of water delivered by the American Water Company is acceptable.

19. When examining the water quality deterioration more closely, it is evident that internal corrosion (tuberculation) is the source of Fort Monmouth's water quality problems. This coupled with low water velocities creates a stagnant environment suitable for producing higher turbidity levels, increased iron concentrations, and the presence of iron bacteria. In addition, the presence of ferrous ions imposes a chlorine demand upon the water, thus causing a decrease in chlorine residuals (Rich, 1963).

20. An attempt to control this problem was made by installing sodium hypochlorite injection sites at the interconnections. This would boost the available chlorine levels within Fort Monmouth's distribution systems. The injection sites were placed at the five active interconnections (three in the main post and two in Camp Charles Wood) and equipped with flow control devices for the correct release of the chemical into the system (Birdsall Corporation, 1984). This practice was also halted after short use, because of problems with the chemical injectors being insensitive to low velocities which are common for the fort. Chlorine injection has not been reinitialized since that time.

21. The water storage facilities in the main post are also a problem source. Presently, there are two storage tanks: one 250,000-gal elevated storage tank and one 500,000-gal ground storage tank. The elevated storage tank is closed and contains water that is to be used for fire purposes and emergencies. The water in the tank is stagnant and could possibly pose

serious health hazards if introduced into the distribution system due to the loss of the chlorine residual over time. The ground water tank is closed the majority of the time. It is flushed periodically with booster pumps present adjacent to it. Flushing does not take place frequently, and the water contained within the tank is stagnant and poses a possible health hazard if introduced into the system. The elevated storage tank in Camp Charles Wood is operated in an acceptable manner. It is filled by booster pumps in the basement of the Hexagon Building and provides adequate water and pressure to the Hexagon Building.

22. As a result of the 1982 consultant study (T and M Associates, 1982), all storage tanks, including the elevated tank in Camp Charles Wood, were inspected. The main post elevated tank was cleaned and painted both interior and exterior, while the ground tank was not rehabilitated. The Camp Charles Wood tank was cleaned and painted on both the interior and exterior.

23. While maintenance of this type is desirable, it does not solve the problem of water quality within the tanks. An operating policy that allows all storage facilities to fill and drain on a regular basis (preferably daily) is necessary to insure acceptable water quality within the tanks.

PART IV: FIELD MEASUREMENTS AND OBSERVATIONS

24. Fire flow tests and head loss tests were conducted at both the main post and Camp Charles Wood. The purpose of these tests is to determine system pressures and flowrates under stressed conditions as well as the extent of internal roughness in the pipes. These tests also give the opportunity to visually characterize the water and to test system components such as fire hydrants and valves.

25. Field inspection revealed that system components were in good condition and worked reliably. This observation is in agreement with a comprehensive look at system components by T and M Associates (1982). The color of the water flowing from the hydrants, however, was noticeably red. This was especially true at the main post. Red water was seen for the duration of testing (4 days) which indicates a true area-wide red water problem and not just localized sediment stirred up by temporarily high flows.

26. The volume of water and pressures supplied by the New Jersey American Water Company were adequate for fire protection the majority of the time. Pressures were monitored at select interconnection sites over a period of time. These results are listed in Table 6 as average pressures during the time of testing. The results show that adequate pressures are being supplied to Fort Monmouth even under stressful conditions. Camp Charles Wood did show low pressures during the tests performed with alternate interconnections shut, but on the whole were adequate. Other weak areas are shown in Tables 7 and 8. The tests were performed during the middle of June on an extremely hot day with temperatures reaching nearly 100° Fahrenheit. During the time of testing, a water alert was put into effect by Monmouth County officials requesting voluntary conservation of water use. Thus, the period of testing, combined with the tests that were performed, put the Fort Monmouth water distribution systems under severe stress.

27. Tables 7 and 8 list all fire flow tests results for both systems. The observed flows and pressures were used to calculate the theoretical flow at a residual pressure of 20 psi which is used as a standard by the Army and Insurance offices for evaluating fire flow capacities. The following equation is used to calculate the flow at 20 psi (Walski, 1984):

$$Q_{20} = Q_t \left(\frac{P_s - P_{20}}{P_s - P_t} \right)^{0.54}$$

where

Q_{20} = discharge at residual pressure corresponding to 20 psi, gpm

Q_t = discharge during test, gpm

P_s = residual pressure with no hydrants open, psi

P_{20} = residual pressure during fire condition = 20 psi

P_t = residual pressure during test, psi

These calculated flows were then compared to Army flow standards (EM 1110-3-166, 1984 and MIL-HDBK-1008, 1985) for buildings and occupancies to determine if the observed flows were acceptable or unacceptable. Six of the fifteen tests proved unacceptable. However, four of these six failures occurred in tests with interconnections shut. This scenario would involve a doubly catastrophic event (e.g. fire and main break) and should be noted as a measure of system reliability instead of true fire flow capacity. Thus, only two failures (Riverside Dr. and Megill Ave) occurred under normal operating conditions. These areas will be evaluated in further detail after a rehabilitation scheme for the entire fort has been developed (WES Volume II report). Internal roughness was also measured in several pipes. The results of these tests expressed as C-factors and equivalent sand grain roughness height are given in Table 9. The measurement of C-factor gives an estimate of the amount of internal roughness inside the pipe. A high C-factor indicates smooth pipe (low roughness height), while a low value indicates a rough interior surface. A typical range of C-factor is from 40 (old, rough) to 130 (new, smooth). Most cast iron pipes tested at Fort Monmouth exhibited very low C-factors. This is expected given the age of the system (majority over 50 years) and the fact that most of the pipes have never been cleaned. The asbestos cement pipes present in Camp Charles Wood exhibit a higher C-factor. This is also expected because internal roughness of cast iron pipes may be caused by tuberculation due to corrosion of metallic surfaces, a condition known to exist at Fort Monmouth. Internal buildup in asbestos cement pipes would be more likely to occur from scale-forming water which is not present at Fort Monmouth.

PART V: COMPUTER MODEL DEVELOPMENT AND CALIBRATION

28. When developing a computer model for the analysis of water distribution systems, it is important that the mathematical (computer) model be an accurate representation of actual field conditions. This is known as model calibration. Calibration may be achieved by adjusting input variables describing the system such as water usage and pipe roughness until heads and flows predicted by the model match field measurements such as those observed in fire flow tests. These measurements (Table 7 and 8) provide needed hydraulic information, namely flows and pressures, for many different operating conditions. Thus, this information provides a wide range of values to accurately calibrate the system.

29. System calibration was performed using a nonlinear optimization technique developed by Sharp and Chase (1988). The underlying principle of this technique is to minimize the differences between observed (measured) and predicted (modeled) heads. This is accomplished by adjusting variables within the computer model. The variables used in calibrating the Fort Monmouth models are pipe roughness (C-factor), nodal water demand, and global demand factor. The C-factors and water usage determined by calibration are given in Tables 1-4. Other calibration results for both systems are presented in Tables 9 and 10.

30. Global demand factors of 1.44 and 2.28 were determined during system calibration for the main post and Camp Charles Wood, respectively. These values are multiplied by every nodal demand to account for seasonal or temporal variations in the demand pattern. These values were verified from instantaneous flow measurements taken in the field and dividing this measured flowrate by the 4-year average demand used in the model. An average value of 2.2 was obtained, which shows reasonably good agreement with the calibration results.

PART VI: REHABILITATION ALTERNATIVES

31. Alternatives to rehabilitate Fort Monmouth's water distribution systems should focus on water quality (namely, red water and chlorine residuals) and a tank operating policy. The condition of both systems is poor, particularly the main post. The pipes are old and have received minimal system-wide rehabilitation over the years. Thus, a comprehensive rehabilitation plan is necessary to solve Fort Monmouth's water distribution problems. Efforts directed toward specific areas will only solve short-term, localized problems and not the overall problems present.

32. This study shows that corrosion is the major cause of poor water quality at Fort Monmouth. As already discussed, it is the cause of red water and a source for a decreasing chlorine residual. To alleviate this problem, tuberculation must be removed from the pipes. Then, corrosion must be controlled to prevent new tuberculation in the future. There are several measures that can be taken to accomplish both of these tasks.

33. A routine flushing program will help remove the iron and rust sediments from the pipe. However, it cannot stand alone as a method for the removal of tuberculation, especially in the badly deteriorated pipes at Fort Monmouth. Internal cleaning is necessary, and "pigging" is a common and reliable way of removing internal buildup. Pigging can be very effective if properly planned and coordinated with a dependable, qualified contracting firm (Sharp, 1988). Mechanical scraping will also remove the internal corrosion but should always be accompanied by lining because the metal scrapers tend to penetrate into the pipe walls and expose corrosion pits.

34. To control future corrosion after the pipes have been cleaned, internal lining must be present. This can be done by either chemical injection or mechanical means such as cement lining. However, given the relatively small diameter of pipe present at Fort Monmouth, mechanical lining can be shown to be cost-intensive based on capital costs (Walski, 1985). Also, since chemical injection sites are present on the fort, they can be utilized to help cut costs. Another alternative for system rehabilitation is replacement. Although this is usually economically infeasible for an entire system, pipe candidates for replacement of several specific pipes may greatly help the entire system. Table 12 defines the choices for rehabilitation alternatives suitable for Fort Monmouth. The alternatives listed will help solve both

water quality and quantity concerns. The costs shown are based primarily on telephone conversations with contracting companies who specialize in one or more of the alternatives. These costs provide general guidance only and are shown to display the relative differences in cost between the alternatives.

35. The assessment scale is used to help order the alternatives. A range of 1 to 5 has been adopted. A value of 5 corresponds to an extremely good rating while a value of 1 corresponds to an extremely poor rating. Thus, the alternatives with the highest sum correspond to the best rehabilitation efforts. Cost is not reflected in this summation, but should be weighed accordingly. Each alternative has an amount of inconvenience to the operator (owner) that should also be considered. Cement cleaning and lining, for instance, has a higher capital cost then pigging and chemical injection. However, chemical injection is potentially labor intensive and susceptible to mechanical failure. It is this type of trade-off that cannot be quantified in numbers alone, but needs careful thought and insight.

PART VII: CONCLUSIONS AND RECOMMENDATIONS (PHASE II STUDIES)

36. A second phase (Volume II) of this study is necessary to address all problem areas adequately. The problems at Fort Monmouth are not uncommon, but large in magnitude. The alternatives given in Table 12 will resolve the major problems. However, there are other problems which must be addressed in the second phase of this study.

37. The developed computer model will be expanded to include the New Jersey American Water Co. system. Then, using this model, the following problem areas can be examined:

- a. Adequate water storage for Fort Monmouth.
- b. The possibility of removing excess storage.
- c. Defining an operating policy for the storage facilities needed.
- d. Identifying stagnant areas within the fort and scenarios (valving, alternating interconnections, looping, flushing) to eliminate them.

38. Another problem to resolve is bringing the chemical injection sites back into operation. This is necessary for the addition of chlorine or a corrosion inhibitor. These injection sites will be checked for flow sensitivity and proper injection concentrations. If necessary, a manufacturer's representative will be brought to the fort so that these sites will operate correctly. Proper chemical injection is necessary for a successful rehabilitation plan at Fort Monmouth.

39. Phase 2 of this study will also include a comprehensive study of the selected rehabilitation plan. This will include a methodical approach starting with contract specifications and selection, leading to implementation and completion of the chosen alternatives. These decisions will be made in FY89 by Fort Monmouth and WES personnel.

REFERENCES

Birdsall Corporation. 1984 (Dec). "Report on Operating Procedures for Chemical Feed Systems--Fort Monmouth, New Jersey," Preliminary Report No. 50032.000.

Gessler, Johannes, and Walski, T. M. 1985. "Water Distribution System Optimization," Technical Report EL-85-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Office, Chief of Engineers. 1984 (Apr). "Engineering and Design: Water Supply, Fire Protection Mobilization Construction," Engineer Manual 1110-3-166, Washington, DC.

Mil-HDBK-1000, 1985 (Apr). "Military Handbook: Fire Protection for Facilities Engineering, Design, and Construction," Department of the Army, Washington, DC.

Rich, Linvil G. 1963. Unit Processes of Sanitary Engineering, John Wiley and Sons, New York.

New Jersey Safe Drinking Water Act, Department of Environmental Protection. 1985 (Nov). N.J.A.C. 7:10-1.1 through 7.3.

Sharp, Wayne W., and Chase, Donald V. 1988. "Verifying Water Distribution Computer Model Calibration Results," AWWA Computers and Automation Specialty Conference.

Sharp, Wayne W. 1988. "Effects of Polyurethane Sponge Cleaning on Carrying Capacity of Potable Water Mains," Technical Note, US Army Engineering and Housing Support Center, Fort Belvoir, VA.

T and M Associates. 1982 (Feb). "Study of Fort Monmouth Water Distribution System."

Walski, T. M. 1984. Analysis of Water Distribution Systems, Van Nostrand Reinhold, New York.

Walski, T. M. 1985. "Cost of Water Distribution System Infrastructure Rehabilitation, Repair, and Replacement," Technical Report EL-85-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1

Physical Characteristics - Main Fort

Pipe Number	Node	Node	Pipe Diameter (in.)	Pipe Length (ft)	Hazen Williams C-Factor	Material
1	1	3	12	660	20	Cast Iron
2	2	3	8	130	20	Cast Iron
3	3	4	8	650	20	Cast Iron
4	2	5	12	1110	20	Cast Iron
5	5	6	12	640	20	Cast Iron
6	7	74	8	880	22	Cast Iron
7	7	8	8	450	22	PVC
8	7	9	8	900	22	Cast Iron
9	9	10	6	685	22	Cast Iron
10	10	11	12	200	22	PVC
11	10	12	8	815	22	Cast Iron
12	6	12	8	700	22	Cast Iron
13	12	13	8	190	22	Cast Iron
14	11	13	6	675	22	Cast Iron
15	11	14	12	450	22	Cast Iron
16	15	75	12	890	130	PVC
17	14	16	6	755	130	Asbestos Cement
18	15	17	10	610	130	Cast Iron
19	17	18	10	925	130	Cast Iron
20	15	18	10	1650	130	Cast Iron
21	15	19	10	2290	130	Cast Iron
22	20	76	8	750	100	Cast Iron
23	20	21	8	1020	100	Cast Iron
24	21	22	12	825	94	Cast Iron
25	23	24	6	830	94	Cast Iron
26	27	28	6	825	94	Cast Iron
27	29	30	8	850	94	Cast Iron
28	22	23	12	210	94	Cast Iron
29	23	28	8	280	94	Cast Iron
30	28	29	8	295	94	Cast Iron
31	23	31	12	200	20	Cast Iron
32	31	32	12	165	20	Cast Iron
33	6	31	12	590	90	Cast Iron
34	21	24	12	215	94	Cast Iron
35	24	27	12	215	94	Cast Iron
36	27	30	12	245	94	Cast Iron
38	25	33	6	960	94	Cast Iron
39	33	34	6	225	86	Cast Iron
40	30	36	12	1615	86	Cast Iron
41	34	35	6	755	86	Cast Iron
42	34	37	6	1075	86	Cast Iron
43	37	38	6	890	86	Cast Iron

(Continued)

Table 1 (Continued)

Pipe Number	Node	Node	Pipe Diameter (in.)	Pipe Length (ft)	Hazen Williams C-Factor	Material
44	69	73	6	1415	86	Cast Iron
45	36	42	8	1315	51	Cast Iron
46	35	36	12	65	90	Cast Iron
47	35	41	12	700	101	Cast Iron
48	35	39	6	290	51	Cast Iron
49	29	65	6	1130	51	Cast Iron
50	29	69	8	215	85	Cast Iron
51	41	43	12	655	101	Cast Iron
52	24	25	6	85	93	Cast Iron
53	42	43	6	210	51	Cast Iron
54	41	45	6	870	102	Cast Iron
55	39	45	6	1110	102	Cast Iron
56	45	46	6	65	102	Cast Iron
57	43	44	12	410	99	Cast Iron
58	44	68	10	700	99	Cast Iron
59	67	68	6	80	99	Cast Iron
60	66	67	6	420	99	Cast Iron
61	65	66	6	370	90	Cast Iron
62	64	65	6	950	100	Cast Iron
63	63	66	6	805	100	Cast Iron
64	62	67	6	775	100	Cast Iron
65	61	68	10	825	100	Cast Iron
66	61	62	8	495	100	Cast Iron
67	62	63	8	410	100	Cast Iron
68	63	64	8	225	100	Cast Iron
69	52	64	8	265	100	Cast Iron
70	57	70	6	550	103	Cast Iron
71	51	55	6	400	103	Cast Iron
72	51	52	8	220	103	Cast Iron
73	56	57	6	220	103	Cast Iron
74	54	55	8	220	103	Cast Iron
75	56	71	6	780	104	Cast Iron
76	53	54	8	625	104	Cast Iron
77	38	53	8	330	104	Cast Iron
78	48	53	8	690	104	Cast Iron
79	48	49	8	150	104	Cast Iron
80	49	54	6	400	104	Cast Iron
81	50	51	8	150	103	Cast Iron
82	49	50	8	75	103	Cast Iron
83	46	48	8	310	103	Cast Iron
84	47	50	6	220	103	Cast Iron
85	46	47	6	245	103	Cast Iron
86	43	47	6	1180	101	Cast Iron
87	57	58	6	560	88	Cast Iron

(Continued)

Table 1 (Concluded)

Pipe Number	Node	Node	Pipe Diameter (in.)	Pipe Length (ft)	Hazen Williams C-Factor	Material
88	58	59	8	405	88	Cast Iron
89	59	62	8	640	88	Cast Iron
90	59	60	8	530	88	Cast Iron
91	60	72	6	580	88	Cast Iron
92	52	70	8	160	103	Cast Iron
93	53	71	4	275	104	Cast Iron
94	61	72	6	310	87	Cast Iron
95	38	73	6	235	85	Cast Iron
96	6	74	8	1690	22	Cast Iron
97	14	75	12	880	130	PVC
98	16	76	8	115	100	Cast Iron
100	100	1	12		Check valve	
101	101	8	8		Check valve	
102	102	42	12		Check valve	
122	16	22	12	950	100	Cast Iron
142	37	46	6	590	90	Cast Iron
155	55	56	6	300	103	Cast Iron

Table 2

Camp Charles Wood Physical Characteristics

Pipe No.	Node	Node	Diam. (in.)	Length (ft)	Hazen Williams C-Factor	Material
1	1	2	8	420	94	Asbestos Cement
2	2	3	8	870	94	Asbestos Cement
3	3	4	8	890	94	Asbestos Cement
4	3	5	8	1830	94	Asbestos Cement
5	5	6	8	1700	94	Asbestos Cement
6	6	7	8	670	94	Asbestos Cement
7	7	27	6	790	94	Asbestos Cement
8	8	9	6	840	94	Asbestos Cement
9	9	10	6	360	94	Asbestos Cement
10	10	11	6	160	94	Cast Iron
11	2	11	8	1470	94	Asbestos Cement
12	9	12	6	710	106	Asbestos Cement
13	12	13	6	95	106	Asbestos Cement
14	13	14	6	520	118	Cast Iron
15	15	37	6	780	118	Cast Iron
16	13	15	4	320	90	PVC
17	15	16	6	235	90	Cast Iron
18	16	17	6	290	90	PVC
19	12	17	6	150	98	Asbestos Cement
20	16	18	6	140	90	Cast Iron
21	18	19	4	150	90	PVC
22	19	20	6	350	130	Asbestos Cement
23	20	21	6	1330	97	Cast Iron
24	21	22	6	200	97	Cast Iron
25	22	23	8	925	20	Asbestos Cement
26	23	24	6	380	20	Steel
27	21	24	6	890	20	Steel
28	24	25	8	150	20	Steel
29	20	44	6	1330	130	Asbestos Cement
30	23	26	8	575	20	Asbestos Cement
31	25	26	6	720	130	Asbestos Cement
32	26	29	8	130	130	Asbestos Cement
33	28	29	8	140	130	Asbestos Cement
34	19	28	6	1090	130	Asbestos Cement
35	8	27	6	300	82	Asbestos Cement
36	28	30	8	80	97	Asbestos Cement
37	30	31	8	305	97	Asbestos Cement
38	31	42	6	835	98	Asbestos Cement
39	8	31	8	515	90	Cast Iron
40	29	43	6	1070	94	Cast Iron
41	30	32	6	1070	47	Cast Iron
42	7	32	8	845	47	Cast Iron
43	33	34	6	70	52	Cast Iron
44	34	35	6	50	52	Cast Iron

(Continued)

Table 2 (Concluded)

Pipe No.	Node	Node	Diam. (in.)	Length (ft)	Hazen Williams C-Factor	Material
45	35	36	6	720	52	Cast Iron
46	14	37	6	55	118	Cast Iron
47	37	38	6	95	118	Cast Iron
48	36	38	6	465	60	Cast Iron
49	38	39	6	490	60	Cast Iron
50	39	45	6	1185	60	Cast Iron
51	36	40	6	1615	20	Cast Iron
52	40	41	8	2065	20	Asbestos Cement
53	33	41	8	2500	20	Asbestos Cement
54	22	33	8	880	20	Asbestos Cement
55	17	42	6	195	98	Asbestos Cement
56	32	43	6	220	47	Cast Iron
57	25	44	6	320	130	Asbestos Cement
58	40	45	6	1145	20	Asbestos Cement
100	100	1	8		Check Valve	
101	101	33	8		Check Valve	

Table 3

Fort Monmouth Main Site Node Data

Node No.	Elev. (ft)	Demand GPM x 1.44 = Total Demand
1	20	0
2	21	8
3	18	2
4	12	4
5	17	3
6	11	1
7	21	1
8	15	0
9	15	0
10	16	0
11	16	1
12	16	0
13	17	0
14	15	0
15	19	3
16	16	0
17	21	23
18	25	19
19	16	0
20	12	0
21	16	4
22	15	0
23	16	3
24	15	0
25	13	5
26	15	0
27	14	0
28	13	0
29	12	0
30	14	1
31	13	0
32	12	0
33	20	0
34	13	3
35	16	0
36	14	3
37	12	0
38	10	1
39	13	0
41	13	0
42	8	5
43	10	0
44	8	0
45	13	8
46	12	0

(Continued)

Table 3 (Concluded)

Node No.	Elev. (ft)	Demand GPM x 1.44 = Total Demand
47	13	0
48	11	0
49	12	0
50	11	0
51	11	0
52	11	0
53	10	0
54	11	0
55	11	7
56	9	0
57	7	0
58	9	1
59	8	0
60	7	2
61	9	0
62	11	1
63	11	0
64	11	1
65	12	0
66	10	1
67	7	0
68	7	1
69	11	1
70	11	0
71	8	0
72	10	0
73	9	0
74	15	1
75	17	0
76	16	0
Interconnection "E"	20	Supply Pressure: 63 psi
Interconnection "F"	15	Supply Pressure: 65 psi
Interconnection "C"	8	Supply Pressure: 69 psi

Table 4

Camp Charles Wood Area Node Data

Node No.	Elev. (ft)	Demand GPM x 1.44 = Total Demand
1	32	10
2	34	0
3	44	0
4	63	10
5	68	0
6	67	40
7	68	0
8	53	0
9	39	0
10	50	0
11	50	10
12	46	0
13	43	0
14	36	0
15	47	0
16	50	0
17	47	0
18	48	0
19	47	0
20	48	0
21	56	0
22	53	0
23	49	0
24	48	0
25	47	4
26	48	10
27	55	0
28	46	0
29	43	0
30	46	0
31	48	0
32	53	15
33	47	0
34	47	0
35	47	0
36	39	0
37	40	0
38	36	0
39	34	0
40	43	0
41	32	0
42	47	0
43	52	0
44	48	0
45	43	50
Interconnection "A"	32.0	Supply Pressure: 55 psi
Interconnection "B"	47.0	Supply Pressure: 60 psi

Table 5

New Jersey Safe Drinking Water Act (Nov 1985)

Water Quality Parameter	Units of Measure	Limits	Percent Failed Samples (Within Fort)
Chlorine Residual	ppm	Free available chlorine residual shall range from 0.2 @ pH up to 7.0, 0.3 @ pH 7.0 to 8.0, and 0.4 @ pH 8.0 to 9.0	60
Iron	mg/ℓ	0.3	45
Turbidity	NTU	5	45

Table 6

Time-Averaged Measured Interconnection Pressures

Interconnection Site (see Fig. 1 and 2)	Average Pressure (PSI)
A (Main Fort)	55
F (Main Fort)	63
C (Charles Wood)	69

Table 7

Fire Flow Test Results Main Fort Area (All Interconnections Operating Normally Unless Noted)

Test No.	Location	Elev (ft)	Number of Hydrants Flowed	Pressure (PSI)	Total Discharge (gpm)	Fire Flow at 20 psi (gpm)	Army Standards for Fire Flow (gpm)	Test Status
1	Riverside Dr.	8.7	0	62	0			
	by DEH		1	30	627			
	(residual node #72)		2	20	914	914	2000	Unacceptable
2	Memories Ln	16.4	0	60	0			
	by theatre		1	43	918			
	(residual node #75)		2	24	1420	1521	1000	Acceptable
			3	15	1621			
3	Messenger Ave	15.8	0	63	0			
	(residual node #76)		1	49	948			
			2	40	1340	1878	750	Acceptable
4	Irwin Ave	14.9	0	62	0			
	near elev tank		1	52	731			
	(residual node #23)		2	48	1046			
			3	36	1772	2295	1500	Acceptable
5	Nicodemus	16.2	0	64	0			
	(residual node #74)		1	42	992			
			2	26	1340			
			3	18	1864	1819	750	Acceptable
6	Gosselin	10	0	61	0			
	by NCO housing		1	40	530			
	(residual node #73)		2	34	670	839	750	Acceptable

(Continued)

Table 7 (Concluded)

Test No.	Location	Elev (ft)	Number of Hydrants Flowed	Pressure (PSI)	Total Discharge (gpm)	Fire Flow at 20 psi (gpm)	Army Standards for Fire Flow (gpm)	Test Status
7	Memories Ln.	16.4	0	65	0			
	by theatre		1	50	918			
	(residual node #75)		2	30	1420	1626	1000	Acceptable
	Interconnection F closed							
8	Nicodemus	16.2	0	62	0			
	(residual node #74)		1	22	443			
	**Interconnection I closed*		2	16	809	770	750	Acceptable (but weak)
9	Riverside Ave.	8.7	0	67.5	0			
	(residual node #72)		1	30	581			
	**Interconnection C Closed*		2	15	746	706	2000	Unacceptable

Table 8

Fire Flow Test Results Camp Charles Wood Area (All Interconnections Operating Normally Unless Noted)

Test No.	Location	Elev (ft)	Number of Hydrants Flowed	Pressure (PSI)	Total Discharge (gpm)	Fire Flow at 20 psi (gpm)	Minimum Army Standards for Fire Flow (gpm)	Test Status
1	Megill	42	0	60	0			
	Officer Housing		1	25	556			
	(residual node #45)		2	20	604	604	750	Unacceptable
2	Wake Ave.	48.2	0	56	0			
	(residual node #44)		1	40	855			
			2	28	1401	1604	750	Acceptable
3	Midway Lane	46.2	0	54	0			
	(residual node #42)		1	40	933			
			2	28	1351	1561	750	Acceptable
4	Marivellas Rd.	52.1	0	50	0			
	(residual node #43)		1	30	750			
			2	20	1098			
			3	14	1339	1213	750	Acceptable
5	Alongapo Dr.		0	45	0			
	(residual node #19)		1	20	627			
	Interconnection B closed		2	9	838	688	750	Unacceptable
6	Storage Facilities close to RR		0	50	0			
	(residual node #3)		1	8	556			
	Interconnection A Closed		2	0	593	452	750	Unacceptable
7	Megill		0	45	0			
	(residual node #44)		1	20	474	418	750	Unacceptable
	Interconnection B Closed		2	14	470			

Table 9

Internal Roughness Estimates

Location	Pipe Number (see fig. 1 and 2)	Material*	Diameter (in.)	Measured Flowrate (gpm)	Measured Head Loss (ft)	Length Tested (ft)	C-Factor	Roughness Height (ft)
Riverside Dr. by DEH	91 MF=Main Fort (fig 1)	CI	6	290	28	270	32	0.21
Gusselin Dr. NCO Housing	44 MF	CI	6	237	60	700	30	0.24
Irwin Ave	25 MF	CI	6	314	76	400	25	0.32
Memories Ln. by theatre	21 MF	CI	10	777	19	789	50	0.12
Olangapo	41 CCW=Camp Charles Wood (fig 2)	CI	6	638	9	395	155	Negligible
Midway Ln.	38 CCW	AC	6	768	15	270	116	0.0012
Marivelles	40 CCW	CI	6	437	53	642	53	0.057
Storage area	4 CCW	AC	8	887	32	1900	116	0.0015
Megill by Golf Course	58 CCW	CI	6	265	25	363	36	0.164

* CI = cast iron; AC = asbestos cement.

Table 10

Calibration Results for Main Post

Location	Number of Hydrants Flowed	Observed Head (ft)	Predicted Head (ft)
Riverside Dr.	0	153	160
Memories Lane	0	156	160
	1	116	111
	2	72	58
	3	52	31
Messenger Ave.	0	162	160
	1	129	138
	2	108	122
Irwin Ave.	0	159	160
	1	136	139
	2	127	126
	3	99	104
Nicodemus	0	163	160
	1	112	141
Gosselin	0	150	160
Memories Ln (Interconnection "F" Closed)	0	167	160
Nicodemus (Interconnection "F" Closed)	0	158	160
	1	66	71
Riverside Dr. (Interconnection "C" Closed)	0	166	157
	1	79	84
	2	45	49

Table 11

Calibration Results for Camp Charles Wood

Location	Number of Hydrants Flowed	Observed Head (ft)	Predicted Head (ft)
Megill at Golf Course	0	181	174
	1	101	106
	2	89	99
Wake Ave.	0	177	170
	1	140	126
	2	113	93
Midway Ln.	0	172	169
	1	139	137
	2	112	103
Marivellas	0	168	169
	1	121	113
	2	98	106
	3	84	95
Alongopo	0	151	152
	1	93	105
	2	68	78
Megill (Interconnection B Closed)	0	147	153
	1	89	68
Storage Area by Railroad	0	160	169
	1	62	67

Table 12

Rehabilitation Alternatives

Alternative	Approximate Cost ($/ft)	Hydraulic Improvement	Reliability	Customer/ Environmental Convenience	Total
Replacement	50-60	5	5	2	12
Clean and Cement Line	20	4	4	4	12
Clean and Calcite Line	25	4	2	3	9
Pig and Chemical Injection	2.50 + $20 K/yr	3	3	4	10