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Final Report

OCD Work Unit 4334A

October 1967

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Final Report

VULNERABILITY OF THE WATER, SEWAGE, AND DRAINAGE SYSTEMS IN SAN JOSE

Prepared by:

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OCD Work Unit 4334A

CONTRACT NO. OCD-PS-64-201
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MENLO PARK CALIFORNIA

Prepared for:

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WASHINGTON, D.C. 20310

This report has been reviewed in the Office of Civil Defense and approved for publication. However, an evaluation by OCD indicates that further study of system organizations and operations is required and that the data contained shall not be considered as complete for use in the Five City Study.

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ABSTRACT

The report examines the facilities of the water supply, sewage, and drainage systems in the City of San Jose; assesses their vulnerability to the effects of the nuclear attack postulated for the first iteration of the FIVE CITY STUDY; and presents a preliminary estimate of the postattack capability of these systems and their interaction with the electric power system. Additional data presented are: guides for analyzing the vulnerability of water, sewage, electric power, and natural gas facilities to the effects of a 5-MT nuclear burst; and methods for performing rapid network analysis of water supply systems.

PREFACE

The research covered in this report was conducted in the Institute's Management and Social Systems Area on Contract Number OCD-PS-64-201, Subtask 39, as part of the OCD FIVE CITY STUDY. The research was directed by Richard K. Laurino, Manager, Operations Analysis Program. Project leader was David W. Goodrich. This report constitutes a final report on OCD Work Unit 4334A monitored technically by Richard E. Bothun, of the SRI Civil Defense Technical Office.

Assistance in data collection under the direction of Judson A. Harmon was provided by Engineering-Science, Inc., Arcadia, California, through subcontract to SRI.

Assistance in describing the water and sewage system operations was provided both to ESI and SRI by Mr. L. F. Dunton, Manager, Planning Division, San Jose Water Works, and Mr. Frank M. Belick, Manager, San Jose-Santa Clara Water Pollution Control Plant.

The authors also wish to express their appreciation for the research assistance of Lung Hsin Wu, Lyle Schump, and Rae Wong.

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I INTRODUCTION AND SUMMARY

Five City Study

In addition to making efforts to protect the population from the initial effects of nuclear attack, the Office of Civil Defense must make efforts to ensure that the population surviving such attacks also has adequate facilities and supplies to sustain themselves during the period necessary to effect recovery of the nation. Studies of the survivability of population, resources, industry, and utilities and their ability to recover from the effects of nuclear attack must be made. The FIVE CITY STUDY includes certain elements of the research program involved with investigating the many and varied problems concerned with the damage to and recovery of selected metropolitan areas from the effects of nuclear attack.

Office of Civil Defense Work Unit 4334A, "Local Vulnerability of Utilities," as one of the many studies participating in the FIVE CITY STUDY, has been concerned with the vulnerability of the water, sewage, and drainage systems in San Jose, California.

Scope

As originally conceived, Work Unit 4334A was concerned with essentially all local utilities, namely, water, sewage, drainage, electric power, natural gas, communications, and transportation. Subsequent to initiation of the study, the scope was reduced to include water, sewage, drainage, transportation, and communications systems.

The FIVE CITY STUDY is an iterative process. This report deals with the first iteration of the FIVE CITY STUDY in San Jose, California, and reports the expected damage that would result from an assumed 5-MT nuclear weapon detonation 14,500 feet over the southern end of San Francisco Bay north of the City of San Jose (Latitude 372735N, Longitude 1220329W at 8:52 pm PDT on August 24, 1965.

This report describes and analyzes the vulnerability of the water, sewage, and drainage systems facilities in San Jose as they existed on August 24, 1965, with civil defense preparedness and countermeasures that existed at that time. No attempt is made to analyze postattack recovery; this is the subject of another OCD work unit. The transportation and communications systems are to be analyzed and reported separately.

Objectives

The objectives of this work unit for the water, sewage, and drainage systems were to:

1. Determine the extent of damage and service interruptions to be faced by local utilities in the event of nuclear attack.
2. Review and codify emergency countermeasures that may be employed to modify the interruption of utility services following nuclear attacks.
3. Determine the interactions among the various separate utilities and the effects of these interactions upon the ability of the utility system as a whole to maintain service after a nuclear attack.
4. Provide damage information to facilitate future study of the cost and effort required for the recovery of local utilities following nuclear attack.
5. Develop a methodology by which the effects of nuclear attacks upon local utility systems may be rapidly and comprehensively analyzed, taking into account the interactions among the various separate utilities.
6. Provide information to enable study of the interactions between the local utilities system and other segments of the economy.

Since the FIVE CITY STUDY is an iterative process, these objectives will not be completely achieved until more than one iteration has been performed in each of the FIVE CITIES. However, this report presents an initial effort toward fulfilling the above objectives.

The report presents the damage to the facilities of, and the associated service interruption of, the water, sewage, and drainage systems in San Jose as a result of the assumed attack. Some emergency countermeasures that may be employed to modify the interruption of service are discussed but further work is required in this area. The interactions between the water, sewage, and drainage systems and the electric power system are analyzed, but additional research concerning interactions will be required when the work units studying electric power and natural gas complete their research.

This report and the FIVE CITY STUDY Working Papers* associated with it provide damage information to facilitate future study of the cost and effort required for recovery of the water, sewage, and drainage systems in San Jose and also provide information allowing stud-- of the interactions between these utilities and other segments of the economy in San Jose. This report also presents the basis for development of a methodology to analyze the effects of nuclear attack upon local utility systems and discusses methods for rapidly performing network analyses of water supply systems.

Summary

Water Supply

The water supply system in San Jose is highly dependent on electric power for well and booster pumping. However, since the San Jose Water

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* "San Jose Water Supply System--Station Damage Reports," FIVE CITY STUDY Working Papers 5S-11101-4334A-01 to -19, Stanford Research Institute, TN-OAP-101 to -119, October 1966.
"San Jose Water Supply System--General System Description Report," FIVE CITY STUDY Working Paper 5S-11101-4334A-20, Stanford Research Institute, TN-OAP-120, November 1966.
"San Jose Drainage System," FIVE CITY STUDY Working Paper 5S-11101-4334A-21, Stanford Research Institute, TN-OAP-121, December 1966.
"San Jose Sewage System," FIVE CITY STUDY Working Paper 5S-11101-4334A-22, Stanford Research Institute, TN-OAP-122, January 1967.
"San Jose Water Supply System--System Degradation Report," FIVE CITY STUDY Working Paper 5S-11101-4334A-23, Stanford Research Institute, TN-OAP-123, January 1967.

Works obtains its water supply from both groundwater and surface water sources, some residual supply capability will exist in the event that the supply of electric power is interrupted.

Immediately after attack, if power is interrupted, the water supply system will be able to supply about 2 days' normal demand in 90 percent of the service area. This will deplete available distribution storage, and after 2 days, the capability would drop to 25 percent of normal demand for an additional 47 days. This will deplete impoundment storage. Without power for well and booster pumps, water for sustained fighting of mass fire or for other high consumption rate uses would not be expected to be available at the required volumes or pressures.

In the event electric power is not interrupted or after the initial power failure was corrected, the water supply system would be able to supply 125 percent of the average August 1965 demands without depleting available distribution storage. The availability of excess pumping capacity and distribution storage would be expected to permit limited firefighting, provided that firefighting flow did not withdraw water to such an extent as to degrade the water pressure below required minimums. This provision could present a major problem in the sustained fighting of mass fire even with an undamaged water system.

After several days to, at most, a few weeks following the attack, full preattack production capacity and distribution would be expected to be available.

The lack of fallout will be a deciding factor in the postattack capability of the water system. If fallout were present, postattack manual control of the system would be difficult at best, with a resulting decrease in capability.

Sewage

The sewage collection system in San Jose was found to be only slightly dependent upon electric power, since the collection system is predominantly a gravity collection system. No significant damage is expected to occur to the collection system as a result of the attack, and therefore no postattack problem is expected to hinder the collection of sewage in the city of San Jose.

The sewage treatment plant, which performs both primary and secondary treatment, is highly dependent on electric power for its operation. The problem is different, however, from that encountered with the water supply system, since the San Jose-Santa Clara Water Pollution Control Plant produces its own power and has no provision for the importation of outside power.

The sewage treatment plant, in addition to using large amounts of power, requires large volumes of process air. Extensive damage is expected to occur to the power generation and air production equipment and the auxiliary equipment necessary for power distribution and plant control. As a result of the damage, no sewage treatment will be possible, and the sewage will therefore have to bypass the plant through an existing bypass line and discharge directly to San Francisco Bay. After some postattack emergency repair, perhaps on the order of several man-days, chlorination to attempt disinfection of the bypassed sewage may be performed.

Sufficient repair to permit primary treatment before bypassing the sewage to the bay would require perhaps on the order of a few man-years. Restoring the treatment plant's ability to perform full primary and secondary treatment and sludge handling would demand extensive reconstruction, requiring perhaps on the order of several man-years of repair and reconstruction effort.

Since no problem is expected regarding the collection of sewage in the City of San Jose, only the treatment of this collected sewage will be of concern in the postattack period. All the sewage treatment plants serving the cities of Menlo Park, Palo Alto, Mountain View, Sunnyvale, and Milpitas form a semicircle around the postulated nuclear burst; therefore the postattack sewage problem is one of regional concern, comprising water pollution control and pest-vector-odor control in the southern end of San Francisco Bay. Whether this is a significant postattack problem remains to be determined and is beyond the scope of this work unit.

Drainage

The drainage system in the City of San Jose is essentially 182 separate, predominantly gravity systems tied together by improved and unimproved natural drainage ways. No significant damage is expected from the effects of the postulated attack, hence no significant postattack problems are expected to occur with regard to the drainage system in San Jose.

II WATER SUPPLY SYSTEM

Introduction

The water supply system in San Jose was analyzed in three phases. Phase I was a development of a description of the physical components and operation of the system. Phase II was an examination of the physical damage to be expected as a result of a hypothetical nuclear attack postulated for use in the FIVE CITY STUDY. This examination viewed each Water Works facility as a separate entity and did not take into account any interactions among facilities or interactions between the water works and other utilities. Phase III was an integration over the set of physical damage estimates developed in Phase II to arrive at an estimate of the water system degradation to be expected as a result of the postulated attack. This integration took into account the interactions among the facilities of the water works and interactions between the water works and the other utilities to the extent possible.

The analysis described above is reported in detail in a series of FIVE CITY STUDY Working Papers designated by the code number 5S-11101-4334A- plus a serial number. Phase I is reported in a "System Description Report," serial number 20. Phase II is reported in a series of "Damage Reports," serial numbers 1 through 19. Phase III is reported in a "System Degradation Report," serial number 23. These working papers are summarized in the following sections of this chapter.

General Service Data

The San Jose Water Works is a privately owned corporation operating under the regulation of the Public Utilities Commission of the State of California to serve 93 percent of the incorporated City of San Jose and its environs. All of the 118 square miles of service area are located within Santa Clara County and include the cities of San Jose, Los Gatos, Monte Sereno, Saratoga, and parts of Campbell, Cupertino, and Santa Clara. Elevations in the service area range from 30 feet to over 1,200 feet above sea level. The bulk of the area served, however, lies between 50 and 250 feet of elevation. The consumer population was estimated in December 1965 to be 457,000 persons, with a total of 120,417 water meters in the system. During the calendar year 1965, 25,531 million gallons of water were produced with an average daily production rate of 69.9 million gallons and a maximum daily rate of [illegible]3.4 million gallons. A total of 51.19 million kilowatt hours of power were purchased during the year.

The system has a designed gravity capability of 27.6 million gallons per day (mgd) and a designed pumped capacity of 225.6 mgd.

Organization

The San Jose Water Works is divided into a Business Department and an Engineering and Operations Department managed by a President and Board of Directors. The Engineering and Operations Department is further divided into a Planning Division, Engineering Design Division, Construction Division, Maintenance and Operation Division, and a Procurement, Stores, and Inventory Section.

The total employment of the San Jose Water Works is about 225. Of these, about 5 percent are management, 29 percent are involved with business operations, 12 percent with planning and engineering design, 7 percent with construction, and 47 percent with operations and maintenance.

A cursory examination of the residence locations of the San Jose Water Works personnel as determined by their telephone exchanges does not reveal any particular distribution of residences other than random, except that the executives tend to live in the western and eastern foothill sections of the area rather than in central San Jose.

Operation and Maintenance

The water supply is developed from groundwater and surface water sources. In the year 1965, 79 percent of the water produced came from wells, and the remainder came from creeks and rivers. Because of topography, the service area is divided into 29 pressure zones. The surface water supply can flow by gravity to much of the service area; from there, it can be transferred to higher or lower adjoining areas by pumping or by gravity flow, depending upon the arrangement of the pipeline network and boosters. Groundwater supplies are similarly handled: the well water is pumped directly to several pressure zones, and from there, it can be transferred to other zones by pumping or by gravity flow. The flow diagram, Figure 1, outlines the transmission of the source supplies and the transfer of supplies by gravity flow or by pumping from one zone to another.

The Water Works has recently installed a comprehensive central computer control, which operates the principal functions of the water system automatically according to a prearranged program. The central control continuously monitors the functions and makes the necessary changes in the operation of the system to maintain required pressures and flows. This control system depends on use of leased telephone lines.

Prior to the installation of the central control system or at the time of the hypothetical nuclear attack (late summer of 1965), most of the system was still operated automatically, but not from a central control. Preset float level controls in distribution and collection reservoirs automatically activated boosters and well pumps to fill the reservoirs when the levels reached a certain minimum elevation, and to shut off the pumps when the reservoirs were full. In case the float level devices failed to operate as planned, overriding pressure controls turned off pumps supplying water to the various zones in the distribution system. Generally, the facilities releasing surface water supplies were regulated manually. Dam tenders at the impoundment reservoirs released water according to a predetermined schedule and as modified by direction of field operating personnel from observations of changes in demand. All operational parts of the system, whether operated manually or automatically, were visited at least once every eight hours. At these visits, manually operated gate valves for the control of surface water flows were adjusted to suit the predetermined surface water and groundwater supply schedule. Adjustments, as needed, in the automatic operational controls were also made during these visits to better suit existing supply and demand conditions.

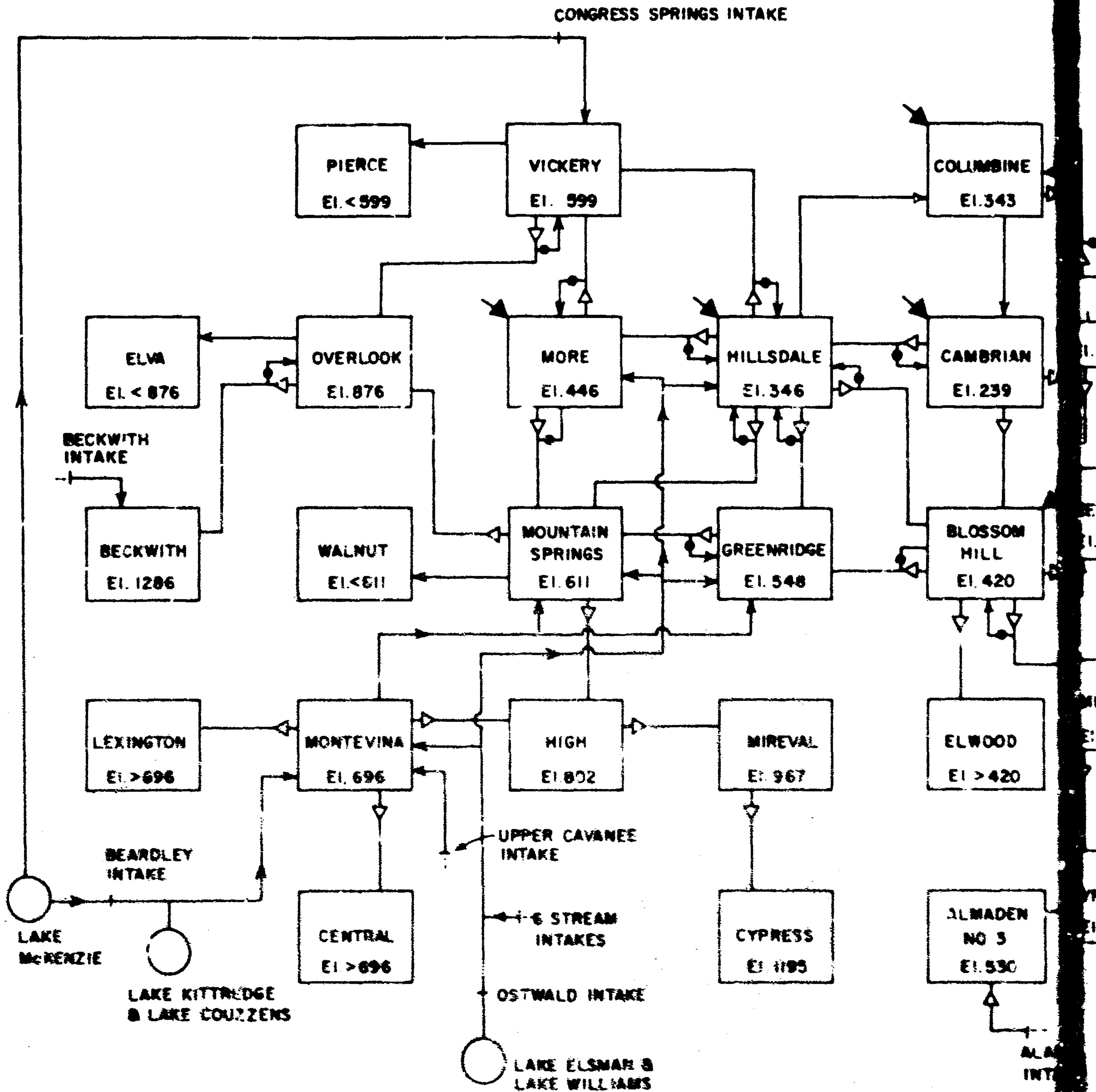
The main office of the Company is located at 374 West Santa Clara Street, San Jose, California. All clerical and engineering functions are performed at this location, including customer accounting and the preparation of customer bills. In addition, the Company's meter shop and materials handling department are at this address. Deliveries of most of the materials used in the construction program are scheduled to permit unloading at the construction site. Stockpiling of large quantities of pipe and other construction materials is not practiced.

Most operation and maintenance work on the water system is performed by Company personnel. This includes practically all of the main and service repairs, meter reading, meter testing and repairing, stores handling, and other related work. Gardening and weed control, maintenance of wells, pumping equipment, and automotive equipment, and repairs to reservoirs and tanks are performed by independent contractors.

The Company employs a 20-man daytime work force for the performance of normal service calls and nine 3-man crews for routine maintenance projects. During the period outside regular working hours, one man is on duty to investigate emergency calls, which are relayed to him from a telephone answering service. He may request assistance as needed from the daytime maintenance force.

Construction work is performed by independent contractors. Mains up to and including 8 inches in diameter, services, meters, and hydrants are installed under a master contract. Reservoirs, wells, pumps, electrical installations, and mains over 8 inches in diameter are handled under contracts awarded by the bidding process.

Operation and maintenance operations are aided considerably by the use of two-way radio communications. The mobile units are powered by each vehicle's electrical system. Communication is possible between mobile units if distances are not too great. A repeater station is maintained on a nearby mountain peak to relay signals to and from more remote areas.

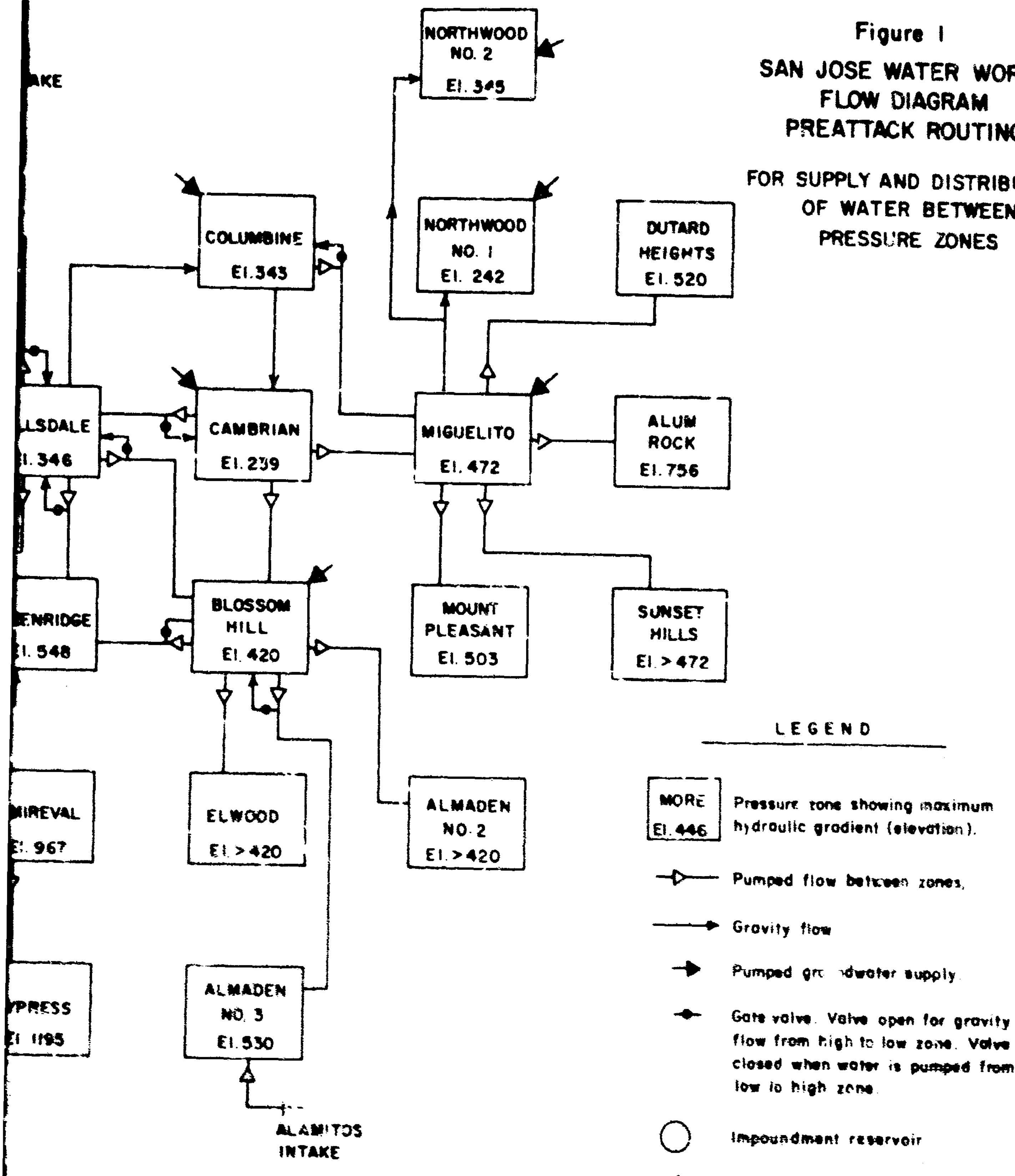


CONGRESS SPRINGS INTAKE
PIERCE
El. < 599
VICKERY
El. 599
COLUMBINE
El. 343
ELVA
El. < 876
OVERLOOK
El. 876
MORE
El. 446
HILLSDALE
El. 346
CAMBRIAN
El. 239
BECKWITH INTAKE
BECKWITH
El. 1286
WALNUT
El. < 611
MOUNTAIN SPRINGS
El. 611
GREENRIDGE
El. 548
BLOSSOM HILL
El. 420
LEXINGTON
El. > 696
MONTEVINA
El. 696
HIGH
El. 802
MIREVAL
El. 967
ELWOOD
El. > 420
UPPER CAVANEE INTAKE
BEARDLEY INTAKE
LAKE McKENZIE
LAKE KITTREDGE & LAKE COUZZENS
CENTRAL
El. > 696
6 STREAM INTAKES
CYPRESS
El. 1195
ALMADEN NO 3
El. 530
OSTWALD INTAKE
LAKE ELSMAN & LAKE WILLIAMS

Figure I

SAN JOSE WATER WORKS FLOW DIAGRAM PREATTACK ROUTING

FOR SUPPLY AND DISTRIBUTION OF WATER BETWEEN PRESSURE ZONES



The Supply Complex

The water system consists of supply sources, transmission facilities, treatment facilities, and a distribution system. The supply sources include (1) a surface supply from five impoundment reservoirs along with several direct stream diversions, and (2) a groundwater supply from wells located at 52 sites within the service area. Transmission facilities transport the source supplies to the distribution system. The water treatment facilities are generally used for treating only the surface supplies. The distribution system consists of a pipeline network subdivided into 29 pressure zones, in which water is transported from one zone to another by means of boosters and pressure regulators. Distribution storage reservoirs are located at 45 sites in the city.

Water Supply

Sources

The system has a design water production capacity of 253.2 mgd, of which 27.6 mgd can be supplied from gravity surface water sources and 225.6 mgd can be supplied from pumped groundwater sources.

The surface water supplies are derived from streamflow. These supplies are transported to the service areas from direct stream diversions and from storage in impoundment reservoirs. During the dry month of August, streamflow is negligible. The surface water supply at this time must come entirely from impoundment reservoir storage.

The groundwater supplies are produced by numerous wells located in eight pressure zones.

In addition to the primary production sources of surface water and groundwater, the distribution reservoirs located in most of the pressure zones provide a short term supply source (about 1-2 days average normal demand).

Reservoir Storage

Surface water impoundment reservoirs provide holdover storage for a supply of water when streamflow is deficient. Distribution reservoirs contain water for use during peak demand.

The total capacity of the five impoundment reservoirs is 2,291 million gallons. These reservoirs are operated to fill during the rainy months of November through April and to release water to the system during the dry period, May through October. Some water is released during the winter months as these reservoirs are readily filled from normal rainfall runoff. Water is released during the 6-7 month dry period according to a pre-established schedule, with reservoirs being nearly empty at the end of the period. Table 1 shows the capacity of each impoundment reservoir and the amount that each contained on August 24, 1965, the date of the hypothetical nuclear attack. The system's maximum supply rate from the impoundment reservoirs is 23.5 million gallons per day. There are 11 pressure zones, making up approximately 89 percent of the total service area, which can be served by gravity flow from the impoundment reservoirs. Table 2 lists those zones that can be served directly from the reservoirs and those that can be indirectly supplied. Water flows through the directly supplied zones to the indirectly supplied zones.

Distribution reservoirs are provided in most pressure zones to maintain distribution system pressures and to provide sufficient gravity flow water during peak demand. Only a few small minor pressure zones are without direct gravity storage. The distribution reservoirs generally function primarily for the benefit of the pressure zones in which they are located. However, depending upon the arrangement of the pipeline network, valves, and boosters, much of the stored water can be transferred to other zones. In normal operation, excluding periods of high emergency demands such as required for firefighting, the reservoirs are drained during the daytime, reaching their minimum levels at about 8:00 pm. The reservoirs fill during the night when water usage is low. Table 3 gives the total distribution storage capacity within each pressure zone and the amount of storage available at 8:52 pm on August 24, 1965, the time of the

Table 1

IMPOUNDMENT RESERVOIR STORAGE

	Amount in Reservoirs (million gallons)	
	Full Capacity	At Attack
Lake Elsman	2,005	903
Lake Williams	51	51
Lake Kittredge	80	65
Lake Couzzens	50	50
Lake McKenzie	105	100
Total	2,291	1,169

Table 2

ZONES SERVED BY GRAVITY FLOW
FROM IMPOUNDMENT RESERVOIRS

Supplied Directly	Supplied Indirectly
Montevina	Blossom Hill
Mountain Springs	Cambrian
Greenridge	Columbine
More	Pierce
Hillsdale	Walnut
Vickery	

Table 3

DISTRIBUTION RESERVOIR STORAGE

Primary Pressure Zones	Amount in Reservoirs (million gallons) Full Capacity	At Attack
Major		
Alum Rock	1.80	1.44
Blossom Hill	21.02	16.82
Cambrian	23.84	19.07
Columbine	21.57	17.26
Greenridge	3.83	3.06
Hillsdale	49.61	39.69
Miguelita	8.78	7.03
Montevina	9.57	7.66
More	44.33	35.46
Mt. Pleasant	0.20	0.16
Mountain Springs	5.02	4.02
Overlook	4.03	3.22
Vickery	13.64	10.91
Minor		
Almaden No. 2	0	0
Almaden No. 3	0.10	0.08
Beckwith	0.11	0.09
Central	0	0
Cypress	0.04	0.03
Dutard Hts.	0.10	0.08
Elva	0	0
Elwood	0	0
High	0.10	0.08
Lexington	0	0
Mireval	0.08	0.06
Northwood No. 1	1.00	0.80
Northwood No. 2	1.50	1.20
Pierce	0	0
Sunset Hills	0	0
Walnut	0	0
Total	210.27	168.22

hypothetical nuclear attack. The storage amount at 8:52 pm is estimated to be 80 percent of full reservoir capacity, as indicated by a random review of records for several of the larger reservoirs.

Groundwater Supply

There are 159 wells in the groundwater production system. Most of the wells pump water into small collection tanks at the ground surface. The collected supplies are boosted into the pressure distribution system. Table 4 gives the groundwater production capacity pumped into each pressure zone. All well pumps are powered by electric motors and there are no auxiliary means of pumping.

It should be noted that the full capacity of 225.6 mgd cannot be counted on at any given time or cannot be available continuously over a sustained period of time. Some wells are shut down because of equipment repair and maintenance. The well system is designed for intermittent operation and cannot deliver full capacity continuously over a prolonged period of time because of excessive drawdown of the groundwater supply. The capacity rate for continuous sustained pumping at any given time is not known, but it is assumed to be on the order of 70 to 80 percent of the total design capacity.

Table 4

PREATTACK GROUNDWATER PRODUCTION CAPACITY

Pressure Zone	Capacity Gal/Min	Capacity Mgd
Blossom Hill	7,450	10.73
Cambrian	59,065	85.05
Columbine	14,855	21.39
Hillsdale	61,940	89.19
Miguelito	300	0.43
More	7,755	11.17
Northwood No. 1	2,615	3.77
Northwood No. 2	2,660	3.83
Total	156,640	225.56

Water Treatment Facilities

The surface water collected is chlorinated before being distributed to customers. In addition, the surface water supply from the Alamitos and Saratoga Creeks is filtered by means of diatomaceous earth filter plants. Periodic tests of chlorine residual and coliform index are made by the San Jose Water Works as well as by the County Health Department, to ensure the safety of the water supply.

Since the well water is either pumped directly into the system or stored in covered reservoirs and tanks, it is not normally chlorinated or filtered.

Booster Facilities

In order to serve water at a higher gradient than that in which it is produced, and also to lift water from one pressure zone to a higher zone, many boosting pump arrangements are employed. There are 89 line boosters located at 41 stations to lift water from one zone to another, and 48 supply source boosters (generally at well production sites) at 29 stations to lift supply source water to a pressure zone. Pumping equipment includes vertical and horizontal submersible pumps, deep well and close-coupled turbine pumps, and horizontal centrifugal pumps. All units are powered by electric motors. There is no provision within the San Jose Water Works for alternate sources of power to operate booster facilities. Table 5 gives the booster capacity for transferring water from one zone to another.

Distribution Pipeline Facilities

A complex pipeline network distributes water of the San Jose Water Works. As of 31 December 1965, there were approximately 1,522 miles of transmission and distribution mains within the system, ranging in size up to 48 inches in diameter. A general idea of the composition of the system may be obtained from the tabulations contained in Tables 6 and 7.

Table 5

PREATTACK INTERZONAL BOOSTER CAPACITY

Interzonal Lift	Capacity Gal/Min	Capacity Mgd
Blossom Hill to Almaden No. 2	100	0.14
to Almaden No. 3	200	0.29
to Elwood	700	1.01
to Greenridge	1,900	2.74
Cambrian to Blossom Hill	4,865	7.01
to Hillsdale	14,100	20.30
to Miguelito	4,900	7.06
Columbine to Miguelito	1,510	2.17
Greenridge to Mt. Springs	2,720	3.92
High to Mireval	70	0.10
Hillsdale to Blossom Hill	3,550	5.11
to Greenridge	4,915	7.08
to More	15,620	22.49
to Mt. Springs	5,580	8.04
to Vickery	5,950	8.57
Miguelito to Alum Rock	1,200	1.73
to Dutard Heights	250	0.36
to Mt. Pleasant	350	0.50
to Sunset Hills	140	0.20
Mireval to Cypress	70	0.10
Montevina to Central	60	0.09
to High	100	0.14
to Lexington	100	0.14
More to Vickery	3,760	5.42
Mt. Springs to High	160	0.23
to Overlook	2,700	3.89
Overlook to Beckwith	260	0.37
Vickery to Overlook	2,990	4.31

Table 6

PIPELINE SYSTEM COMPOSITION BY SIZE OF MAIN

Size of Main (inches)	Percent of Total	Size of Main (inches)	Percent of Total
To 6	58.3	20	2.1
8	13.2	22	0.6
10	4.2	24	2.2
12	11.9	30	0.7
14	0.2	36	0.6
16	2.7	42	0.2
18	3.4	48	0.3

Table 7

PIPELINE SYSTEM COMPOSITION BY PIPE TYPE

Pipe Type	Percent of Total
Steel--cement lined--cement or tar coated	85.2
Cast iron--cement lined	12.0
Asbestos cement	2.8

The Fire Underwriters report of 1962 is quoted as follows:

"No pipe smaller than 6 inches is being installed for hydrant supply. Of the 781.2 miles of pipe in the city, 142.1 are 4 inch, of which 130.0 supply hydrants, and 332.5 miles are 6 inch; dead ends in those sizes total 16.9 miles. All except the single outlet hydrants have 6 inch laterals; all laterals have a valve. The average area served by each hydrant is 58,500 square feet in the business district and 237,000 square feet in residential districts. Hydrants are inspected bi-annually."

There are 7,440 fire hydrants located within the San Jose Water Works system. Maintenance of these hydrants is the responsibility of either the City or the San Jose Water Works by mutual agreement.

At nearly one hundred points in the system, the pipeline is exposed at creek crossings and at one railroad crossing. Most of the system is looped with a good grid system which will provide alternate sources of supply to any given large service area. The San Jose Water Works organization supplies several smaller water systems, which also have their own additional sources of supply. While no significant excess capacity exists in these systems, they could at least theoretically supplement the supply of the San Jose Water Works. These other agencies include the Santa Clara Municipal Water District, the Campbell Water Company, the San Jose Evergreen System, and the Los Altos System.

In the distribution system, there are nearly 900 miles of mains that are 6 inches and smaller in diameter. These mains strengthen the water delivery potential of the network by paralleling larger lines and completing system loops. While old mains of size 2 inches or less are still in service, they are being replaced by larger sizes. The minimum size main being installed at present is 4 inches in diameter. The sizing of pipe is calculated to allow for peak hour design flows and fire demand rates.

Virtually all of the system is metered. The normal domestic meter is the standard 3/4 inch size. Copper service lines are used exclusively. Air release valves are placed in protective boxes. The number of gate valves used at intersections is usually one less than the number of intersecting lines.

The depth of soil cover on top of transmission and distribution piping varies from 3 to 5 feet. Most of the pipe is laid in a heavy clayey sand soil. This material stands in vertical cuts during trenching operations and recompacts well.

Production Requirements

The demand of the consumers plus system losses during the year 1965 required that a total of 25,531 million gallons be produced. The average daily production rate and the maximum daily rate for 1965 were 69.9 million gallons and 123.4 million gallons, respectively. The system's annual average daily rate was broken down for each pressure zone, on the basis of actual records for several larger zones and estimates of area relationships for the remaining zones. Records indicate that for the month of August 1965, the average daily rate was 146 percent of the annual average daily rate. Table 8 gives the average daily production requirements for the year 1965 and for the month of August 1965 for each pressure zone.

Expected Damage

Weapons Effects

Following are the maximum weapons effects expected to be experienced by the physical facilities of the San Jose Water Works, which are located at approximately 139 separate locations, as a result of the hypothetical attack postulated for the first iteration of the FIVE CITY STUDY:

1. Static Overpressure	
Incident	Up to 2.7 psi
Reflected	Up to 3.1 psi
2. Dynamic Overpressure	Less than 0.3 psi
3. Equivalent Wind Speed	Less than 100 mph
4. Thermal Radiation	Up to 30 cal/cm^2
5. Initial and Residual Radiation	None
6. Electromagnetic Pulse	None
7. Groundshock	None

Table 8

WATER PRODUCTION REQUIREMENTS FOR PRESSURE ZONES

Pressure Zones	For Year 1965	For August 1965	Approximate Area Served (sq mi)
Major			
Alum Rock	0.40	0.58	*
Blossom Hill	6.80	9.91	18
Cambrian	17.59	25.62	20
Columbine	5.40	7.87	13
Greenridge	2.20	3.21	2
Hillsdale	19.30	28.11	32
Miguelito	2.09	3.04	4
Montevina	0.69	1.00	1
More	6.30	9.18	9
Mt. Pleasant	0.10	0.15	*
Mountain Springs	2.30	3.35	5
Overlook	1.90	2.77	5
Vickery	2.90	4.23	6
Minor			
Almaden No. 2	0.05	0.07	*
Almaden No. 3	0.05	0.07	*
Beckwith	0.05	0.07	*
Central	0.05	0.07	*
Cypress	0.02	0.03	*
Dutard Heights	0.05	0.07	*
Elva	0.05	0.07	*
Elwood	0.08	0.12	*
High	0.05	0.07	*
Lexington	0.05	0.07	*
Mireval	0.04	0.06	*
Northwood No. 1	0.50	0.73	*
Northwood No. 2	0.75	1.09	*
Pierce	0.05	0.07	*
Sunset Hills	0.05	0.07	*
Walnut	0.05	0.07	*
Total	69.91	101.82	118

* Less than 1 square mile.

Damage

Of the approximately 139 separate physical facilities of the San Jose Water Works, 19 stations are expected to be damaged. The damaged stations consist of well production, booster, and distribution storage facilities. No impoundment reservoirs, stream intakes, or treatment facilities are expected to be damaged. Pipelines are also not expected to be damaged even though these emerge to ground level and are exposed in approximately 100 locations. The significant damage expected at the 19 stations consists mainly of blown down electric power service drops causing station power outage and damaged reservoir float level devices--damage which would preclude automatic operation of well pumps and boosters. Many of the damaged facilities could be repaired by emergency measures during the first few days following the hypothetical attack.

System Degradation

Postattack Situations

Two situations were examined in order to determine the postattack capacity of the San Jose Water Works to supply water to the system's 29 pressure zones. The first situation assumed that degradation of the system capability was due only to damage sustained by the 19 stations from the direct effects of the hypothetical attack. It was further assumed that no emergency repairs or special operational procedures were carried out. The second situation assumed that degradation of the capability was due not to direct damage sustained by the water system, but rather to a loss of power supply which would prevent the operation of well and booster pumps.

In both situations, the surface water supply is the same as preattack. Stored water is available in the five impoundment reservoirs and can be supplied to the service area at the maximum rate of 23.5 mgd. Natural streamflow is assumed negligible. Distribution storage is unaffected

Damaged Station Situation

Groundwater production is reduced from a total preattack capacity of 225.6 million gallons per day to 138.48 mgd because of damaged facilities in the Cambrian, Hillsdale, More, Miguelito, Northwood No. 1, and Northwood No. 2 pressure zones. Groundwater production within the Blossom Hill and Columbine pressure zones is unaffected by the burst. Table 9 shows how the inoperable groundwater production stations affect the total groundwater production capacity in each of the pressure zones.

Table 9

REDUCTION OF GROUNDWATER PRODUCTION CAPACITY

Pressure Zone	Preattack Capacity (mgd)	Postattack Capacity (mgd)	Number of Damaged Stations
Cambrian	85.05	51.36	4
Hillsdale	89.19	46.03	6
Miguelito	0.43	0.00	1
More	11.17	8.97	3
Northwood No. 1	3.77	0.00	2
Northwood No. 2	3.83	0.00	1

Transfer of water from one zone to a higher zone is limited by the capacity of the boosters. The interzonal booster capacity is reduced in this situation for three interzonal transfers. Table 10 shows these reductions. All other interzonal transfers are unaffected and remain as shown in Table 5.

Table 11 summarizes the surface and groundwater supplies available in this damaged station situation. The demand, average daily rate in August 1965, for each pressure zone is shown in Table 8.

An interzonal flow distribution study was made to determine how well the available supplies could meet the immediate postattack demands. The flow chart, Figure 2, shows the flow routings and flow rates for this situation. The study used only the two primary supply sources--impoundment storage and groundwater production facilities--which will be capable of delivering supplies over a prolonged period of time. The flow inputs and outputs for each pressure zone are balanced.

Table 10

REDUCTION OF INTERZONAL BOOSTER CAPACITY

Pressure Zone	Preattack Capacity (mgd)	Postattack Capacity (mgd)	Number of Damaged Stations
Hillsdale to More	22.49	3.63	1
More to Vickery	5.42	3.82	3
Miguelito to Dutard Heights	0.36	0.00	1

The analysis shows that the damage prevailing immediately after the attack does not appreciably degrade the system's capability of supplying water for normal average demands as operated under normal procedures. The system's preattack excess capacity easily takes over damaged facility functions except in one small area, the Dutard Heights pressure zone. There is no supply into this zone because of damaged controls for the supply booster at the Dutard reservoir site. The exception is of minor consequence since the supply booster can be operated by manual control and there is approximately one day's storage available in the zone's distribution reservoir.

For the extreme damage condition (no emergency repair or operating procedures), the average daily demands of August 1965 are met in practically the entire system by withdrawing impoundment storage at the maximum rate of 23.5 mgd and by pumping groundwater at the rate of 78.3 mgd, which is 56.5 percent of the total capacity of the undamaged wells. Distribution reservoir storage, not used in the analysis, is available as a short term supply. An appreciable amount of supply remains unused that is

Table 11

POSTATTACK WATER SUPPLY
(Damaged Station Situation)

Pressure Zones	Reservoir Storage: Impoundment (million gal)	Reservoir Storage: Distribution (million gal)	Groundwater Production Capacity (mgd)
Blossom Hill		16.82	10.73
Cambrian		19.07	51.36
Columbine		17.26	21.39
Greenridge		3.06	0
Hillsdale		39.69	46.03
Montevina	1,169.00	7.66	0
More		35.46	8.97
Mountain Springs		4.02	0
Vickery		10.91	0
Pierce		0	9
Walnut		0	
Subtotal	1,169.00	153.95	138.48
Almaden No. 2	0	0	0
Almaden No. 3	0	0.08	0
Alum Rock	0	1.44	0
Beckwith	0	0.09	0
Central	0	0	0
Cypress	0	0.03	0
Dutard Heights	0	0.08	0
Elva	0	0	0
Elwood	0	0	0
High	0	0.08	0
Lexington	0	0	0
Miguelito	0	7.03	0
Mireval	0	0.06	0
Mt. Pleasant	0	0.16	0
Northwood No. 1	0	0.80	0
Northwood No. 2	0	1.20	0
Overlook	0	3.22	0
Sunset Hills	0	0	0
Total	1,169.00	168.22	138.48

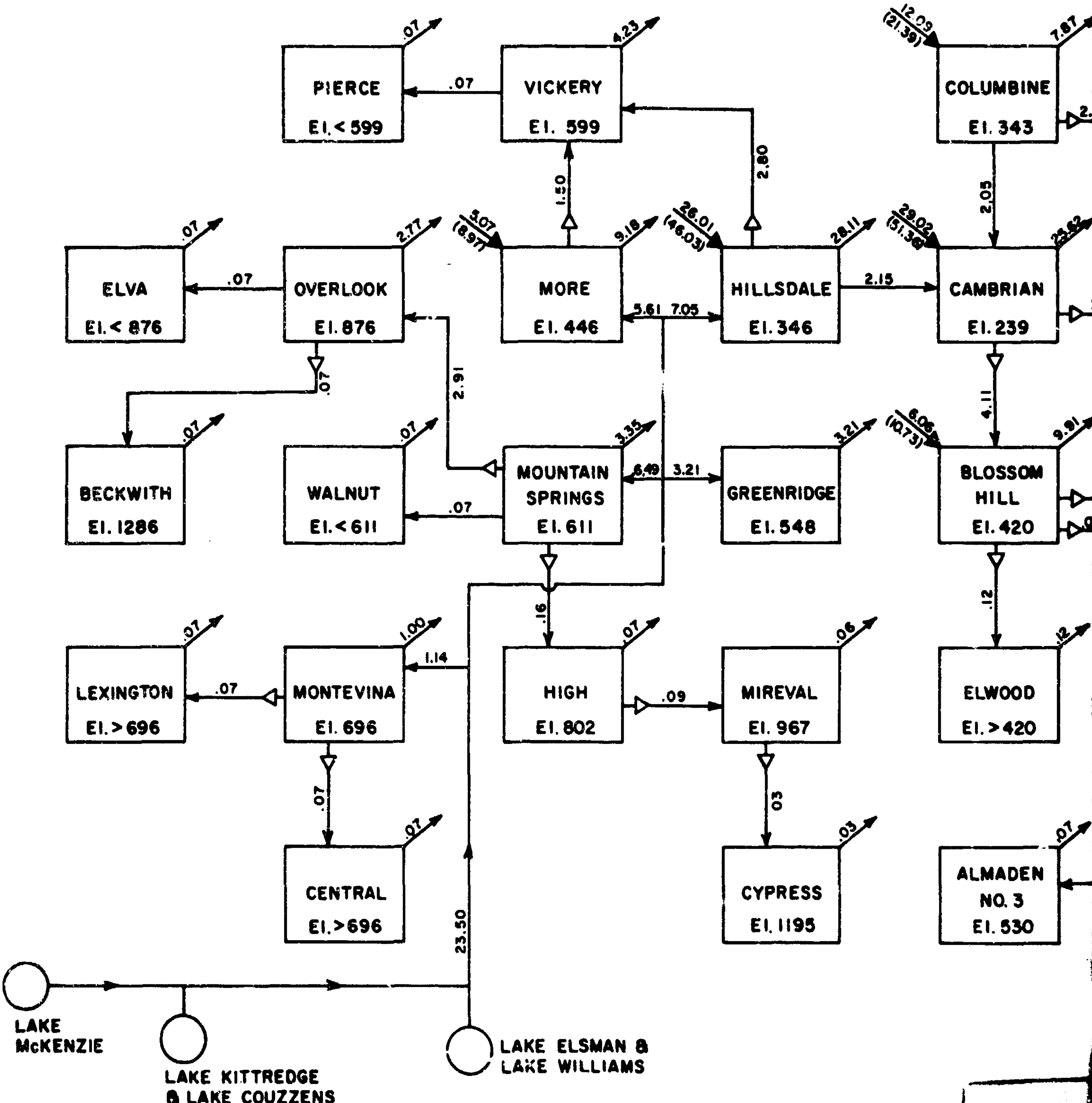
available for above-normal demand. This includes 18.5 percent of the undamaged well capacity (assuming that only 75 percent is available for sustained pumping), or an equivalent of 25.6 mgd plus distribution reservoir storage.

Full preattack production capacity and distribution are attained within several days after the attack, by making first aid repairs and by manually controlling those facilities that cannot be restored to automatic operation.

Power-off Situation

In the event of complete power outage as a result of the hypothetical nuclear attack, the electric powered pumps for the production of groundwater and for interzonal boosting would cease operating. The water supply and distribution in this instance would be derived from gravity flow of storage available in impoundment and distribution reservoirs. Natural streamflow for diversion into the system is negligible at the time of the hypothetical attack (dry season). The flow chart, Figure 3, shows the gravity flow distribution of the stored water. Not shown are possible routings that would not be effective in this situation of supply and demand.

Most of the flow routings shown on Figure 3 are used in the normal operation of the system. However, to accomplish the optimum distribution in this no-power situation, some changes in valve operation (resulting in rerouting of flows) would be made. For example, the normal release of Lake McKenzie storage is south through Beardsley intake and thence into Montevina reservoir. Emergency operation would require that the storage be released northward, to be picked up by Congress Springs intake and thence transported into the Vickery pressure zone. Vickery zone is normally supplied by pumping from the More zone. In the emergency situation where water would be received by gravity from a higher zone in lieu of normal booster pumping from a lower zone, care would have to be taken that the flow was shut off in the upper zone when the lower reservoir was full. This would prevent overflowing of the lower reservoir if it was not protected



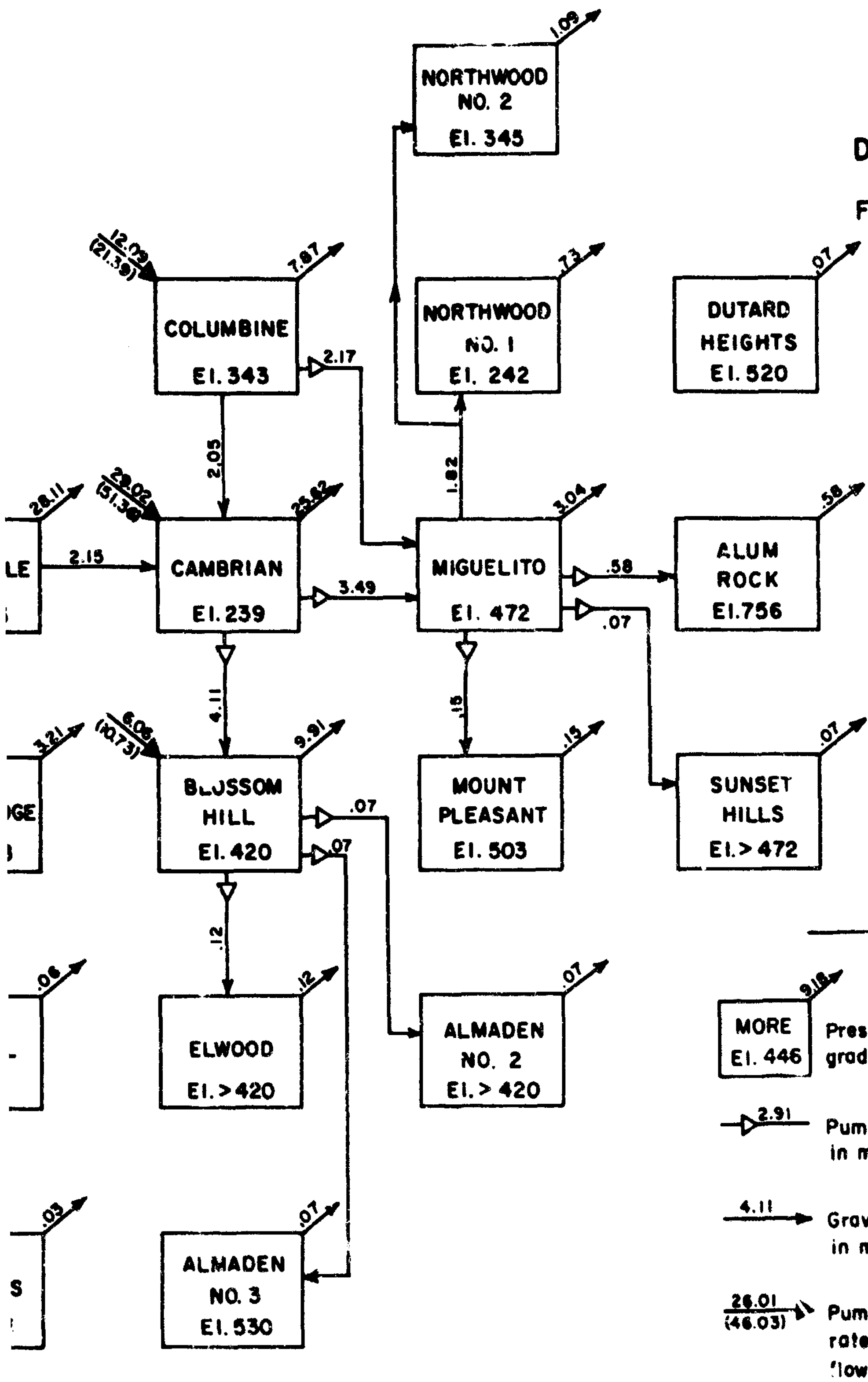
PIERCE
El. < 599
VICKERY
El. 599
COLUMBINE
El. 343
ELVA
El. < 876
OVERLOOK
El. 876
MORE
El. 446
HILLSDALE
El. 346
CAMBRIAN
El. 239
BECKWITH
El. 1286
WALNUT
El. < 611
MOUNTAIN
SPRINGS
El. 611
GREENRIDGE
El. 548
BLOSSOM
HILL
El. 420
LEXINGTON
El. > 696
MONTEVINA
El. 696
HIGH
El. 802
MIREVAL
El. 967
ELWOOD
El. > 420
CENTRAL
El. > 696
CYPRESS
El. 1195
ALMADEN
NO. 3
El. 530
LAKE
McKENZIE
LAKE KITTREDGE
& LAKE COUZZENS
LAKE ELSMAN &
LAKE WILLIAMS
.07
4.23
12.09
(21.39)
7.87
1.50
2.80
2.05
5.07
(8.97)
9.18
26.01
(46.03)
28.11
29.02
(51.36)
2.15
2.77
5.61
7.05
2.91
4.11
6.06
(10.73)
9.91
3.35
6.49
3.21
.16
.12
1.00
1.14
.09
.06
03
.03
23.50

1

Figure 2

SAN JOSE WATER WORKS FLOW DIAGRAM DAMAGED SYSTEM ROUTING

FOR SUPPLY AND DISTRIBUTION OF WATER BETWEEN PRESSURE ZONES



LEGEND

9.18 MORE El. 446 — Pressure zone showing maximum hydraulic gradient (elevation) and demand rate in mil gal/day

2.91 — Pumped water transfer and flow rate in mil gal/day

4.11 — Gravity water transfer and flow rate in mil gal/day

26.01 (46.03) — Pumped groundwater supply and flow rate in mil gal/day. Maximum capacity flow rate in parenthesis.

Impoundment reservoir

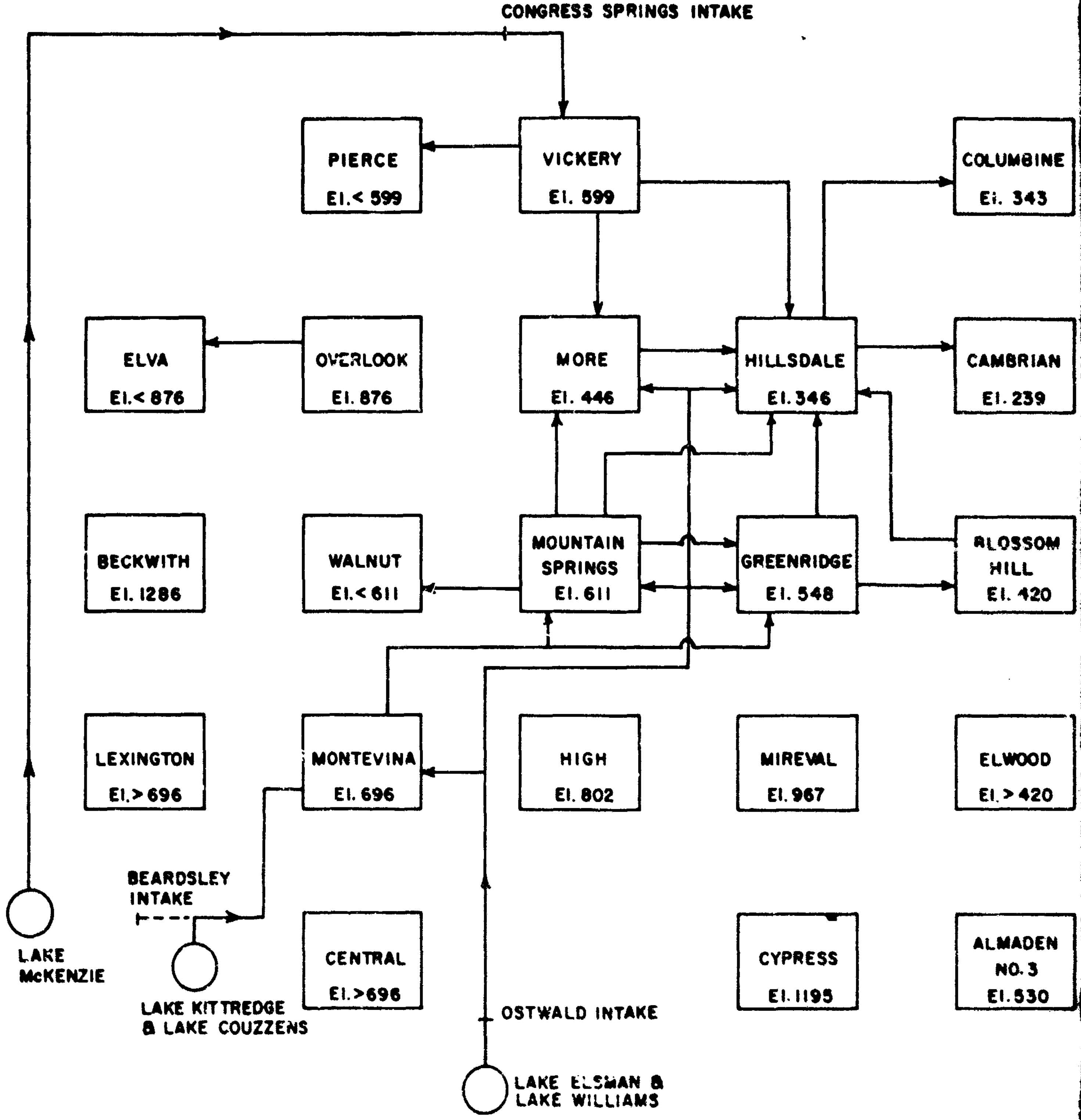
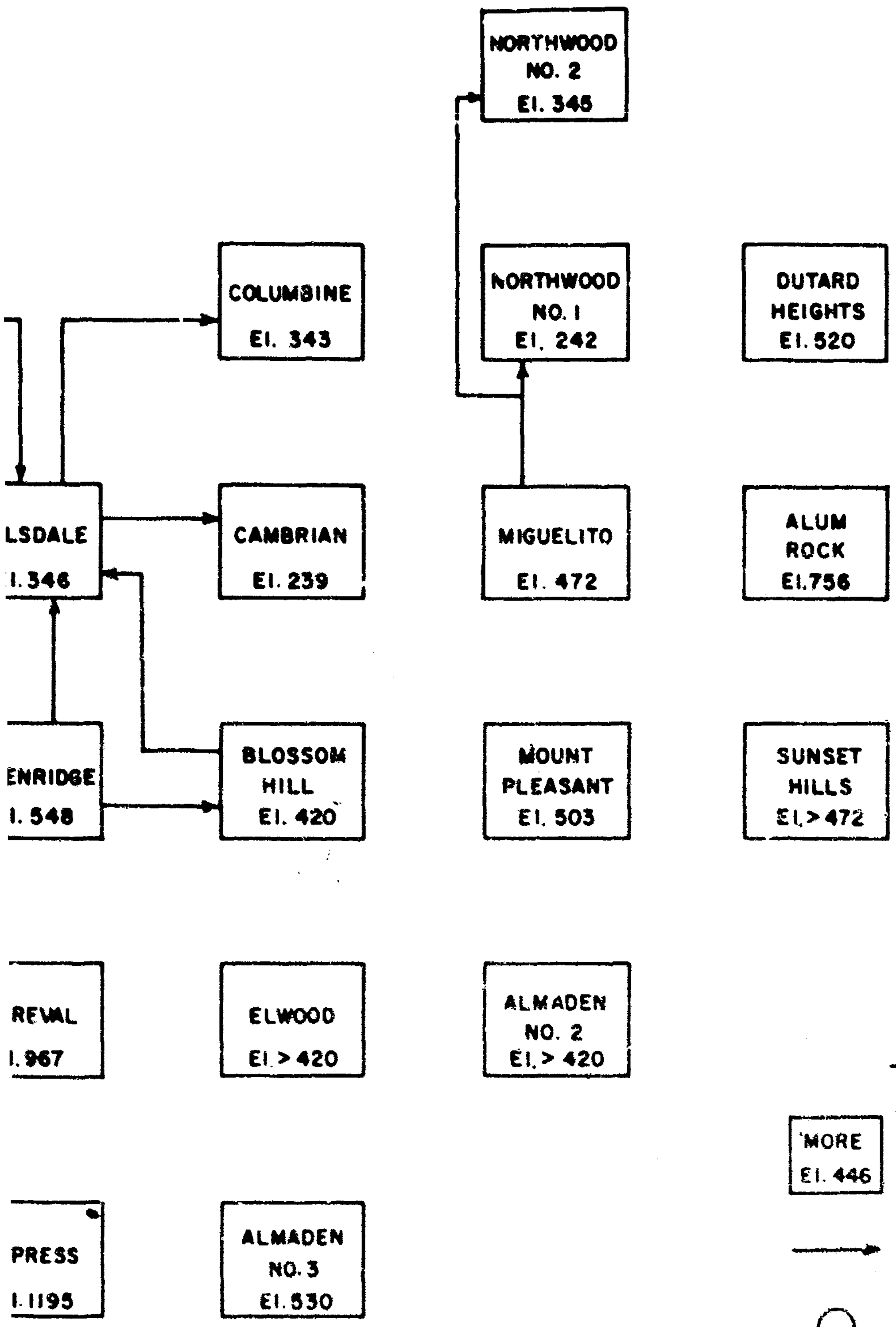
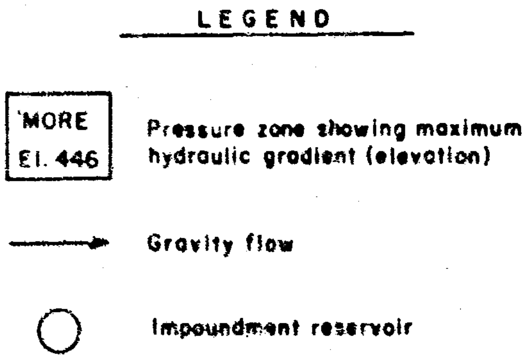

CONGRESS SPRINGS INTAKE
PIERCE
El. < 599
VICKERY
El. 599
COLUMBINE
El. 343
ELVA
El. < 876
OVERLOOK
El. 876
MORE
El. 446
HILLSDALE
El. 346
CAMBRIAN
El. 239
BECKWITH
El. 1286
WALNUT
El. < 611
MOUNTAIN
SPRINGS
El. 611
GREENRIDGE
El. 548
BLOSSOM
HILL
El. 420
LEXINGTON
El. > 696
MONTEVINA
El. 696
HIGH
El. 802
MIREVAL
El. 967
ELWOOD
El. > 420
BEARDSLEY
INTAKE
LAKE
McKENZIE
LAKE KITTREDGE
& LAKE COUZZENS
CENTRAL
El. > 696
CYPRESS
El. 1195
ALMADEN
NO. 3
El. 530
OSTWALD INTAKE
LAKE ELSMAN &
LAKE WILLIAMS

Figure 3
SAN JOSE WATER WORKS
FLOW DIAGRAM
POWER-OFF ROUTING

FOR SUPPLY AND DISTRIBUTION
OF WATER BETWEEN
PRESSURE ZONES





by an altitude valve, and would prevent excessive static pressure buildup in the lower system's pipelines when the lower reservoir was valved off.

An examination of Figure 3 shows the 11 pressure zones, making up 89 percent of the total service area, that would be supplied from the impoundment reservoirs and from their own distribution reservoirs. The remaining 18 zones, making up 11 percent of the total area, are the critical areas since they either are entirely without storage supply or have only a short term water supply from their own distribution reservoirs. These critical zones are mainly small minor zones, which are located at higher elevations around the periphery of the service area, and which are normally supplied by boosters pumping from lower adjacent zones. Some of these small peripheral zones are supplied by direct diversion of natural streamflow when this supply source is available.

The amount of stored supply available for distribution at the time of the hypothetical nuclear attack is shown in the first two columns of Table 11. The demand, average daily rate in August 1965, is shown in Table 8.

The 11 pressure zones that would be supplied from both impoundment and distribution storage (the top 11 listings in Table 11) have a total of 1,322.95 million gallons (1,169 million gallons of impoundment storage and 153.95 million gallons of distribution storage) available to supply a normal August usage rate of 92.62 mgd. The interconnections of pressure zones by pipelines permit interzonal gravity distribution of supplies. The maximum supply rate from impoundment storage is 23.5 mgd, as limited by the physical works.

Of the 92.62 mgd requirement, 23.5 mgd would be furnished from impoundment storage, leaving 69.12 mgd to be supplied from distribution storage. By supplying the full normal demand for as long as the storage holds out, the water system would be faced with two flow-duration conditions:

1. Supply from impoundment storage at maximum rate of 23.5 mgd would last for 49.7 days.
2. Supply from distribution storage at rate of 69.12 mgd would last 2.2 days.

Thus, the supplies from both reservoir storage sources would be capable of satisfying the full normal demand of 92.62 mgd for 2.2 days following the attack; and thereafter, the remaining impoundment reservoir supplies would be available for an additional 47.5 days, at the rate of 23.5 mgd--or approximately 25 percent of the normal demand.

Rationing of water to the consumers would be the logical course to pursue in a crisis situation where the supplies were drastically reduced. For example, assuming a reduction of 50 percent in the normal demand--equivalent to 46.31 mgd--the two storage sources could serve this requirement for 6.7 days; and thereafter, the remaining impoundment storage would continue to supply 23.5 mgd (equivalent to 51 percent of the reduced demand) for another 43 days.

The bottom 18 listings of Table 11 shows the 18 pressure zones, making up a small part of the total service area, which cannot be served from impoundment storage. Most of these zones have sufficient distribution storage for at least one day's normal demand. Some of the zones have no distribution storage of their own but can rely on a distribution storage supply by gravity flow from an adjacent higher zone, while other zones are without any provisions for being supplied distribution storage by gravity.

From an examination of the flow chart, Figure 3, and the available supply shown in Table 11, it is found that there are five zones which are the most critical because they would be entirely without a water supply during the time when the booster pumps were not operating. These zones, namely Almaden No. 2, Central, Elwood, Lexington, and Sunset Hills, are very small residential areas covering only a few blocks each.

The remaining 13 areas have sufficient distribution storage to last from 1 to 2.5 days when using water at a normal rate.

Table 12 shows the number of days that each of the pressure zones (or a group of zones if interzonal gravity transfer is possible) can be supplied at the normal demand rate.

Table 12

FULL WATER SUPPLY DURATION
(Areas Excluded from Impoundment Storage Supply)

Pressure Zone	Duration (days)
Almaden No. 2	0
Central	0
Elwood	0
Lexington	0
Sunset Hills	0
Almaden No. 3	1.1
Alum Rock	2.5
Beckwith	1.3
Cypress	1.0
Duterd Heights	1.1
High	1.1
Miguelito, Northwood No. 1, Northwood No. 2	1.9
Mireval	1.0
Mt. Pleasant	1.1
Overlook, Elva	1.1

Rationing of supplies would extend the water supply duration. For example, a reduction of 50 percent in water usage would allow the distribution storage to last twice as long.

System Postattack Capability

How do the two situations just analyzed approximate the general postattack situation? If the hypothetical attack destroyed the power transmission complex at the southern end of San Francisco Bay and damaged power substations in the northern part of San Jose, it is also possible that the attack would create sufficient power system disturbances and conditions of instability to cause transmission outages from circuit breakers tripping elsewhere in the system. After the effects of these disturbances were corrected, power could be delivered to San Jose via undamaged power facilities from the south. Those Water Works installations that obtain power from damaged power substations would still not be able to receive power. Generally speaking, however, the damaged power substations would be expected to be in the general vicinity of the damaged Water Works stations to which they supply power. The two situations analyzed, then, are bounds for the postattack situation.

Postattack Chronology

The chronology of anticipated events would be as follows:

1. In the event that electric power was lost--the second situation analyzed--the water system would be able to supply normal demand for a maximum of 2.2 days in about 90 percent of the system by using the available distribution storage. After this period, only about 25 percent of normal demand could be supplied for an additional maximum of 47.5 days. Of the remaining 10 percent of the system, 13 pressure zones would have only about one day's normal supply available and then would be without water until power was restored; the remainder would be totally without water.

2. After the initial power failure was corrected, the capability of the water system to deliver water would be limited by the 19 damaged water works stations, plus any possible additional limitation caused by damage to power substations. This would be represented by the first situation analyzed. The water system would be able to supply the average August 1965 daily demands of 101.8 mgd to practically the entire system. An additional well capacity of 25.6 mgd, plus distribution reservoir capacity of 168.2 million gallons, would be available.

2. After several days to, at most, a few weeks following the attack, full preattack production capacity and distribution could be restored by making first aid repairs and instituting special emergency procedures, such as manually controlling those facilities that cannot be restored to automatic operation.

Demand Factors Affecting Water System Capability

In the preceding discussion, normal average August 1965 demand has been assumed. It is quite obvious that the postattack demand would be anything but normal or average. The postattack demand would be lowered because of population and housing damage. Also, the surviving population would not be concerned with such nonessential matters as washing cars, watering lawns, etc. On the other hand, postattack demand could be increased because of firefighting needs and, to a lesser extent, by damage to service connections at damaged and destroyed structures. The physical distribution of postattack demands would also be altered because of population relocation because of housing damage and sheltering. Of all these considerations, firefighting needs are probably of the most concern.

The water system serving San Jose is able to provide a fireflow of approximately 14 thousand gallons per minute in business districts and lesser amounts in outlying areas without degrading water pressure below allowable minimums. These normal needs are met by additional storage capacity in distribution reservoirs and by excess pumping capacity at well and booster stations. Again, firefighting needs resulting from a nuclear attack would be expected to be anything but normal. Therefore, attempting to fight a mass fire resulting from a nuclear attack may, at best, be difficult and perhaps impossible without degrading water pressure below required minimums, even with a well-designed, undamaged water system. The water systems are just not designed to deliver that much water in that many places all at the same time.

III SEWAGE SYSTEM

Introduction

Sewage flow in the City of San Jose is collected and transported in sewers to a treatment plant located north of the San Jose business district near the southern end of San Francisco Bay. The total developed service area tributary to the treatment plant covers 175 square miles and includes the cities of San Jose and Santa Clara; Sanitation Districts of Cupertino, and Sunol-Burbank; and County Sanitation Districts 2, 3, and 4. The City of San Jose, by agreement, provides staffing and direction of the joint treatment plant through its Department of Public Works. Each city and district involved retains control of its respective collection system.

Approximately two-thirds of the sewage treated in the joint treatment plant originates in the City of San Jose. The San Jose sewage system consists of a sewer collection system including several small pumping stations and a treatment plant designated as the San Jose-Santa Clara Water Pollution Control Plant.

A FIVE CITY STUDY working paper (code number 5S-11101-4334A-22) titled "San Jose Sewage System" was prepared which describes the sewage system in general and presents a description and vulnerability analysis of the Water Pollution Control Plant. The results of the description and analysis are summarized in the following paragraphs of this chapter.

Sewer System

The sewer collection system comprises about 1,100 miles of sewers, ranging in size from 6 inches to 66 inches in diameter. Pipe materials include vitrified clay along with some cast iron in the smaller sizes, reinforced concrete in the larger sizes, and brick and morter in the older sewers.

In recent years, manholes have been built from standard precast concrete concentric rings. Older manholes were constructed with brick. Manhole covers are usually of cast iron and in some cases are bolted in place.

There are two land outfalls extending from the center of the city to the treatment plant. The older of these two outfalls is a 60-inch diameter sewer constructed of brick and mortar, with brick also used in manholes. This sewer, completed in 1885, is 32,000 feet in length, and has a capacity of 55 million gallons per day (mgd). Several sections of this sewer have been relined with concrete in recent years; however, it is in good condition for the most part. Superficial failures have occurred from corrosion in, and near, junctions with other pipes. The second land outfall was completed in 1959. It is 60-inch diameter reinforced concrete pipe, 33,700 feet in length, and has a capacity of 55 mgd.

There are 150 or more inverted siphons where sewer lines cross under creeks and rivers. In most instances, the pipe under the watercourse is encased in reinforced concrete, but in a few cases the crossing is non-encased cast iron pipe. There are no crossings over watercourses where pipe might be exposed by being suspended from bridges.

Although the system of sewers is a separate sanitary system in that it does not carry storm water runoff, infiltration of extraneous water into the system occurs during rainstorms in several ways, thus increasing the total flow to the treatment plant by more than 100 percent during severe storms. However, this is not considered excessive and is handled by the Water Pollution Control Plant without the necessity of bypassing.

Because of heavy cannery activity in the San Jose area, sewage flows vary considerably during the year. During the eight months from November through June, the average daily dry weather flow is 54.4 mgd with peaks of 80.0 mgd. During the four-month canning season, the average daily dry weather flow is 73.6 mgd with peaks of 93.0 mgd. During storms, infiltration of rainfall and groundwater has increased flows up to 118.3 mgd with peaks up to 136.0 mgd. The plant is designed for a peak storm capacity of 225.0 mgd. For the months of August and September 1965, the average flows were 78.6 and 82.9 mgd.

Pumping Stations

There are 11 pumping stations in the San Jose system, only one of which is considered to be a permanent installation. The combined capacity of all stations is about 8 million gallons per day. Together they handle less than 5 percent of sewage originating in the City of San Jose. The permanent station is a reinforced concrete building installation; three stations are complete prefabricated factory manhole type units; and all others are site-constructed large manhole type installations. Most of these stations will be eliminated by improvement of the collection system in specific areas. Sewage is pumped by electric motor-driven pumps or lifted by ejectors powered by compressed air from electric motor-driven air compressors. Power supply is from pole drops located at curbside and installed underground to manholes located usually under streets. There is no auxiliary power available in any of these pumping stations.

Water Pollution Control Plant

General

The sewage treatment plant provides primary and secondary treatment of the sewage. Unless otherwise stated, all buildings at this plant are of earthquake-resistant design, and all pipelines, power conduits, and related components are located either within structures or below grade in special pipe tunnels.

Figure 4 presents a flow diagram which traces the sewage flow through the various plant processes. Figure 5 presents a layout of the plant.

Because of considerable fluctuation in sewage flow, some of the treatment plant equipment is on a standby basis during most of the year. However, at the time of the hypothetical nuclear attack, which is during the canning season, the plant is using most of its equipment.

This plant is highly automated and instrumented--the instrumentation being one of the most complete in existence--and the treatment processes and equipment are quite complex and interrelated.

Figure 4

SEWAGE TREATMENT FLOW DIAGRAM

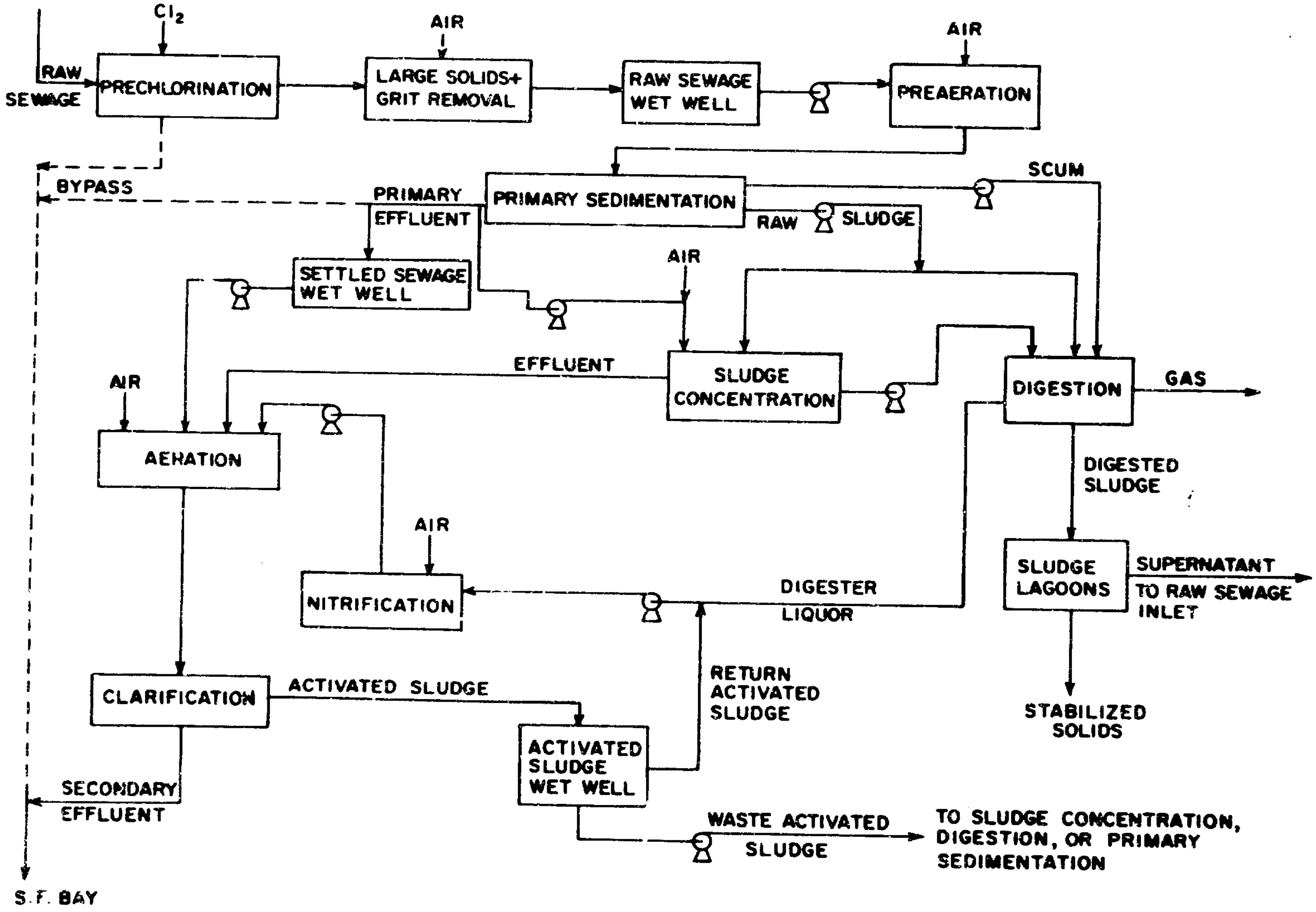
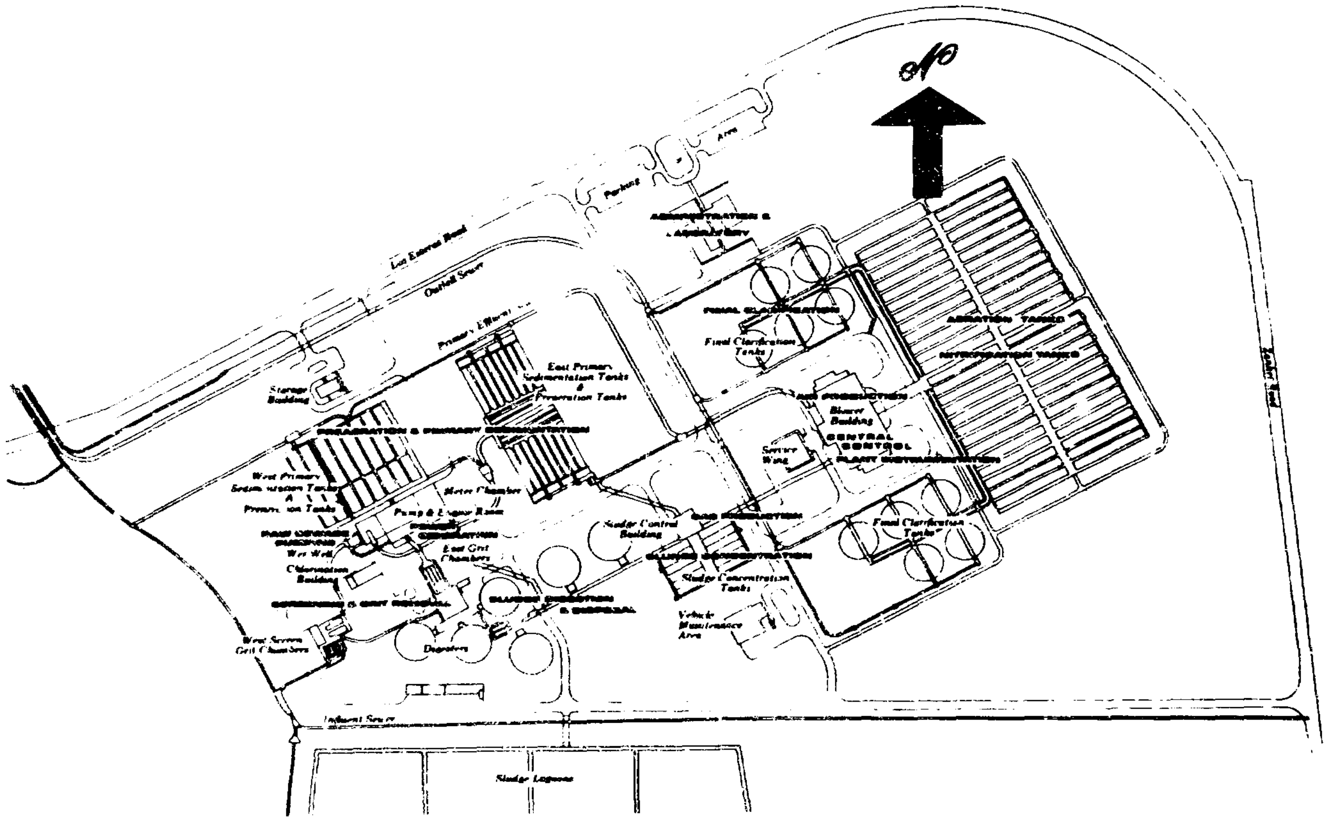


Figure 5

SAN JOSE - SANTA CLARA WATER POLLUTION CONTROL PLANT



Prechlorination

The first stage of sewage handling is prechlorination of the raw sewage. The chlorine is stored in approximately 20 one-ton chlorine tanks under a reinforced concrete beam and slab canopy which is supported by steel pipe columns. This canopy is attached to the chlorination building, which is a small one-story bearing-wall structure with glass block windows. In this building are two chlorinators, two evaporators, an oxidation-reduction potential recorder, and a control panel. From this building, chlorine is fed through a 6-inch pipeline to the inlet overflow structure and supplied to the raw sewage through diffusers. This chlorination is for odor control only, not disinfection.*

Large Solids and Grit Removal

Bar screens with a 3-inch mesh are used to screen out large solids such as sticks and bottles. The screenings are continually dropping onto a conveyer belt and carried by the belt to a hopper for disposal. The four bar screens, each with a 95 mgd capacity, are automatically cleaned. Just beyond these four units are four barminutors. These units screen out some of the solids passing through the 3-inch mesh, shred the solids to a size small enough to prohibit them from clogging sewage pumps, and then dump the shredded matter back into the sewage.

The screening equipment and barminutors are partly below grade, are electric motor driven, and are fairly massive. The electric controls for this screening and comminuting equipment are all housed in the southern end of the west grit chamber building.

After the screening and comminuting, the sewage flows by gravity to grit chambers. Grit removal is a process by which small inorganic solids

* Chlorination for disinfection is a common sewage treatment process but is not used at this particular plant because to do so would destroy the organisms required for the activated sludge secondary treatment process.

are removed by differential sedimentation. These solids, being inorganic, do not need treatment, and being primarily mineral, would contribute to scour of plant equipment if left in the sewage.

The west grit chambers consist of two large below-grade reinforced concrete chambers that use aeration through swing diffusers to produce the desired flow velocity. The air is fed from the pump and engine building. A screw conveyor in each chamber conveys the grit from the bottom of the chambers to the hoppers in the west grit chamber building, a small reinforced concrete structure.

The east grit chambers make use of adjustable gates rather than aeration to maintain a rate of flow that permits the sedimentation of grit while keeping the organic material in suspension. This sedimentation takes place in four parabolic-shaped below-grade reinforced concrete channels. The grit settles onto a revolving rack at the base of each of the chambers, from which it is raised by a bucket conveyor inside the east grit chamber building. The grit is dumped onto a cross screw conveyor and then into a hopper for disposal. The electric control panel for this equipment is inside the east grit chamber building. This building is constructed of reinforced concrete wall panels (approximately 10 inches thick), parapet walls, and pilasters. The rest is concrete beam and slab.

Raw Sewage Pumping

Sewage flows by gravity from the west and east grit chambers, through reinforced concrete conduits, into below-grade wet wells at the west and south ends of the pump and engine building. The two wells have a common line between them to provide for pressure equalization. From the wet wells, six pumping units within the pump and engine building send the sewage through a 102-inch force main to a below-grade meter chamber where the raw sewage is proportioned to the east and west preaeration tanks.

Two of the six raw sewage pumps are 110 mgd variable speed pumps and are driven by 400 horsepower wound rotor motors. These units and their associated control panels are below grade in the basement of the pump and engine building. The remaining four pumps, each rated at 18 mgd, and their associated control panels are also located in the basement of the pump and engine building. These four pumps are driven by induction motors, which are housed on the ground floor at the west portion of the pump and engine building.

Preaeration and Primary Sedimentation

The preaeration is accomplished by forcing air into the sewage. The air bubbles passing through the sewage attach themselves to grease particles and other low density substances, bringing them to the surface in the form of scum. This scum formation does not take place until the sewage has passed into the sedimentation tanks. Preaeration also provides odor reduction.

The separation of matter that takes place in the sedimentation tanks, with a combined capacity of 94 mgd, may be considered the heart of the primary treatment process. It is here that sewage separates into three layers: the top layer is scum (containing mostly grease particles) which is removed by a collecting device and transported to the digesters; the middle layer is settled sewage; the bottom layer is raw sludge which, depending on its dilution, is sent either to the digesters or to sludge concentration tanks. The primary effluent or settled sewage, then flows by gravity to a wet well located in the blower building.

Both the east and west preaeration and sedimentation tanks are below-grade reinforced concrete rectangular tanks. Most of the valves, regulating flow through these tanks, are manually operated from floor stands. The scum collection and sludge collection are accomplished by a continuous cycle of boards that scrape the sewage surface and tank floor. These boards are chain driven by small electric motors. These motors and their gear reducers are in the open and anchored to reinforced concrete. The east and west tanks have their motors and aeration controlled by motor control centers housed in small structures of very light construction called primary control buildings. The east tanks depend on blowers from the blower building for their preaeration; the west tanks depend on three small blower units on the first floor of the pump and engine building.

Aeration and Nitrification

The high degree of treatment required at this plant is accomplished by the secondary units--the heart of which are the below-grade reinforced concrete aeration and nitrification tanks. By injecting air into the settled sewage over a period of time, a material known as activated sludge is produced which contains large floculent particles of suspended material. The floc contains millions of microorganisms which feed upon the organic matter of the sewage.

To provide the organisms with a more balanced nutrient, a mixture of activated sludge and waste digester liquor is continuously added to the aerated sewage. The mixture is first aerated in nitrification tanks for 24 hours before being pumped to the aeration tanks. As a result, higher loadings may be used, resulting in smaller aeration tanks.

The wastes being treated at the San Jose-Santa Clara plant have an extremely high oxygen demand and thus require large amounts of air. Air is introduced into the sewage on both sides of the aeration tank at different levels. The lower, diffused air is discharged 2 feet above the tank bottom through diffuser tubes which produce thousands of minute air bubbles. The upper, distributed air is discharged 5 feet below the tank surface through a device which produces much larger bubbles. The two air systems supply the needed oxygen as well as keep the activated sludge floc in suspension.

Air Production

One of the most impressive plant structures is the blower building which houses six engine driven blowers and accessories for supplying air to the aeration tanks. The three blowers supplying the diffused air system are each rated at 60,000 CFM at 8 psig discharge pressure and the three blowers supplying the distributed air system are each rated at 85,000 CFM at 4 psig discharge pressure, for a total blower capacity of 435,000 CFM.

In the blower building, the only major pieces of equipment that are not supported by the building are the six very large tri-fuel engines which drive the blowers. Each one rests directly on its own massive foundation, which is supported by piles. The building foundations do not make use of piles or foundation walls. The basement floor consists of a reinforced concrete slab about 2 feet thick. The basement walls, pilasters, and columns are reinforced concrete. Some of the major pieces of equipment in the basement are: heat exchanger equipment for the engines (engine heat is used to heat the sewage plant buildings and the digesters); the settled sewage wet well; the settled sewage pumps; return activated sludge pumps and motors; waste activated sludge pumps and motors; nitrification liquor pumps and motors; distributed air equipment and piping; and diffused air equipment and piping. The engine starting air system for the blower engines is also in this basement, and this system consists primarily of two air compressors, three high pressure (250 psig) storage tanks, compressor start and stop controls, safety relief valves, pressure gauges, sediment traps, and air distribution lines. The high pressure system, chiefly for instrumentation, sludge concentration, and scum ejection, is also in the basement. This high pressure system (110 psig) consists primarily of three motor driven compressors, storage tanks, and related equipment.

The first floor is made of reinforced concrete slabs, supported by reinforced concrete beams and composite beams. There are no floors above ground level, except for walkways around the inside perimeter of the two rooms that comprise the main section. The exterior walls of the main section between the first floor and the walkway consist of glass panels, a few masonry panels, and composite columns. Above the walkway level, the building has structural steel columns, with structural steel roof beams and purlins supporting a a concrete slab roof. The exterior of the building above the walkway is of frangible metal panels, most of which are louvers for the blower system. Cantilevered out about 3-1/2 feet in front of these panels is an ornamental facade made of 1/4 inch thick steel tubing. This facade and the frangible metal panels would be a significant contributor to debris damage of the building contents.

In each of the two rooms of the main section are three very large tri-fuel engines, each one driving a speed increaser, which in turn drives a blower unit. Three 1,850 horsepower engine-blower units in the south room provide 4 psig distributed air; the three 2,400 horsepower units in the north room provide 8 psig diffused air. The diffused and distributed air comprises the low pressure air system for the plant. These six engines operate on a mixture of digester gas, natural gas, and/or diesel fuel. In addition to greater horsepower, these engines differ from those in the pump and engine building (to be discussed later) in that these engines do not require a minimum of diesel fuel. Diesel fuel is stored below ground for emergency use.

All six units draw air from the outside, usually through a louvered plenum chamber on the roof, but during warm weather, air is drawn through the louvered sides of the building to provide for heat dissipation of the six engines. The distributed air needs no filtration, but the diffused air, because it eventually has to pass through the fine openings of the diffusers, must pass through fairly efficient and delicate filter bags.

The control room, located above the entrance to the blower building, has its floor on the same level as the walkway of the main section. The control room structure consists of reinforced concrete columns, beams, and slabs; the exterior walls are made of 4-inch concrete block panels with 4-inch interior tile facing, 4-inch exterior precast concrete facing, and a small amount of window area.

The only major piece of equipment in the control room is the control console. This console is used to control the clarification process (to be discussed), and the aeration and nitrification process. In addition, this console records information concerning aeration, clarification, and some of the primary treatment processes, then sends this recorded information to a data logger in the administration building (to be discussed later).

Final Clarification

Just as turbulence prevented sludge settlement in the aeration tanks, quiescence promotes sludge settlement in the clarification tanks. As the activated sludge settles, it is displaced from the tank bottom by an electric motor-driven rotating header. The sludge is then sucked up into a below-grade collecting well. From here, some of the activated sludge is mixed with digester liquor and returned to the nitrification tanks. The remainder of the sludge is waste activated sludge and is sent to the sludge control building. The clarified effluent is discharged to San Francisco Bay.

Final clarification takes place in ten separate reinforced concrete cylindrical tanks. The tops of the tanks are slightly above-grade level, and have no roofs. Flow to the tanks is by open channel conduit partly above-grade; flow from the tanks is by below-grade conduits. The entrance to these tanks is manually controlled by a butterfly valve.

Sludge Control and Concentration

Sludge treatment is controlled from the sludge control building. This building receives sludge from two sources--waste activated sludge from final clarification, and raw sludge from the east and west primary sedimentation. At the sludge control building, the sludge passes through a density meter to be checked for solids content. Sludge with at least 4 percent solids content is sent to the digestion system; that which is below 4 percent is sent to the concentration tanks south of the sludge control building. The concentration of dilute sludge, although not necessary for treatment, results in fewer digesters being required. The concentration tanks are used mainly during the canning season.

The method of concentrating sludge employs a dissolved air flotation process used in oil refineries. The waste activated and dilute raw sludge are pumped to each concentration tank in a common pipe. Just prior to being discharged to the concentration tank, the sludges are mixed with screened primary effluent that is under pressure and to which has been added air that has become dissolved in the liquid. When this mixture is released to atmospheric pressure in the concentration tanks, air bubbles are formed that carry the sludge to the tank surface, from which it is removed by a chain-driven skimming device and pumped to the digesters. The underflow or effluent flows to the aeration tanks. Solids which settle in the concentration tanks are either pumped to the plant influent sewer or reconcentrated.

The sludge control building is a relatively small one-story structure with a basement. The building is made of 8-inch concrete bearing walls with 4-inch precast concrete facing, slabs, and some interior beams and columns. The basement contains sludge pumps and lines, pressure retention tanks, air lines, sewage lines, and related equipment. The first floor contains primarily a control console and control panels for the sludge concentration and digestion processes, sludge density meter, and three motor-driven gas compressor units. In addition to containing indicating instruments, control switches, etc., the electric control equipment records information concerning concentration, digestion, and gas production, and sends this information to a data logger in the administration building.

Sludge Digestion and Gas Production

Sludge that is of suitable density is sent from the sludge control building to six sludge digesters. These digesters are above-ground cylinders about 100 feet in diameter and 30 to 40 feet in height, with floating metal roofs and with reinforced concrete walls approximately one foot thick. In these tanks, the organic, or volatile, content of the sludge is reduced and a less objectionable, more stable product is produced.

The three products of digestion are: stabilized (digested) sludge; a supernatant called digester liquor, which is used in the previously mentioned nitrification process; and methane gas, which is used as one of the fuels for the plant engines. Heat from the engines at the pump and engine building and the blower building is used to maintain a temperature of about 95 degrees Fahrenheit at the digesters. The methane gas, or digester gas, leaves the digesters through a flexible line connecting the center of the floating roof to a stationary line attached to the outer edge of each tank. From here, the gas passes to the sludge control building where it is compressed, blended with natural gas, and then sent to the engines in the pump and engine building and in the blower building. The digested sludge, upon leaving the digesters, is pumped to sludge lagoons at the northern and southern boundaries of the sewage treatment plant. The supernatant is withdrawn from the lagoons and is sent to the plant influent sewer line. After the sludge dries in these shallow open lagoons, the remaining solids are removed to be used as fertilizer.

Electric Power Supply

One of the essential requirements of almost every stage of the sewage treatment at this plant is electric power. The highly automated plant uses electric motors extensively for different operations--conveyors, bar screens, scum collectors, sewage pumps, sludge pumps, gas compressors, blower units. Electric power is provided entirely by five engine-generator units on the first floor of the pump and engine building. All five use a minimum of 8 percent diesel fuel combined with digester gas or natural gas. Diesel fuel storage is underground.

Three of the engine-generator units, in the west portion of the pump and engine building, are each rated at 625 KVA (kilovolt-amperes) and produce a total of 1,600 KVA at 480 volts. Two larger units, in the east portion of the building, are each rated at 2,188 KVA and produce a total of 4,400 KVA at 4,160 volts.

All five engine-generator units feed the same transformer. The generated power is distributed at 4,160 volts to load centers in the pump and engine building, blower building, and sludge control building. A fourth, smaller load center is located in the administration building. The larger motors in these areas are operated at 4,160 volts while transformers are provided to lower the voltage to other items of equipment.

The present plant generating capacity is sufficient to furnish power to a municipality of 10,000 population.

A standby diesel generator is maintained to provide auxiliary power to start the generators in the event of complete power failure, since there is no connection to outside power sources. One of the engine-generator units is maintained in standby status at all times to provide power in the event one of the operating units malfunctions.

The motor control centers for the five engine-generators are located along the south wall of the engine room. For convenience, the starters for most electric motors are installed in motor control centers located throughout the plant. Electric control devices are located in consoles near meters for more efficient process operation.

The west portion of the pump and engine building (completed about 1954) is of curtain wall construction with pilasters and parapet walls. The roof is a concrete slab supported by steel trusses and purlins. The east portion of the same building (completed in 1964) is of structural steel beam and column design. The roof is a concrete slab supported by steel beams; the walls are double precast concrete panels, 4 inches thick, used as an inside and outside facing for the steel framework. The building is one story, about 40 feet high, and has a mezzanine and a basement.

Administration and Laboratory

The blower building control room, mentioned previously, is the plant operation headquarters. Here, the operator on duty observes the flows to the remotely located units, spots equipment malfunctions, and makes adjustments in rates of flow. One man is always on duty here to receive messages and relay information to other operators throughout the plant.

Interpretations of laboratory analyses are sent to the control room by the engineer-superintendent, with instructions concerning changes in flow rates, etc. The control room console contains 33 indicating and/or totalizing meters. A second control console in the sludge control building contains 35 indicating and recording meters pertaining mainly to primary treatment and sludge handling. Signals from both consoles are transmitted electrically to a data logger in the administration building. The logger stores the incoming information and summarizes it every 24 hours on a printout containing 47 readings, including: volume of raw sewage pumped to the primary sedimentation tanks; settled sewage to aeration tanks; return sludge to aeration tanks; total air for aeration; volume of raw sludge pumped to digesters; gas produced by each digester; and fuel oil consumed by various engines. The information transmitted to the logger, coupled with the laboratory analyses of the preceding day, gives the engineer-superintendent a complete picture of the plant operation.

The administration building is divided into two wings housing the laboratory and engineering personnel. The laboratory contains four basic areas, each designed for the efficient performance of various chemical and bacteriological analyses, including fish bioassays to determine the effect of the treated effluent upon the marine life of the bay. The engineering wing includes administrative offices, drafting room, blueprint room, industrial waste section, and the engineer-superintendent's office.

The administration and laboratory building is one story with no basement. The framework is mostly structural steel, with reinforced concrete floor and roof slabs. The wall panels are a double layer of masonry units with precast concrete panels for exterior facing.

Operation and Maintenance

All sewage system activities are under the direction of the Department of Public Works, City of San Jose. Maintenance of the sewage system, as well as the drainage system within San Jose and minor new construction, is performed by the Engineering Operation and Maintenance Division of the Department, which also maintains the sewers in the Sunol-Burbank Sanitation District. Sewer maintenance in the other districts outside the City of San Jose is under authority of the individual agencies.

The operation of the Water Pollution Control Plant is under the direction of the Engineer-Superintendent. The plant staff includes 82 full-time and 2 part-time employees as follows: Plant Operations, 42; Plant Maintenance, 26; Laboratory, 5; Engineering, 4; Accounting, 3; Industrial Wastes, 2; and Plant Management, 2. The minimum operating crew on duty nights and weekends consists of eight men, two of whom are engine operators. In emergencies, at least 40 persons not on duty are subject to call. In extreme emergency, about 20 of the remainder of the staff would be available, but at least 10 persons are always unavailable because of vacations, illnesses, etc.

Design of additions to sewage and drainage collection systems is performed by the Engineering Division of the Department of Public Works. Minor construction work is done by city crews, and major projects are constructed by private contractors under bid.

For treatment plant improvements, major work is designed by private consultants, and the work is performed by private contractors under bid. Minor jobs within the treatment plant are handled by the engineers and maintenance people within their own organization.

The three City Corporation Yards which house the maintenance equipment and personnel are discussed in Chapter IV.

Expected Damage to Treatment Plant

Weapon Effects

In the postulated attack, the Water Pollution Control Plant will receive:

1.	Static overpressure	6.0 psi
2.	Dynamic overpressure	0.6 psi
3.	Duration of positive phase	4.8 sec
4.	Equivalent wind speed	157 mph
5.	Thermal radiation	76 cal/cm^2

6. Nuclear radiation none
7. Electromagnetic pulse none
8. Ground shock none

The expected damage resulting from the above weapon effects is discussed in the following paragraphs.

Prechlorination

The chlorinators, evaporators, the oxidation recorder, and the control panel receive extensive damage from blast and debris, leaving the prechlorination system inoperable. Some of the 1-ton chlorine tanks have been blown from their platform but no leakage of the lethal chlorine gas has taken place. The chlorination building received some minor permanent deformation and joint fracture, but is still structurally sound. Neither the chlorine diffusers nor the sewage inlet structures received any significant damage. With some emergency repair, the chlorine feed to the raw sewage can be manually operated to attempt disinfection until the plant can resume sewage treatment.

Large Solids and Grit Removal

The screening and comminuting equipment receives no significant damage except for a jammed belt conveyor and extensively damaged electric control panels. This damage leaves the equipment without power. Without power supply to the motors, the bar screens clog up and prevent the flow of sewage to the grit chambers. If the screening and comminuting equipment is manually removed, then the large solids in the sewage will clog process pumps.

As for the west grit chambers and equipment, the upper portion of the two grit screw conveyors are bent out of alignment and are inoperable. Aeration is discontinued because of debris damage to the blower units in the first floor of the pump and engine building. The control panels (part of the same console that controls the screening and comminution) are extensively damaged. The grit removal system for the west grit chambers is no longer operable.

The east grit chambers and related equipment receive no significant damage, with the exception that the control panel inside the east grit chamber building has been severely damaged from blast and debris, and requires major repair. Therefore, without electric power to the motors, the east grit removal system is inoperable.

The east grit chamber building has experienced minor deformation of its shell, some joint fracture, and translation of window and door fragments.

Raw Sewage Pumping

The six raw sewage pumps are undamaged. However, two of the four induction motors, which drive the four 18 mgd pumps, receive debris damage sufficient to render them inoperable. All raw sewage pumping is inoperable because of damage to the power generation equipment, to be discussed later.

Preaeration and Primary Sedimentation

As a result of blast damage to their control centers, the preaeration and sedimentation processes are inoperable. The motor control centers for both the east and west tanks have undergone severe deflection and distortion; the indicating and recording instruments, control switches, circuit breakers, etc., need extensive repair or replacement. The lightly constructed shelters for these motor control centers provide no appreciable blast protection. This damage causes power failure to the motors, and hence a disruption of the skimming and sludge removal mechanism. The small blower units supplying compressed air to the west preaeration tanks are housed in the west portion of the pump and engine building and have been rendered inoperable from debris damage in the building. The preaeration for the east tanks has been disrupted because of damage to the blower system in the blower building, as discussed later.

Aeration and Nitrification

The diffusers and distributors, and the aeration and nitrification tanks and appurtenances have received no appreciable damage. The secondary treatment process, however, is completely inoperable because of damage to air production and power generation. Loss of air prohibits keeping the activated sludge in suspension and prohibits aerobic decomposition of the sewage. Loss of power prohibits the return of digester liquor and activated sludge to the nitrification tanks. The aeration and nitrification tanks will become, in effect, settling tanks with no means of removing the settled sludge.

Air Production

The masonry and glass panels of the blower building have been blown in and shattered, as have the ornamental facade and the metal siding. Noticeably deformed and battered, but still standing, are the beam and column framework, the walkways, and the roof and floor slabs.

As for the building contents, the blower building load center, which distributes power for the aeration and clarification systems and power needed within the blower building, is on the first floor and receives no building protection from the blast wave. The switchgear units have been severely distorted and a few have overturned; all of the units are inoperable. The engine control centers are dished in and, in some cases, overturned; the switches and recorders are inoperable. The filter system for the diffused air has been destroyed. The basic engine blocks of the six blower units receive no appreciable damage. However, they have numerous appurtenances such as fuel lines, lubrication lines, cooling water lines, air supply lines, exhaust heat lines, etc., many of which (60-70%) have been damaged and preclude engine operation. The speed increasers and blowers have their casings deformed and ruptured from blast and debris, requiring repair before becoming operational. The large air mains running from the blower units to the aeration tanks have not experienced appreciable damage, partly because their flexible couplings are able to absorb some of the shock energy.

In the control room, the control console is deformed by the shock wave, and severely battered by impact from blown-in masonry panels. Dials and recorders are shattered, and switches are inoperable. One of the less obvious results of failure to the air production system is that pneumatic controls throughout the sewage treatment plant have become useless.

Final Clarification

The clarifiers, which are massive circular reinforced concrete cylinders primarily below grade, are undamaged. But the sludge from the clarification process can no longer be disposed of because of damage to the blower building load center which supplies power to the electric motors driving the rotating headers, and because of damage to the motors driving the sludge pumps.

Sludge Control and Concentration

The burst has caused no significant damage to the contents of the sludge control building basement. The windows and doors of the ground floor have been blown in, including the rolling steel doors that were closed at the time of attack. The roofs are moderately dished in and the bearing walls have experienced some permanent deflection, spalling, and joint fracture, but the building shell is still standing and provides some shelter to equipment. The load center and electric control equipment has received some blast protection by the building shell, but the control panels and switch gear have still been deformed and caved in, and are inoperable. Almost all of the indicating and recording instruments have been damaged by the burst, and the flow density meter is overturned.

The gas compressor motors are well anchored and enclosed and still operable, except that damage at the pump and engine building, as well as damage to the sludge control building load center, has disrupted their power supply. The gas compressors have basically survived the weapon effects but some of the numerous small gas and air lines at the gas compressors have been ruptured. The outdoor traveling screens located south of the east preaeration tanks for the settled sewage are still operable except that the power supply to their motor has failed. The sludge concentration tanks and appurtenances received no appreciable damage. The sludge control building receives no electric power because of damage at the pump and engine building, no gas because of damage to the digestion system (discussed later), and no air because of damage at the blower building.

Sludge Digestion and Gas Production

The floating roofs of the digesters have been torn, buckled, and completely destroyed. Digester heating ceases because of engine failure at the blower building. Since the walls of the digester tanks receive nothing but superficial debris damage, the sludge remains in the tanks.

The steel cylindrical low pressure gas holder has been demolished by the blast wave. The gas in the holder immediately ignites and burns out but no explosion occurs. Similar ignitions of digester gas occur over the destroyed roofs of the digesters. This burning gas causes no additional damage to other plant equipment. Replacement of the gas holder is not essential to the restoration of gas supply for the treatment plant engines.

The flexible portions of the gas lines attached to the tank roofs are destroyed. Main power failure has stopped the transfer of sludge to and from the digesters. The failure of heat supply to the digesters retards the decomposition process. The sludge lagoons are left unharmed by the burst.

Power Generation

The windows and doors of the pump and engine building have been blown away, including the rolling steel door on the west side. The roof is dished in. Many concrete joints have fractured in the west portion. The north wall of the east portion of the building is only partly remaining; many of its precast panels, containing only temperature steel and not being monolithic with the frame, have failed and have contributed to the debris damage of the building contents on the first floor. The remainder of the building shell, despite some permanent deformation, is intact and the building still provides some shelter for the equipment. No damage is experienced by the basement or its contents.

Window and door fragments, spalled concrete particles, and numerous other bits of debris, as well as direct blast pressures, have caused failure of the three smaller engine-generator units on the first floor of the west portion of the pump and engine building. All three units were operating at the time of attack, and the entry of debris particles into the generators has caused damage to their windings and brushes, disrupting their generation of power. A much heavier steel mesh or wall in front of these generators might have prevented such debris damage. The basic engine blocks of these three units have experienced no damage. However, they have numerous fuel lines, lubrication lines, cooling water lines, air supply lines, exhaust heat lines, etc., many of which (roughly 20-30%) have been damaged enough to inhibit engine operation. Recovery measures will probably make use of cannibalizing the most damaged units to restore partial power. The motor control centers for the five engine-generators are located along the south wall of the engine room. Their panels are dished in, their dials are shattered, and almost all of their recording and control instruments are inoperable.

The remaining two larger engine-generator units located on the first floor of the east portion of the pump and engine building were subjected to more massive debris elements because of failure of some of the concrete wall panels. Still, the engine blocks are operable, as soon as the numerous water, fuel, lubrication, and air lines previously mentioned are repaired. Roughly 40-50% of these lines have been ruptured. Generator No. 5 was operating at the time of the attack, and was severely damaged by debris entering through the front of its housing. Generator No. 6 was on standby and therefore received only minor debris damage. Recovery operations may include the cannibalizing of Generator No. 5 to return Generator No. 6 to operation.

In summary, all generation of power has stopped and no source of outside power is available.

Administration and Laboratory

The masonry and glass panels of the administration and laboratory building are blown in, the roof is dished in, and some permanent distortion of the framework is apparent. The primary thermal pulse has ignited papers and documents throughout the building, but for lack of fuel, the fires are not sustained. The data logger has received considerable direct and indirect blast damage and is completely inoperable, doubly so because main power failure and damage to the control consoles in the blower and sludge control buildings have also left it useless. Most of the laboratory instruments used for chemical and biological analyses have been rendered useless by blast and fire. In order to perform biological sewage analyses during the postattack phase, the emergency recovery operations may consider partial restoration of the laboratory.

Summary

The hypothetical attack has rendered the San Jose-Santa Clara Water Pollution Control Plant completely inoperable.

The sewage treatment equipment which is fairly massive and for the most part below grade, is relatively undamaged except for the floating roofs on the digesters. However, the auxiliary equipment--which provides process air and power and the equipment for plant control--is severely damaged, enough to preclude plant operation without extensive repairs.

The treatment plant is extremely dependent upon power. Since in normal operation it provides all its own power, there is no provision for drawing outside power. The power generation capacity of the plant must be at least partly restored before sewage can be treated. In the meantime, with some minor repair, the prechlorination system can be repaired, and the sewage can be chlorinated to attempt disinfection and then bypassed to San Francisco Bay.

Primary treatment of the sewage before bypassing it to San Francisco Bay will require: at least partial restoration of the plant's power generation capacity; repair of the blower units in the pump and engine building; repair of the power load center in the sludge control building and blower buildings; restoration of the floating roofs on the sludge digesters; minor repair to the screening and grit removal system; and restoration of control facilities for the primary treatment process.

To accomplish secondary treatment of the sewage will require restoration of the blower facilities in the blower building, additional repair of the blower building load center, and restoration of the control facilities for the secondary treatment process.

Expected Damage to the Collection System

Weapon Effects

The weapon effects on the collection system are maximum at the treatment plant entrance. Most of the collection system, however, experiences less than 3 psi static overpressure.

Pumping Plants

Damage is expected to the power service drops for the pumps in two of the collection system's 11 pumping stations. The sewage flow handled by these stations represents, however, less than one percent of the total system flow. In addition to this physical damage to the collection system, it is expected that the remaining nine pumping stations would be without power because of the expected power failure in San Jose. This power-out situation would last perhaps for some days. The combined loss of sewage flow for all 11 stations is less than 5 percent of the total system flow.

Collection Mains

No damage is expected to the underground collection mains since they are all buried to a minimum depth of 4 feet.

Summary

For all practical purposes, no significant reduction of sewage flow or sewage handling capability is expected because of damage to the sewage collection system. The only reduction in postattack sewage flow will be because of postattack living conditions and reduction of commercial cannery and industrial operations.

Conclusions

1. No significant reduction of postattack sewage treatment load is expected because of damage to the collection system.
2. There will undoubtedly be some reduction of postattack sewage treatment load because of postattack living conditions and reduction of commercial cannery and industrial operations. The amount and significance of this reduction are beyond the scope of this report.
3. The sewage treatment plant is completely inoperable, not primarily because of damage to the treatment equipment, but because of damage to power generation equipment, air production equipment, and the control equipment necessary to permit operation.
4. Immediately following the attack, sewage must bypass the plant and flow through an existing bypass conduit to the bay. With some repair, chlorination for disinfection purposes, can be provided to the raw sewage through the existing chlorine feed line from the chlorination building to the overflow structure. This repair work would require perhaps several man-days.
5. With the partial restoration of the primary treatment process, the sewage can be given primary treatment and then released through an existing bypass conduit to the bay. This repair work would require perhaps a few man-years.
6. Returning full primary and secondary treatment and sludge handling would demand very extensive reconstruction. This would require several man-years of repair and reconstruction effort.

IV DRAINAGE SYSTEM

Introduction

The drainage system in San Jose is essentially 182 separate small drainage units tied together by a system of natural stream channels, some of which have been improved. For all practical purposes, the system operates completely by gravity flow. A FIVE CITY STUDY working paper (code number 5S-11101-4334S-21) titled, "San Jose Drainage System" was prepared which describes the drainage system in general and presents a limited vulnerability analysis. The description and vulnerability analysis of this system are limited because the system is not expected to experience any significant damage from the hypothetical nuclear attack postulated for this iteration of the FIVE CITY STUDY. The results of the description and analysis are summarized in the following paragraphs of this chapter.

Three major stream systems traverse the city of San Jose from south to north and discharge into the southern end of San Francisco Bay. These streams drain surface water runoff from surrounding areas. Man-made assistance in runoff drainage is provided by a storm drain collection system, which intercepts a large portion of the runoff and transports it to numerous outlets discharging into natural stream channels. The collection system covers about 80 percent of the city and includes all of the business section and most of the residential areas. The Department of Public Works, City of San Jose, handles all activities of the drainage system.

Drainage Basins

San Jose is situated in the lower elevation areas of Santa Clara Valley and occupies parts of three major drainage basins. These are the Coyote River or East Basin, the Guadalupe River or Central Basin, and the

San Tomas Aquinas-Saratoga-Calabazas Creek or North Central Basin. The outer limits of the basins are defined by ridges of hills on the east, south, and southwest varying in elevation from 2,200 to 4,200 feet above sea level. The basins drain generally northward into San Francisco Bay. The total area of these three basins is 580 square miles.

San Jose, together with surrounding communities, occupies 175 square miles of alluvial plains in the central portion of the valley floor at elevations between 10 and 300 feet above sea level. In the foothills on three sides of the city, and on low ground between the city and San Francisco Bay are large agricultural areas occupied by groves, orchards, vineyards, and truck gardens. The hills forming the boundaries of the basins are covered by scrub and brush interwoven with networks of small creeks, which are dry much of the year.

Several reservoirs have been created by the construction of dams on creeks in the hills. The more important of these are the Vasona and Lexington Reservoirs on Los Gatos Creek, and the Guadalupe, Almaden, and Calero Reservoirs on the headworks of the Guadalupe River, all of which are included in the Guadalupe Basin. Anderson Lake is the principal body of water in the Coyote Basin.

Annual mean rainfall in the drainage basins, which occurs primarily during the period September through April, varies with the location and elevation of measuring stations. In general, the low-lying areas within the city of San Jose receive from 13 to 14 inches of rainfall annually. In the foothills surrounding the populated areas, mean annual rainfall varies from 20 to 40 inches. In the hills along the boundaries of the drainage basin, some stations have a mean rainfall of 40 to 50 inches annually, with one station at Saratoga Gap, elevation 2,600 feet, recording 57 inches on a long term basis.

Collection System

The collection system serving the city of San Jose consists generally of an underground sewer system with outlets into the rivers and creeks in the area. At a few places, small natural drainage ways have been improved by deepening and widening for use as storm water drains.

The underground drainage collection system is constructed in units of various sizes, depending on how each sewer system fits the local topography. A slope allowing a minimum of 2 feet per second is maintained in all storm drains, with gravity flow in the entire system, except for a few minor privately operated pumping stations in railroad and highway underpasses. The latter are for lifting water into gravity trunks. The system consists of approximately 182 separate drainage units, each of which discharges into a creek or river at a separate location within the city.

There are between 600 and 650 miles of pipe in the entire underground drainage system, ranging in size from 10 inches to 72 inches in diameter. Pipe material is mostly concrete. Sizes 12 inches in diameter and larger are reinforced. Manholes in the older parts of the system were constructed of brick and mortar, but in recent years, precast reinforced concrete rings have been used. Manhole covers and seating rings are of cast iron, with covers bolted in place where hydraulic gradients require. Gratings for curb opening inlets are of cast iron. Laterals from catch basins to trunks are not less than 8 inches in diameter. Pipes are buried to a minimum of 4 feet of cover from the crown of pipe to the surface of the ground, except in a few instances where circumstances have warranted a shallower cover.

There are no exposed pipes in the drainage system, because drainage lines terminate at the banks of the rivers and creeks. At all outlets, the pipe is supported by a concrete headwall or sack riprap, and the outlets are protected by a cast iron, automatic swing-check gate or rebar grill. Gates are mounted on a framework which is bolted to the concrete, thus preventing back flow.

There are some inverted syphons in the system, where drain pipes dip under other structures, temporarily lowering the flow line. Whenever drain pipes pass under railroad crossings, the pipe is protected by a sleeve of larger pipe, usually corrugated iron, and the annular space is filled with grout or compacted sand fill.

Operation and Maintenance

All drainage activities are under the direction of the Department of Public Works, City of San Jose. Maintenance of the drainage as well as the sewage system and minor new construction is performed by the Engineering Operation and Maintenance Division of the San Jose Department of Public Works. The main City Corporation Yard located at Sixth and Taylor Streets is headquarters for this activity. There are two branch yards, one at Monterey and Snell Roads; and the other, the west branch yard, at Doyle and Williams Roads. During weekdays, over 100 pieces of equipment and up to 280 men are available at the main yard for all the utilities. Of these, eight crews of two to four men are assigned to sewer maintenance to answer trouble calls and service pump stations. A construction crew of 13 men has available up to 10 pieces of heavy equipment such as bulldozers, cranes, and loaders. During the night and on weekends, one sewer maintenance crew of three men is on radio call for emergency service, in addition to the night auto mechanic and two assistants stationed at the main yard.

At the branch yards, there are no personnel on night duty. The Monterey yard maintains two or three sewer maintenance crews with six pieces of equipment on weekdays. At the west branch yard at Doyle and Williams Roads, there are no personnel engaged in sewer maintenance, but there are 10 to 12 pieces of equipment available if necessary.

Design of additions to sewage and drainage collection systems is performed by the engineering division of the Department of Public Works. Minor construction work is done by city crews, but major projects are constructed by private contractors under bid.

Expected Damage

Stream Channels

The hypothetical weapon effects experienced by the various components of the drainage system are shown in Table 13. As may be seen, the stream channels receive, by far, the greatest intensity of effects; however, these effects occur in the undeveloped low-lying baylands. In the built-up portion of San Jose, the weapon effects experienced by the stream channels are: less than 5 psi overpressure, less than 0.3 psi dynamic pressure, less than 100 mph winds, and less than 60 cal per sq cm thermal radiation. While some debris will be produced along these stream channels, it is not expected that debris blockage of the channels will be of major significance in the immediate postattack period.

Collection Mains

The collection mains will receive, at most, 3.5 psi overpressure. Since nearly all mains are buried to a minimum of 4 feet of cover, no damage is expected to the collection system. If heavy rains occur, however, debris blockage of the collection mains could become a problem because of the large amount of debris in streets and curbs.

Reservoirs

The dam and reservoir closest to ground zero is Vasona Dam and Reservoir, which receives 1.5 psi overpressure. This overpressure is insignificant to this structure, and hence no damage will occur to any of the reservoirs. Because there will be no damage to the dams, the sudden release of stored water will not be a problem.

Corporation Yards

The main corporation yard at Sixth and Taylor Streets and the branch yard at Doyle and Williams Roads receive about the same weapons effects--i.e., 2.3-2.5 psi overpressure, 23-26 cal per sq cm thermal radiation,

Table 13

WEAPON EFFECTS EXPERIENCED BY COMPONENTS OF THE DRAINAGE SYSTEM

Component	Weapon Effects
Stream channels	Up to 20 psi overpressure
	Up to 3.2 psi dynamic pressure
	Up to 346 mph winds
	Up to 500 cal per sq cm thermal radiation
Collection system	3.5 - 1.0 psi overpressure
Reservoirs	
Vasona	1.5 psi overpressure
Lexington	1.2 psi " "
Guadalupe	1.0 psi " "
Almaden	< 1 psi " "
Calero	< 1 psi " "
Anderson	< 1 psi " "
Corporation yards	
Sixth and Taylor	2.3 psi overpressure
	23 cal per sq cm thermal radiation
Monterey and Snell	1.25 psi overpressure
	9 cal per sq cm thermal radiation
Doyle and Williams	2.5 psi overpressure
	26 cal per sq cm thermal radiation
All yards	< 0.3 psi dynamic pressure
	< 100 mph winds

less than 0.3 psi dynamic pressure and less than 100 mph winds. Some light damage is expected to occur to the maintenance and construction equipment because of debris and light missiles. For the most part, such damage is expected to consist of shattered windows, broken gages, and dented bodies. However, all equipment is expected to retain its capability to perform its intended function.

The branch yard at Monterey and Snell is not expected to receive any significant damage.

Pumping Stations

As was stated previously, the drainage system operates almost exclusively by gravity flow, except for a few minor privately operated pumping stations at railroad and highway underpasses. Since these stations are not part of the San Jose drainage system, per se, their precise location was not determined. In the immediate postattack period, the power supply to operate these pumping stations would probably not be available for at most a matter of days. In the absence of any heavy rainfall, loss of power or damage to these stations is not expected to be significant; in the event of rain, the power loss and damage would be of relatively minor significance.

Summary and Conclusions

The drainage system in San Jose is essentially 182 separate small drainage units tied together by natural streams, which convey the rainwater runoff northward from the city and empty into the southern end of San Francisco Bay. The drainage system is essentially a completely gravity system. All collection mains are buried to a minimum depth of 4 feet and none "daylight"--i.e., emerge to surface level.

The only possible significant point of vulnerability to the effects of the hypothetical nuclear attack postulated for this iteration of the FIVE CITY STUDY appears to be (1) the accumulation of debris in gutters, which would then wash into collection mains in the event of heavy rain, and (2) the production and accumulation of debris in the natural stream channels. If the accumulation of debris were great enough and there were a heavy rain storm, possible local flooding could occur. Since the collection system is composed of 182 separate units, the probability of this occurring and causing a widespread flooding problem is much less than it would be if the collecting system were one unit.

The drainage system is essentially a gravity system, although there are a few privately owned pumping stations that lift drainage up to the gravity mains. These pumping stations will probably be without power immediately postattack. However, the amount of drainage handled by these stations is small enough that the emergency installation of portable pumps could handle any minor flooding problems which might occur.

In summary, then, the possible failure of the drainage system does not appear to be a significant problem.

V PHYSICAL VULNERABILITY

Weapon Application

A primary purpose of this study is to determine the expected immediate effects of a postulated 5 MT nuclear weapon detonation on the water supply and waste water disposal systems serving the City of San Jose. For this attack, the most significant damage will be from blast, and to a much lesser extent, from the thermal pulse. The storm water system will be essentially undamaged. Hence, it is excluded from the following discussion.

Water Supply and Sewage System Components

The water supply and sewage systems for the city are composed of thousands of building elements, miles of pipelines, and equipment components. The myriad physical units have varying degrees of vulnerability, interdependency, and importance to the systems. Some items considered important during normal conditions would be insignificant during a post-attack situation.

The buildings range from a very small prefabricated metal structure to a large multimillion-dollar structure. Window areas, as a percentage of exterior walls, range roughly from 100 percent to 0. Story height ranges from about 8 feet to 40 feet. Various kinds of building elements are involved:

Footings
- Pile footings
- Spread footings
- Continuous footings
- Combined footings

Wall Elements
- Bearing walls
- Panel walls
- Curtain walls
- Parapet walls

Wall Materials (Combinations of)	Roof and Floor Designs (Reinforced Concrete)
Poured-in-place concrete	Flat slab
Precast concrete	Ribbed
Insulated metal	One way
Glass	
Air space	
Concrete block	**Horizontal Framing Design**
Tile block	Beams
Insulated porcelain enamel	Girders
Wood	Trusses
Sheet metal	Purlins
Corrugated metal	Girts
Louvered metal	

Column Materials	Horizontal Framing Materials
Reinforced concrete	Reinforced concrete
Structural steel	Structural Steel
Composite	Composite

Some building elements and equipment are below the groundwater table, a significant determinant of structural response to blast loading.

Building age, especially because age dates the structural design used, is another consideration. Some newer buildings are based on ultimate strength design procedures rather than on the older standard elastic design procedures, resulting in more efficient use of materials and a lower factor of safety against failure, whether the failure results from standard loads or from blast loading. Since the buildings of interest in the San Jose water supply and sewage systems were built after 1933, they are considered to be of earthquake resistant design, and of course, capable of withstanding greater blast loads than buildings of conventional design.

Limitations on Accuracy of Analysis

The structural vulnerability analysis reported herein was subject to two major types of limitations on accuracy: limitations due to inaccuracy of the method, and limitations due to inaccuracies of the source data.

The limitations inherent in the standard analytical methods are well-known. "Quantities may be in error by a factor of two or more" and "one becomes willing to accept errors of the order of 20 percent as tolerable."[17] Conventional design procedures are also uncertain, as noted in reference 44 on the use of "factor of safety."

As for source data, useful information on utility components is relatively scarce. The best sources of information on nuclear physical vulnerability are documents that emphasize potential military targets. Interactions between structures under blast forces are not found in the literature. Even the best source documents select only a certain range of combinations of weapon effects parameters and target parameters, and then relate these combinations to expected levels of damage. Therefore, in many instances we have had to extrapolate for the megaton range and to exercise engineering judgment.

Failure Modes

Whether an item being loaded by a blast wave is a large building complex or a small vacuum tube, an analysis of external stability, or internal stability, or both, may be appropriate, depending on the assumed mode or modes of failure. Failure due to translation and/or rotation of an item responding as a rigid body is a matter of external stability analysis. Failure due to the material stresses of an item exceeding some specified allowable limit is a matter of internal stability analysis. The failure of some items in the San Jose vulnerability study involved both types of stability. Translation of bricks from a wall is an example of external stability failure (trajectory of the bricks) preceded by internal stability failure (the wall fracture). Damage to an overturned control panel is an example of internal stability failure (damage to control panel components) preceded by external stability failure (the overturning of the unit).

Specific Problem Areas

Debris

The production and distribution of debris were determined by an analysis of combinations of factors. The failure of one item, or even just the item location, could affect the expected damage to another item. A typical example is that of a wall. From the dimensions of a wall, its design and materials, its orientation toward the blast wave, the blast intensity on the wall, and other considerations, it was necessary to determine the response of the wall. If the wall produced debris, then it was necessary to determine the size distribution of debris particles, their path of travel, impact velocities, and final displacements in order to determine the blast effects on other items of interest.

Blast Wave Orientation

Since all items of interest were within the Mach region of blast loading, only the horizontal angle had to be considered for the blast wave orientation of the system components. The peak reflected overpressure as a function of blast orientation was known, but dynamic pressure, impulse, diffraction, and other factors as a function of orientation, had to be considered in determining the occurrence or extent of failure. As already stated, the source documents provided little of such information. However, the source documents did provide principles that this study adopted. For example, a source described briefly the expected damage to a general type of building for 6 psi loading in the Mach region from a 5 MT weapon for face-on orientation. We modified this information by considering the particular details of framing, shielding, windows, terrain, etc., to determine whether a building component such as a particular wall panel would blow in, blow out, or remain standing.

Shielding

Shielding as generally used refers to blast wave attenuation because of shielding of one item by another. The peak pressure experienced by a target can be modified by at least a factor of 2, depending on the degree of shielding. To determine the degree of shielding for a given item in the San Jose study, we examined not only the existence of shielding from blast but also the shielding from debris, and the following shielding characteristics: distance between the shield and the shielded item, the size of the shield, the response of the shield to blast, and overpressure reflection from surroundings. Much more work remains to be done on shielding aspects, and this analysis claims only a start in applying shielding phenomena to a real and complex situation.

Impulse Enhancement

Closely associated with shielding was the problem of the increase rather than reduction of the expected level of damage to a particular item as a result of the proximity of another item. An example from this vulnerability study of the water-sewage complex will illustrate the analytical method. Among the items studied were metal-clad control boxes approximating the shape and volume of a 1 foot cube. Such boxes had three major locations throughout the system, and each location significantly affected the pressure-time function of the blast wave on the control box. For all three cases, the boxes were firmly enough fixed that they would not undergo rotation or translation from the blast. In the first location, the control box was supported by a small metal frame, and in this case, the diffraction phase would be extremely short, and the most damaging agent was dynamic pressure. In the second location, the control box was attached to the leeward side of a large system component which was unaffected by the blast. The control box would be enveloped by an overpressure after rarefaction occurred and also a portion of the dynamic pressure; the overpressure tended to crush the box and the dynamic pressure tended to tear it from the component. In the third location, the control box was attached to the windward side of a large system component. The control box would experience a reflected overpressure with a much longer diffraction phase than was experienced in the first location. Also, the control box would experience overpressure and a portion of the dynamic pressure. A significant point about the loading in this third location is that the reflected overpressure on the control box would be resisted by the large system component. Therefore this reflected overpressure would result in a crushing force on the control box, even though reflected overpressure does not normally result in a crushing force.

From these considerations, the magnitude and effect of increases as well as reductions in the damaging effects of blast were estimated. As in other problem areas previously discussed, quantitative measurements of this impulse enhancement could not be abstracted from source documents, but weapon effects principles and some weapon tests constituted a guide to estimating this effect in the postulated attack.

Physical Vulnerability Application

The vulnerability analysis for the water supply and sewage systems was developed in two phases.

First Phase of Analysis

In this phase, information was extracted from source documents and arrayed as a list relating physical items such as buildings, tanks, pipes, etc., to damage levels for a range of overpressures. However, in extracting and tabulating, we made decisions as to the accuracy and relevance of the source information, since the information was of varying scope and reliability, as already noted. On the basis of expected value criteria, we created Tables 14 through 18, which relate damage levels on given system components to the incident overpressure of a 5 MT weapon, under the assumption that the structures would be in the Mach region. Although such events as a precursor could alter damage level, near-ideal conditions of weapon effects were assumed to prevail. Aside from blast, other damaging agents, such as fire, were not included in the data of Tables 14 through 18.

We included the facilities of other municipal services, such as natural gas supply and electric power, because damage to these services would affect the operation of the water and sewer systems, and in turn, the latter would affect other services.

These tables, then, were based on the average or generalized assumed environment and characteristics of structural items in nuclear attack.

Second Phase of Analysis

The second phase of the vulnerability analysis was concerned with modifying the values in the above-mentioned tables, which are based on the average or commonly assumed environment and characteristics of the item in question. The modification consisted of changes of the damage level-overpressure relationship according to the particular environment and characteristics of the item being studied. It is this step that causes iso-damage curves on a map not to be concentric with overpressure curves or thermal intensity curves.

In any complex systems analysis, there will be numerous details of environment and physical characteristics which will greatly alter the expected level of damage derived by reference to a damage level table. The location of an item within a building, may significantly affect its expected level of damage. The type and moisture content of the soil surrounding a basement affects the response of the basement walls. The critical overpressure may be affected by a factor of 2, depending on shielding and impulse enhancement. The critical overpressure of a surface tank may vary by a factor of 2, depending upon the level of liquid in the tank. The level of damage to a wall and the contents of a building will depend on blast wave orientation and topographic features. A motor control center or power line may resist the direct blast pressures, yet be rendered inoperable as a result of the failure of a nearby tree. The damage level sustained by some pieces of equipment greatly depends on whether or not they are operating at the time of burst. Blast damage to a structure may be minor, yet structural failure may occur as a result of fire from short circuiting or from ruptured fuel lines and fuel tanks.

These and numerous other relationships, such as all of the interdependencies of the various components of a system, had to be considered in order to temper the values from damage level tables to conform with the peculiarities of the environment and characteristics of the item or system of items under study. Therefore, the values found in Tables 14 through 18 will not conform perfectly with the vulnerability analysis of the water supply and sewage systems in San Jose, nor will the damage levels from the tables be applicable to any other specific utility system without due consideration for the many particulars and uncertainties associated with any complex utility system.

Table 14

GUIDE FOR ANALYZING VULNERABILITY OF WATER SYSTEM TO 5 MT BURST

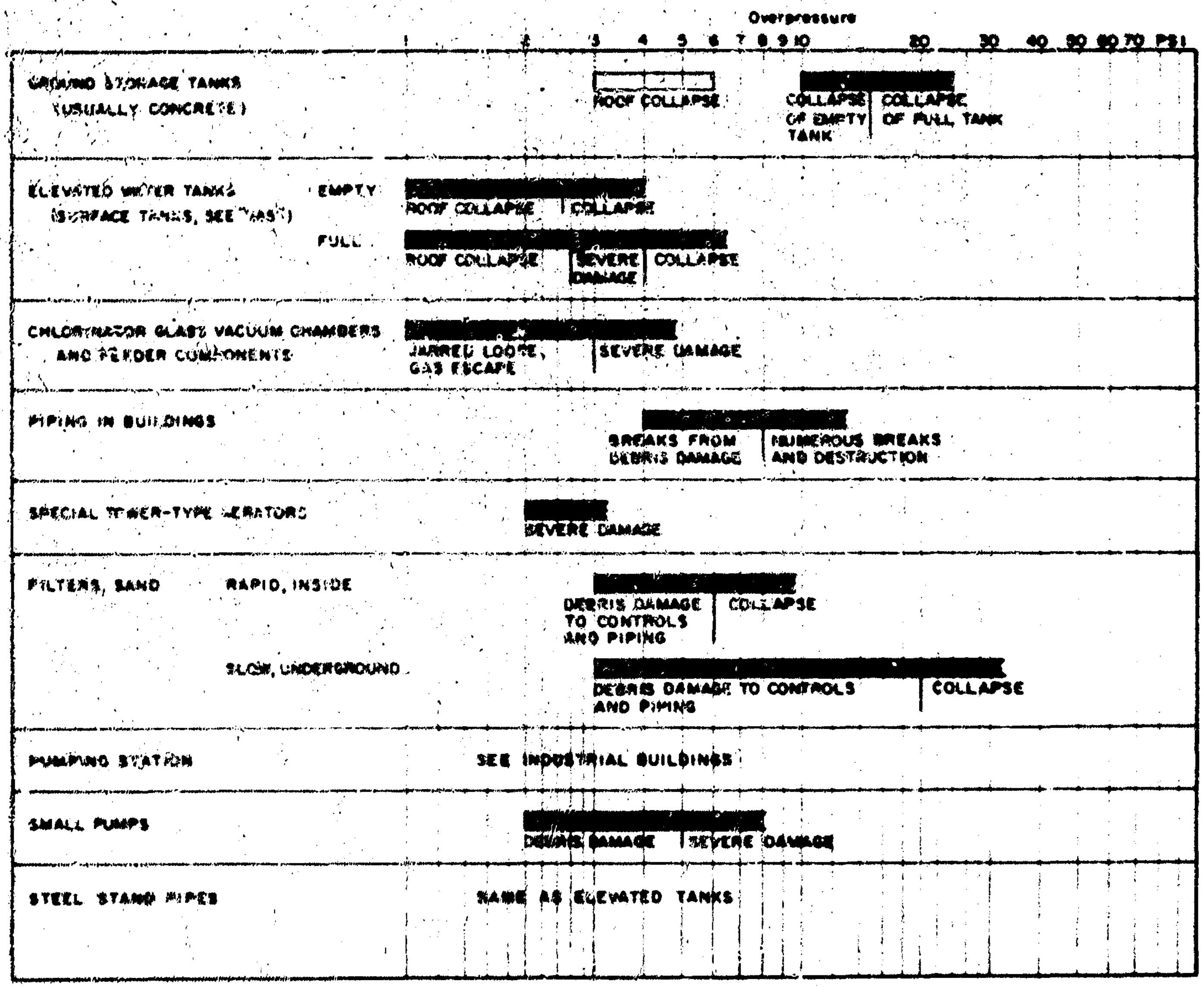


Table 14 (continued)

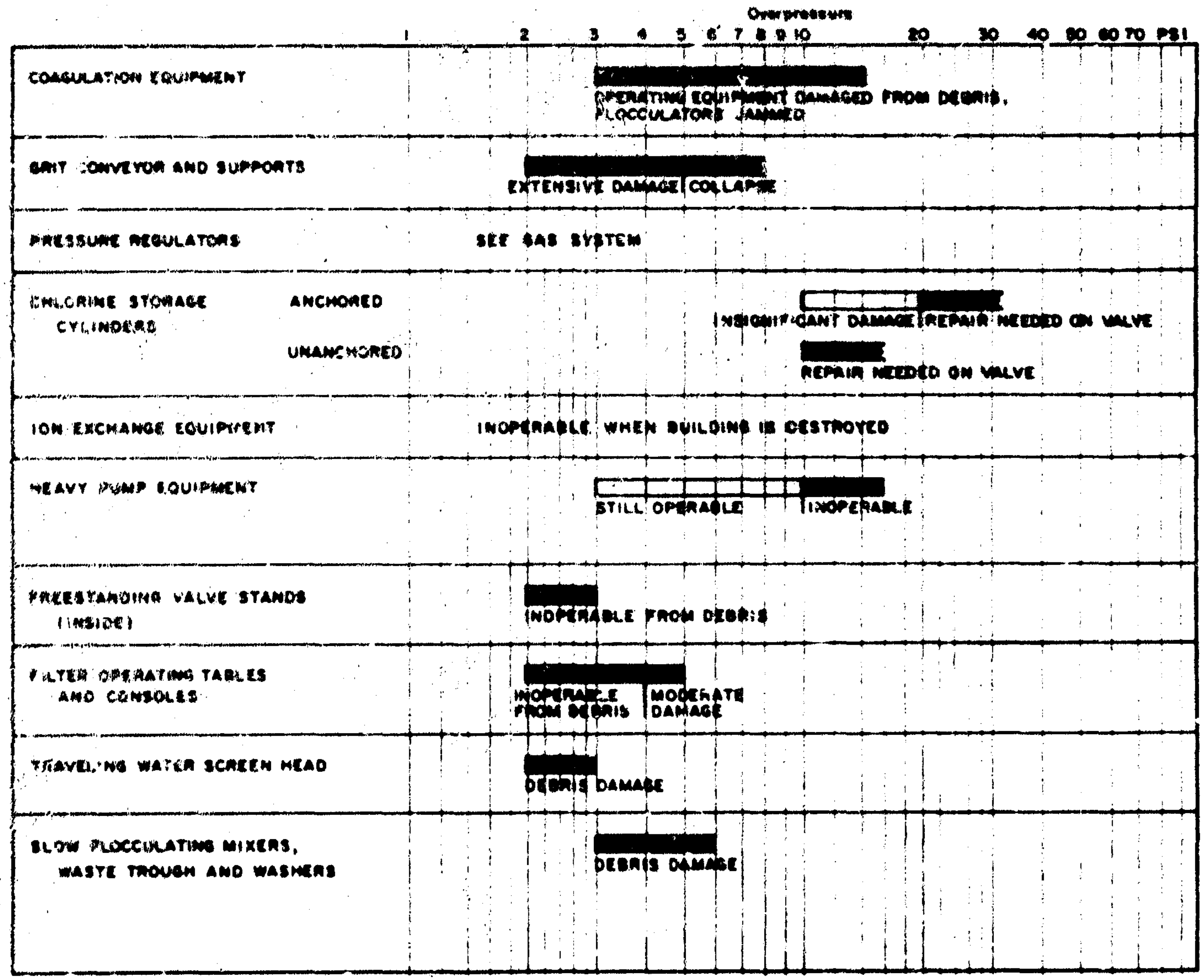


Table 14 (continued)

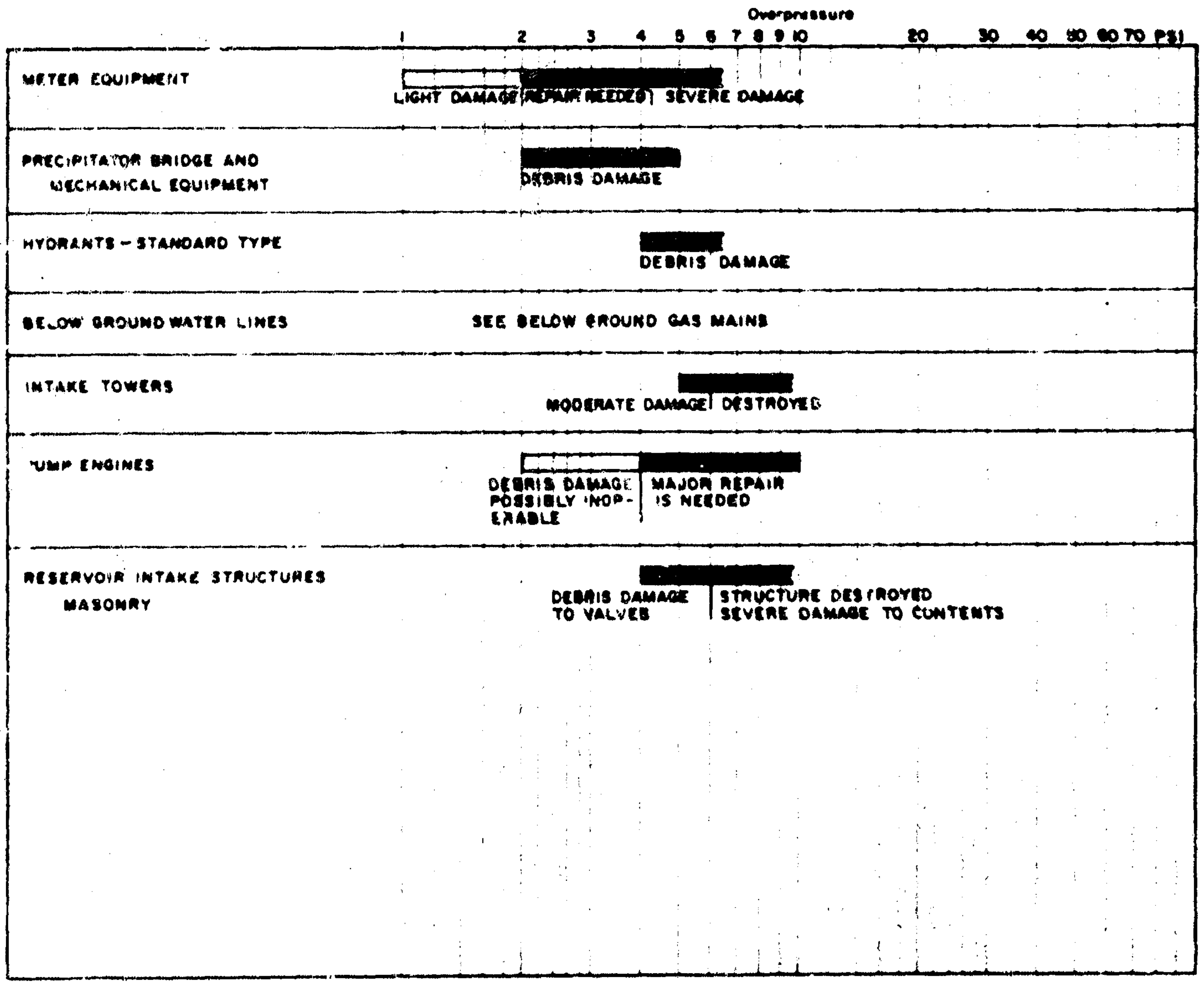


Table 15

GUIDE FOR ANALYZING VULNERABILITY OF SEWAGE SYSTEM TO 5 MT BURST

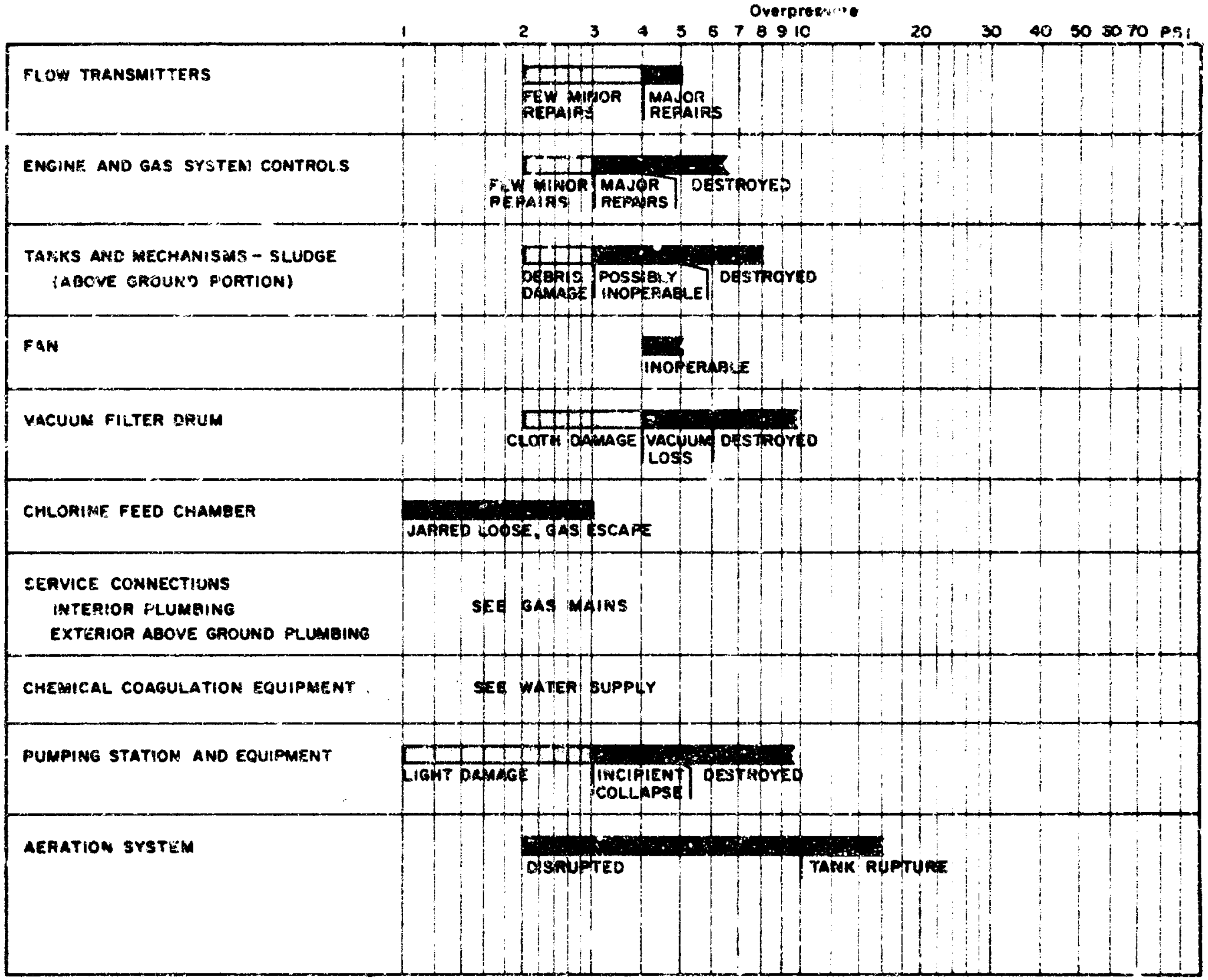


Table 15 (continued)

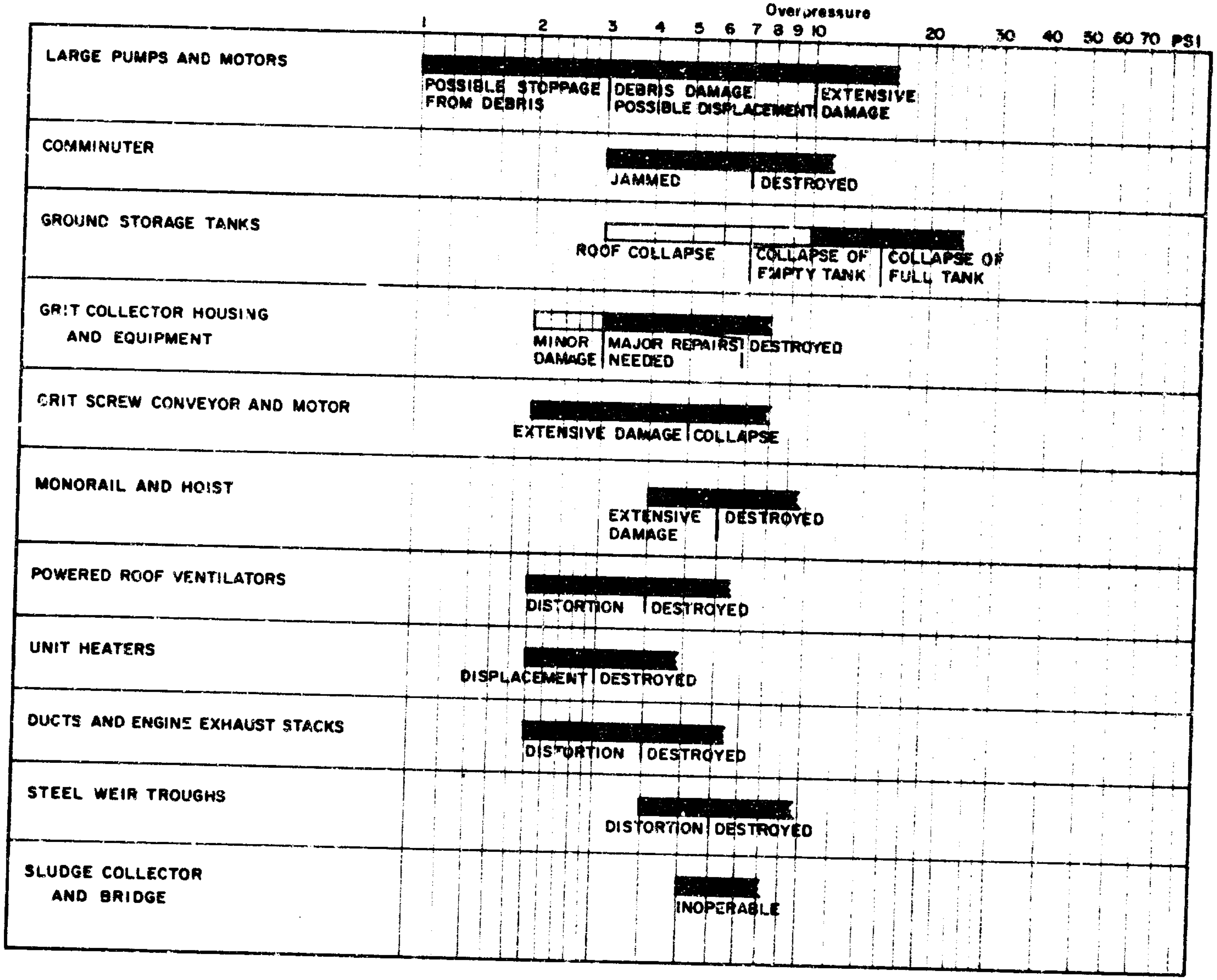


Table 15 (continued)

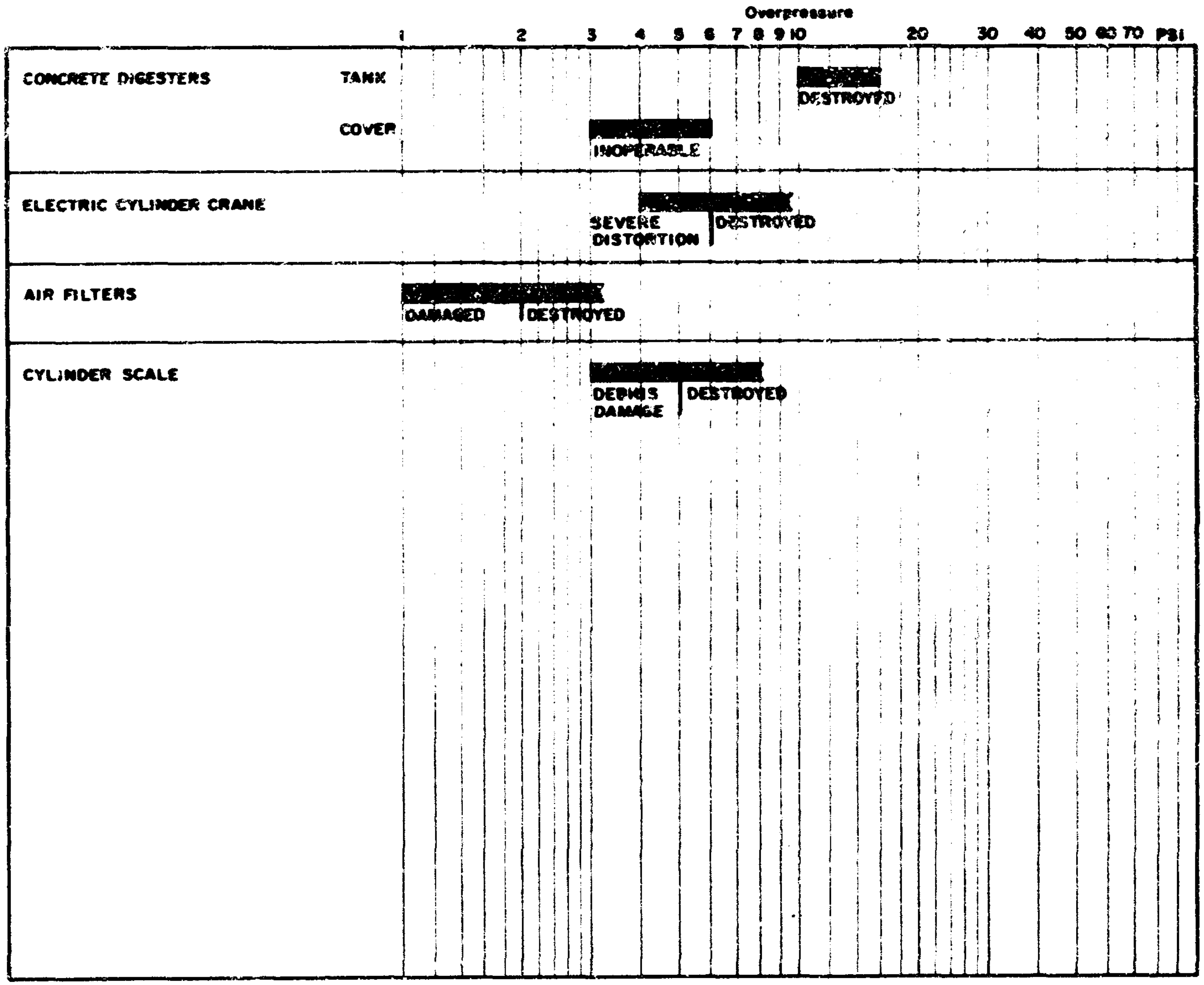


Table 16

GUIDE FOR ANALYZING VULNERABILITY OF INDUSTRIAL BUILDINGS TO 5 MT BURST

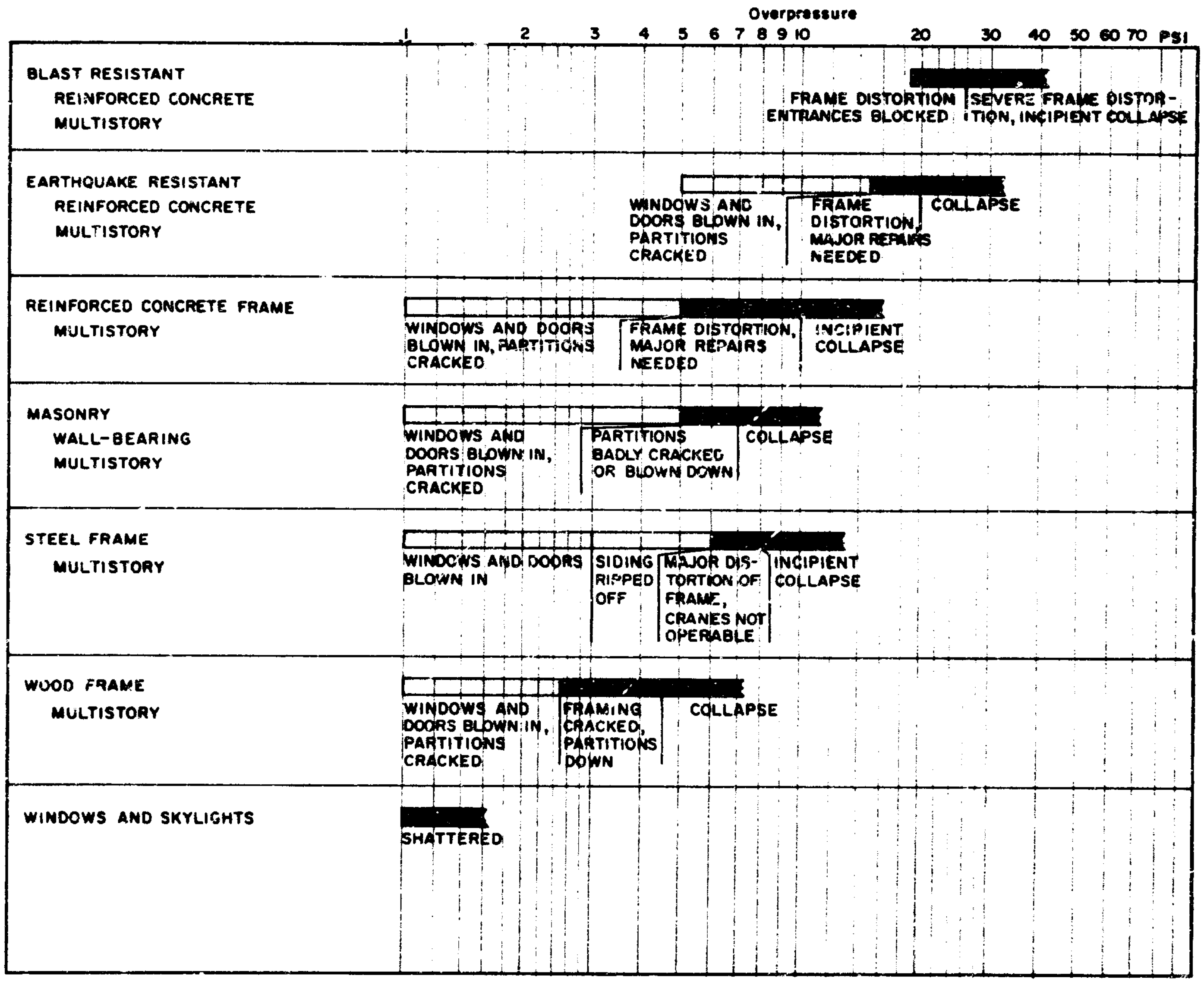


Table 16 (continued)

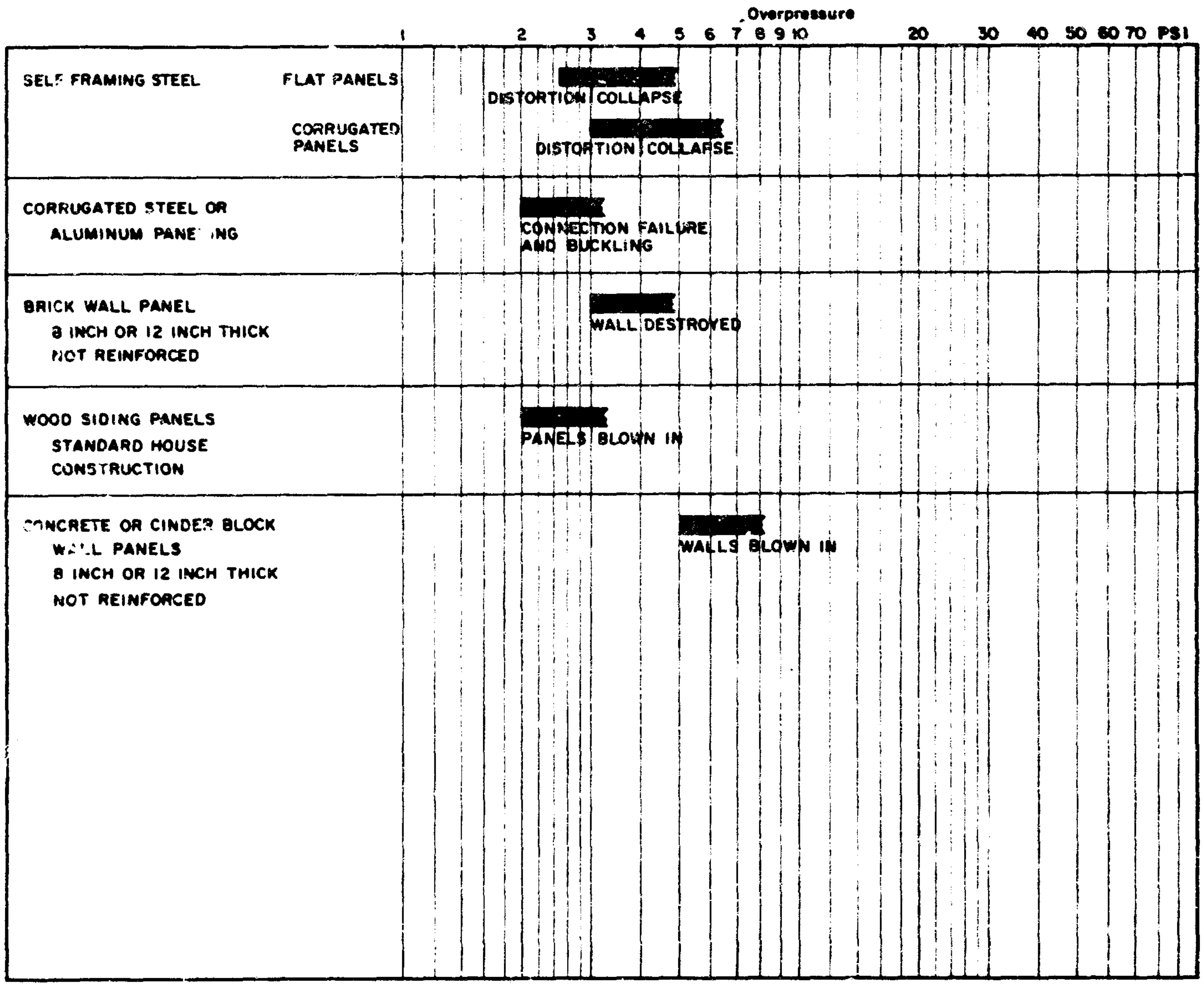


Table 17

GUIDE FOR ANALYZING VULNERABILITY OF ELECTRIC POWER SYSTEM TO 5 MT BURST

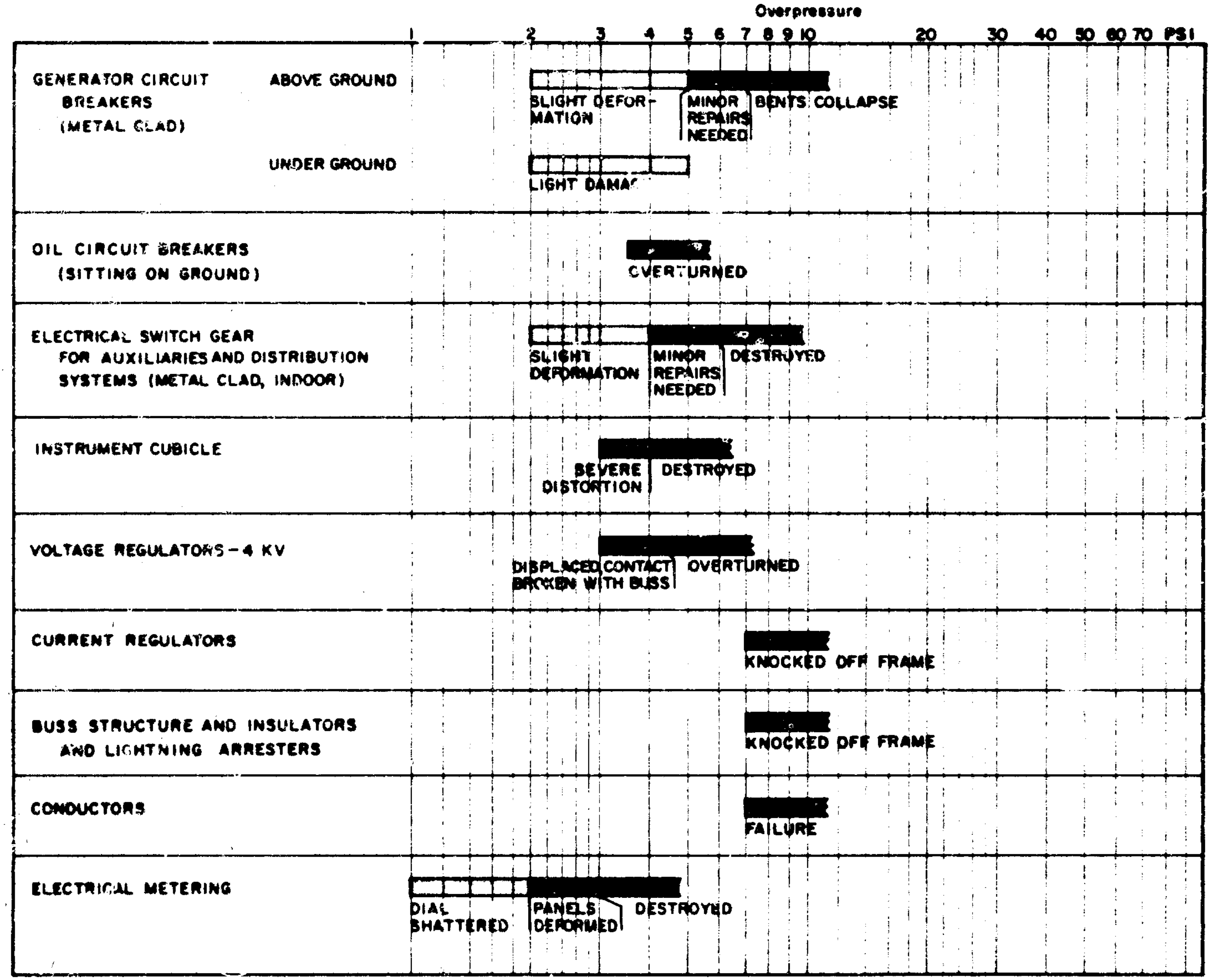


Table 17 (continued)

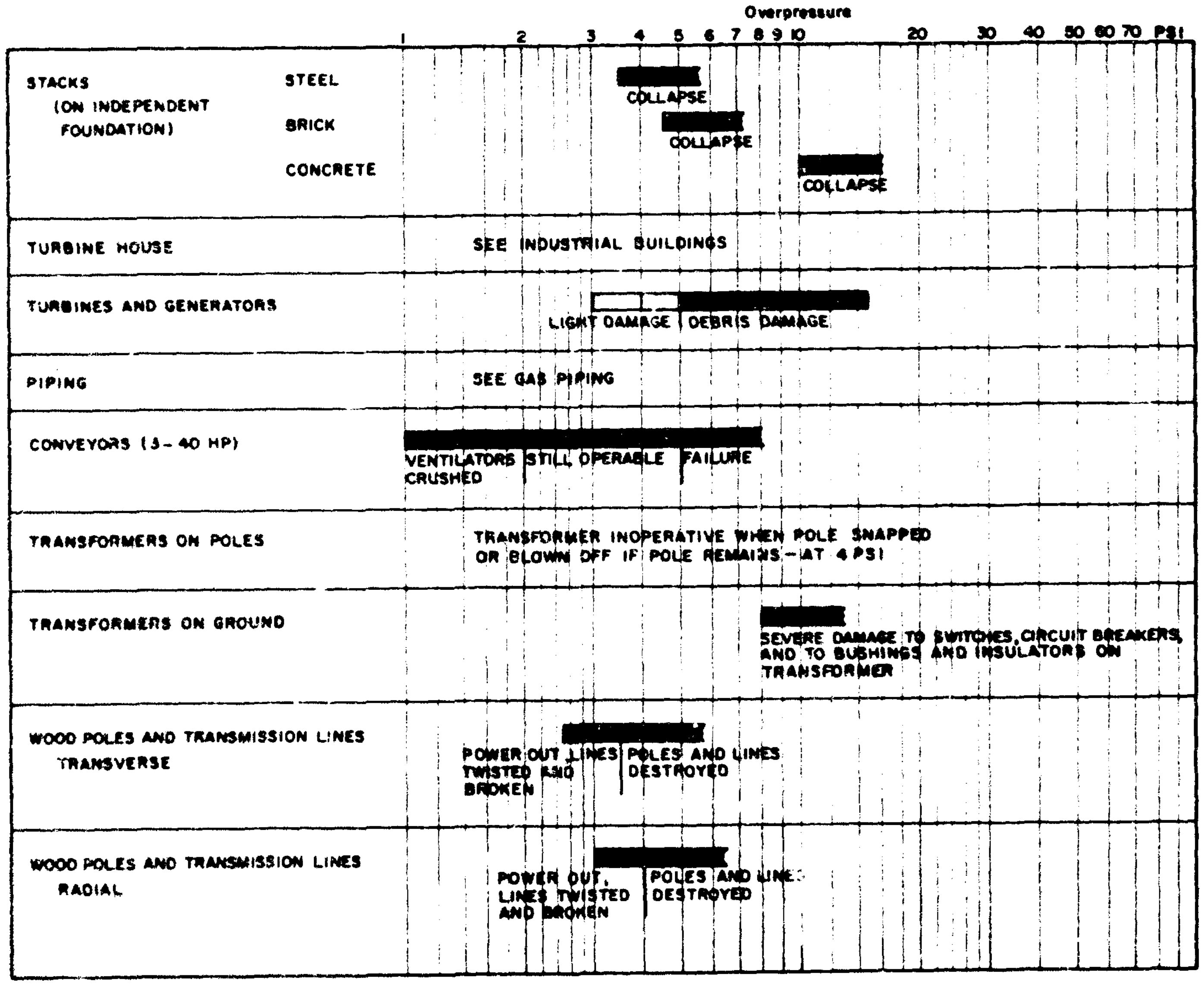


Table 17 (continued)

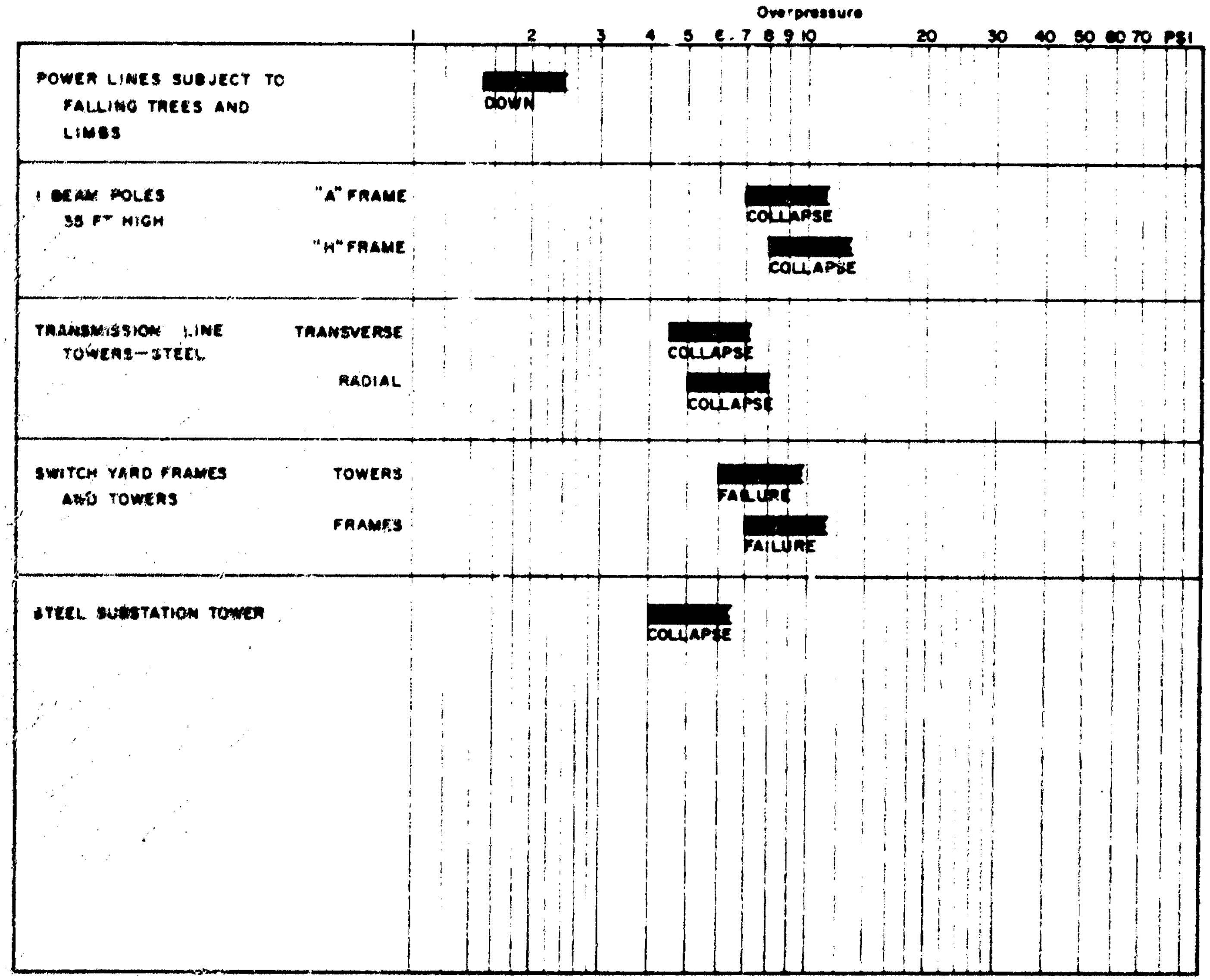
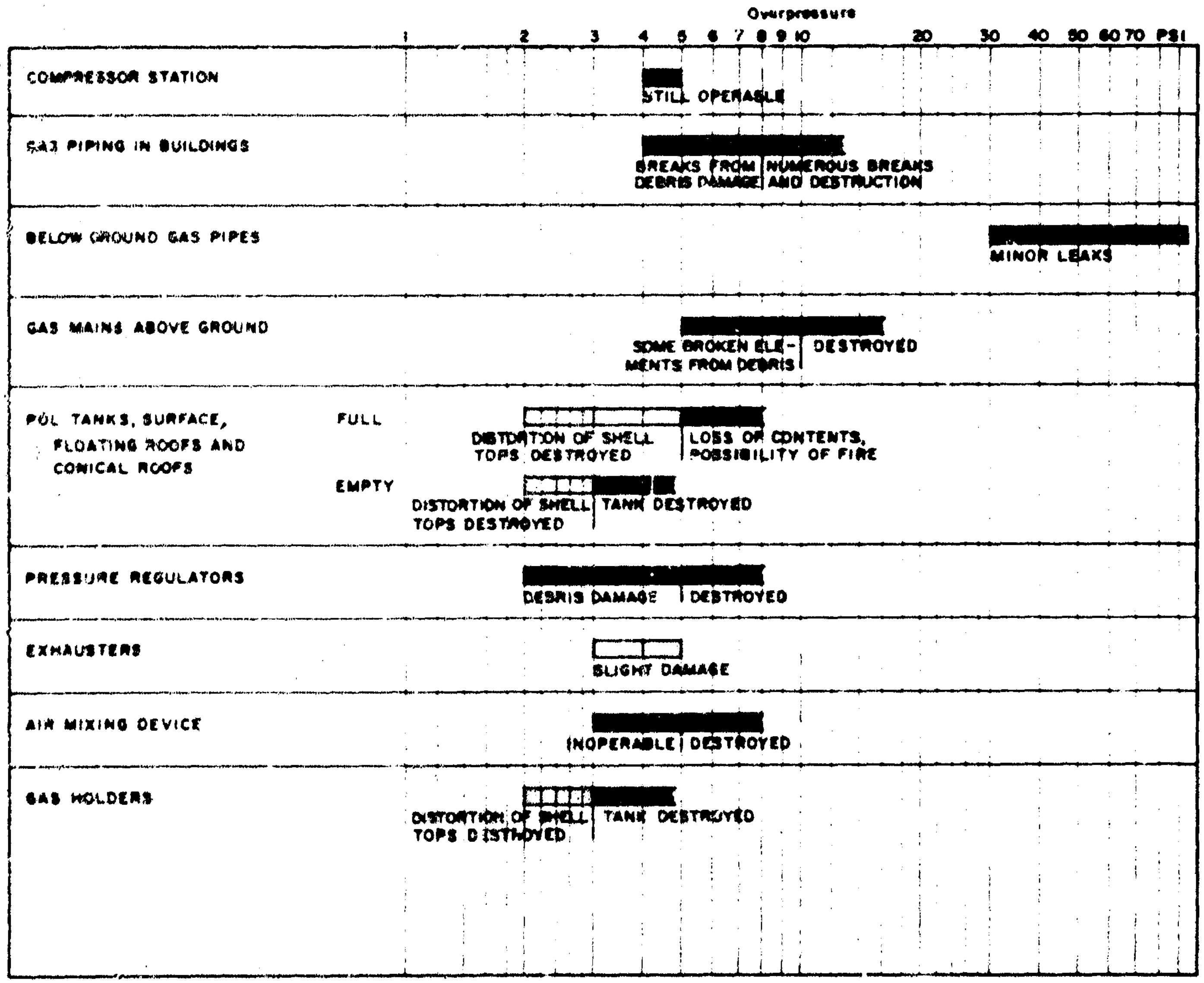


Table 18

GUIDE FOR ANALYZING VULNERABILITY OF NATURAL GAS SYSTEM TO 5 MT BURST



VI WATER NETWORK ANALYSIS

Summary

The problem of whether water will be available for firefighting and for fallout decontamination efforts during the period after nuclear attack depends on the ability to understand the water network in an area.

Practically any change or damage to the water system will alter the water pressure in at least part of that system. An automated water network can compensate for small changes but is inadequate to handle the larger alterations. Determination of exactly how the system will function requires the water network to be analyzed hydraulically. Without an analysis of the network, estimates of how a network will function are only guesswork and should be treated as such.

A knowledge of the pressures in the water network furnishes an indication of whether the water system is functioning adequately. The hydraulic analysis generally used to determine the pressures is the Hardy-Cross method.* This method employs hydraulic equations, graphs, and tables, and is essentially a laborious process of iteration--a step by step calculation of pressure differentials in loops, or portions of the pipeline network. Even with this extensive effort, the Hardy-Cross method cannot handle large system analysis without modification and computerization. This chapter describes the procedures for modifying the Hardy-Cross method to deal with large systems in an efficient manner. The procedures are for the preattack planner against nuclear attack. More study is required to implement the latest research and developments for a postattack analysis of this water system.

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* Analysis of Flow in Networks or Conductors, Univ. Illinois Eng. Exp. Sta., Bull 286 (1936).

Other iterative methods have been explored to solve the water network problems, and a method advanced by Davidon[1] proved the most promising but requires further development before it can compare with the efficiency of the recent modification to the Hardy-Cross method, as is explained later. Davidon's simplified method is given in Appendix B.

Background

In the analysis of situations after nuclear weapon attack, one of the major concerns is the water supply system that would experience emergency demands from the firefighting and decontamination forces. Not only are these demands extreme, but the situation is further aggravated by the loss of water because of broken pipelines. The damaged area must be isolated by closing the valves to that area.

A nuclear detonation will cause scattered fires, if not a mass fire, and the lack of water can frustrate the forces attempting to contain the fires. The radioactive fallout is broadcast by prevailing winds and descends to the ground in the form of dust. Since the decontamination methods will usually require water (street flushing, firehosing), the lack of water can slow the area recovery, endangering both rescue operations and travel through areas contaminated by fallout.

It may not be possible to ascertain the amount of water that is available in different portions of a city under attack until the system is actually tried out. Because emergency measures may close off some pipelines and reroute the water, the water needed in undamaged areas may travel through unaccustomed routes, and knowledge of the new network may not be available. For efficient postattack recovery, the water system must be analyzed to locate recovery forces in a proper manner, so that the water flow in critical areas will not be reduced below an effective level. City fire departments today sometimes lose precious time by sending more equipment to a fire than the nearby water lines can support, and the fire rages on while equipment adjustments are made.

As postattack analysis progresses in the future, the understanding of the water network will be of increasing importance. A scenario of postattack activities should contain some estimate of the water system, since without a water network analysis, the allocation of firefighting and decontamination forces could be ineffective.

A method most commonly used to analyze water networks was developed by Hardy-Cross in 1936. The method, which was originally computed by hand, is now calculated on electronic computers. The Hardy-Cross method in its original form is inadequate to handle a large system because of the time required to run these networks on the computer, and the tedious data preparation necessary to achieve a solution. Modification of the Hardy-Cross system in recent months has bypassed its shortcomings, and it can now be an efficient tool to analyze even the large water networks.

Basic Components of Water Network

In a municipal water distribution system, the pressure throughout is maintained between desired limits. As the water is taken out of the system, the pressure drops, and more water must be added at a higher pressure. The water enters the network from reservoirs, storage tanks, and wells. The well pumps are regulated by the water height in reservoirs and storage tanks, or by the pressure in the system. The pumps not only help replenish the supply of water but also help meet the water demands.

A water distribution system in a large city is made up of a number of smaller networks of different pressure zones; San Jose, for example, has 29 pressure zones. To pass water from one zone to another, pressure reducing valves and booster pumps are used which maintain the difference in pressures between networks.

For the postattack problem, the immediate question is to determine whether the damaged water system can support the firefighting and decontamination equipment. This question is essentially a question about adequate pressures, within limits, in the water system.

To determine whether the pressure at every point in a network is within the desired limits, the network must be analyzed. In the Hardy-Cross method of analysis, a water network diagram must be set up. The analysis will not indicate where new lines should be placed but will only calculate the water flow in the lines given. If a system is damaged, the Hardy-Cross network analysis cannot tell how to repair that network, but it will analyze a new postulated system and show whether it will operate near the desired limits as designed. If upon analysis, the postulated system will not function as was hoped, new information can be learned from that analysis which will aid in designing a network that will finally prove satisfactory.

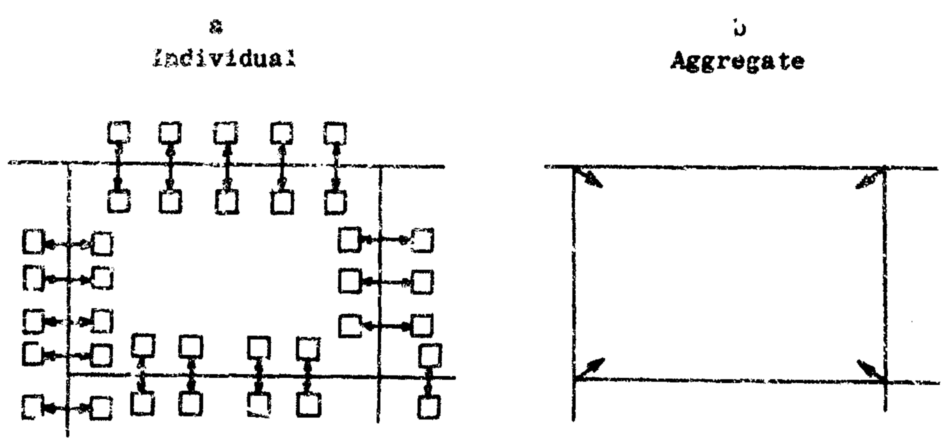
Hardy-Cross Method of Balanced Heads

To formulate the water flow in a network, the static problem is solved for given demands. Water input and output rates are given in terms of million gallons per day (mgd) or in gallons per minute (gpm).

To reduce the size of the network of each zone, the individual demands (i.e., individual house water demands to the main line) are not taken all along a pipeline as they occur, but are aggregated at the junctions.

Figure 6

SCHEMATIC OF WATER DEMAND POINTS



The network in Figure 6a is water going to many places. Figure 6b aggregates the flow of Figure 6a into water going to only four places. The network can be further reduced by eliminating the smaller lines (4 and 6 inch diameter pipes), and for a well-designed system, larger lines can be removed from the network with little loss of accuracy. Care must be taken when setting up the skeleton system since distorted results can be obtained if there are many parallel connections with smaller pipes.

Figure 6b, the aggregated network, is really only a portion of a large water system such as San Jose has. This boxlike portion is called a loop, so that a diagram of small portions of a city system would look like the diagram given in Figure 7.

As the legend of Figure 7 indicates, the loops are numbered consecutively, and each corner of a loop is called a node, designated by encircled numbers, again given consecutively. Each pipeline in the loop is presented as a straight line, and given a number--1, 2, 3, etc.; Figure 7 shows 19 pipelines.

Note that in Figure 7 the node numbers occur from left to right, and this sequence continues for the next level of lines. The pipeline numbers, however, must take account of vertical as well as horizontal lines.

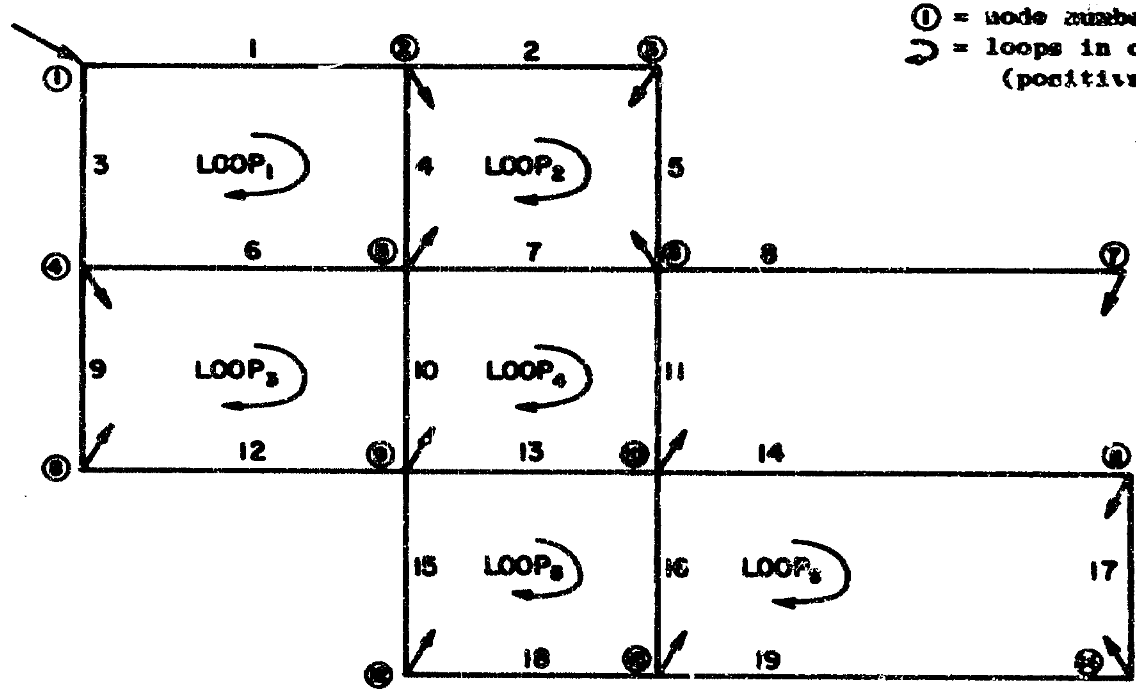
With this framework so far, we now need to know a few more terms, as shown in Figure 8: water demands, elevation and pseudo loop. Water demand is straightforward; numbers in Figure 8 of three digits or more are the demands of that sector of the pipeline network in gpm or mgd. For example in loop 2, all four nodes of that loop have the same demand: 278 gpm.

The elevation (EL) refers to the relative water elevation in the network and it could be the elevation in feet above sea level.

Figure 8 is also a diagram showing the minimum inputs needed by the analyst for any water network: loop, nodes, direction, and water desired. A pump at node 3 inputs a constant amount of water and this is taken into account in the initial estimate of the flow. In practice, the amount of

Figure 7

WATER NETWORK DIAGRAM



Legend

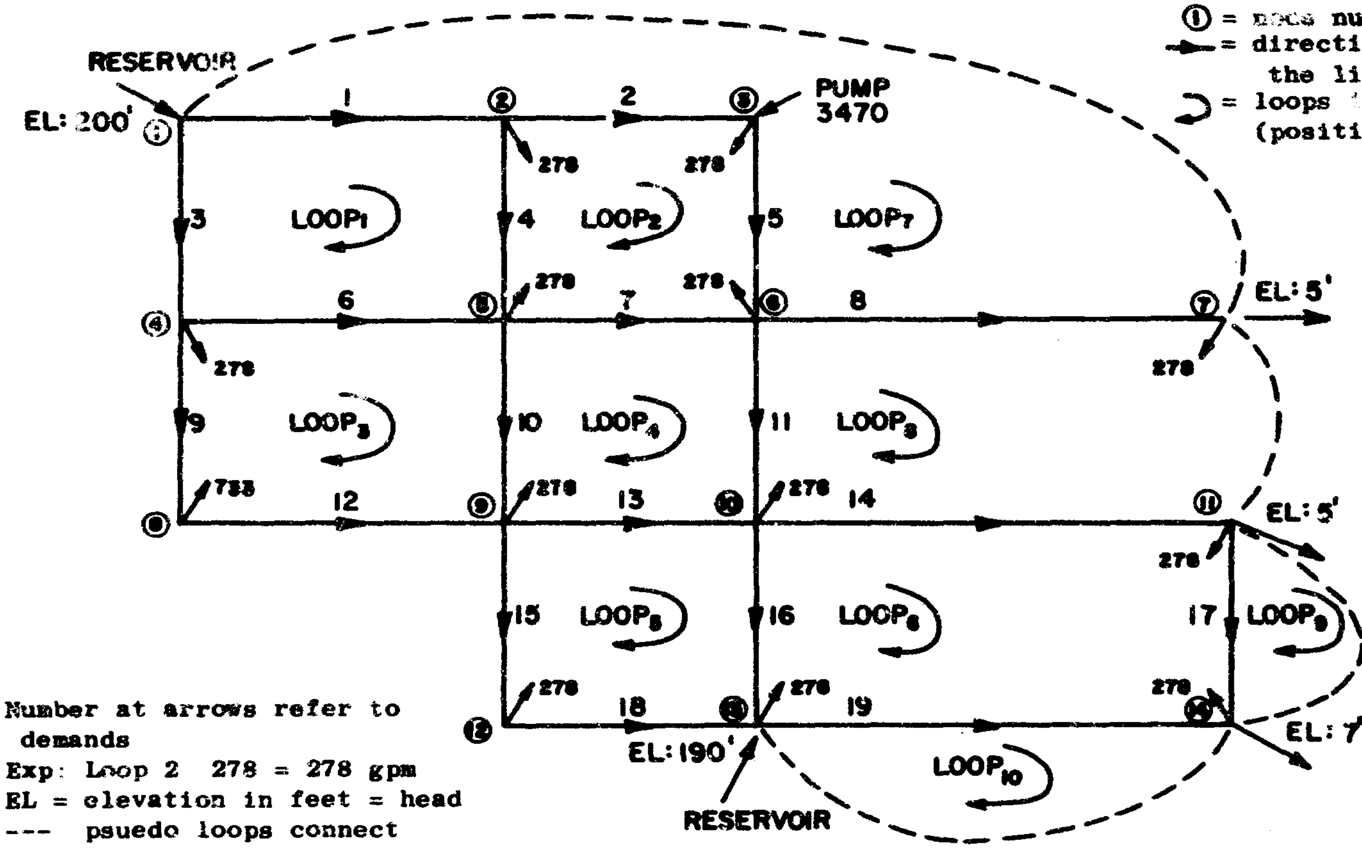
1 = line number

① = node number

= loops in clockwise direction (positive direction)

Figure 8

MINIMUM KNOWLEDGE OF THE SYSTEM REQUIRED TO ANALYZE THE NETWORK



Legend

1 = line number
① = node number
→ = direction of water flow in the line
↻ = loops in clockwise direction (positive direction)

Number at arrows refer to demands
Exp: Loop 2 278 = 278 gpm
EL = elevation in feet = head
--- psuedo loops connect elevation points in an arbitrary manner

water input by a pump is not a constant but varies with the pressure and will be discussed later. The only other entity needed is an artifact of the Hardy-Cross method--the pseudo loop.

As the water flows through a pipe, the energy lost due to friction or viscosity of the water and the turbulent motion is called the head loss, measured in feet. The relation between head loss h and the water flow Q is given experimentally by

$$h = kQ^{1.85}$$

where k is the numerical constant for a particular pipe. (See Table 19 for definitions of symbols.)

TABLE 19

SYMBOLS FOR HARDY-CROSS METHOD

L = length of a pipeline in feet

D = diameter of a pipeline in inches

C = Hazen Williams coefficient which is a constant often taken as 100; it varies with the type of material of the pipe and the age of the pipe

Q = the water flow in a line expressed in gallons per minute

k = the friction term for a pipeline

$k = 10.43\ L/(D^{4.87}C^{1.85})$

h = the head loss measured from one end of a pipe to the other and is expressed in feet

h' = the head loss with a correction term added to the flow $[h' = k(Q + q)^{1.85}]$

The two basic hydraulic principles applicable to network flow are

$$\Sigma Q = 0 \quad \text{node equation}$$

$$\Sigma h = 0 \quad \text{loop equation}$$

The node equation states that the water flow in a network must be balanced at the junctions, and the loop equation states that the algebraic sum of the head losses around a closed circuit must be zero. The equations cannot be solved directly, so the well-known Hardy-Cross relaxation technique is commonly used. With the Hardy-Cross (balanced head) method, the estimates for the initial magnitude and direction of the water flow are made, satisfying the node equation that the water entering and leaving a node must equal. If the network is balanced, the loop equation will also be satisfied, but since the initial flows are only estimated, the sum of the head losses is not zero, and a correction term is added to the flow values. With the new flow estimates, the method is repeated in an iterative manner until the sum of the head losses in every loop is less than the prescribed maximum error.

The derivation for the flow correction, q, in each loop is given as follows:

The sum of head losses for the pipeline is taken in a clockwise direction for each loop of the network, using a plus sign for the head loss when the water flow is in a clockwise direction in that loop, and a minus sign when the water flow is in a counterclockwise direction with respect to the loop.

The equation for loop 1 in Figure 8 is

$$h_1' + h_4' - h_8' - h_6' = 0$$

where h' is the value of the head loss when the system is ultimately balanced: where $h' = k(Q + q)^{1.85}$ and $h = kQ^{1.85}$. The subscripts designate pipeline numbers (for convenience called simply line numbers hereafter).

Then the equation for loop 1 can be written as

$$k_1(Q_1 + q)^{1.85} + k_4(Q_4 + q)^{1.85} - k_6(Q_6 + q)^{1.85} - k_3(Q_3 + q)^{1.85} = 0 .$$

Using the binomial expansion and ignoring terms in higher powers of q, then solving for q given

$$q = \frac{\Sigma h}{1.85\Sigma(h/Q)} = \frac{h_1 + h_4 - h_6 - h_3}{1.85(h_1/Q_1 + h_4/Q_4 - h_6/Q_6 = h_3/Q_3)} .$$

To account for differences in elevation, psuedo loops are introduced (as shown in Figure 8 by the dotted lines) and the head loss of the dotted line is taken as a constant value equal to the difference in elevation. The number of pseudo loops equals the number of given elevation points minus one. The water introduced by a pump is implicitly expressed when establishing the initial estimates of water flow by satisfying the node equations.

Figure 9 presents the steps in the analytical procedure, and Table 20 presents an example of the inputs and outputs for the method.

In the original form of the Hardy-Cross method, the number of iterations necessary to reach a given limit of accuracy varies considerably. For example, the data presented in Table 20 required only 37 iterations to reach the limit of no more than 2-ft head loss per loop; with a slight alteration of the initial flow estimate, and the description of loops 9 and 10, some 185 iterations were required to reach the same limit. By taking a slightly different relation for loops 8 and 9 (in two more computer trials) and asking for a limit of 0.75 feet, the analysis would require some 234 and 236 iterations. The reason for the great difference in the number of iterations required to reach a solution is that in the Hardy-Cross method the corrections q tend to oscillate violently and can often be slow in converging to a solution. The unmodified Hardy-Cross method is too unreliable to handle large networks. Techniques to make the method more dependable, by speeding up the rate of convergence, are discussed later.

Figure 9

PROCEDURE FOR HARDY-CROSS BALANCED HEAD METHOD

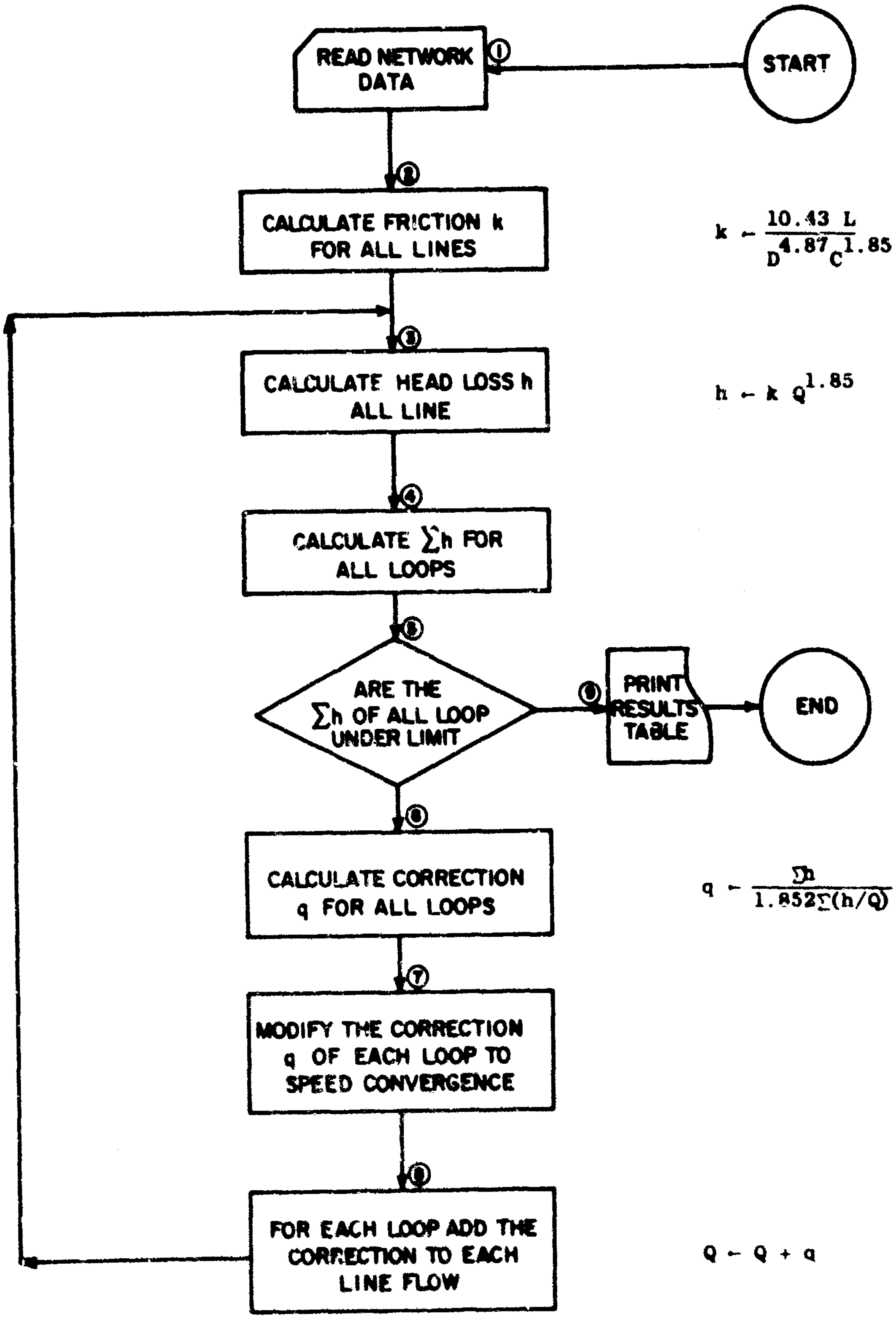


Table 20

EXAMPLE INPUTS AND OUTPUTS FOR HARDY-CROSS ANALYSIS

LOOP DATA

Loop	Unbalance	No. of Lines	Lines in the loop (see Figure 8) 1	2	3	4
1	0	4	1	4	-6	-3
2	0	4	2	5	-7	-4
3	0	4	6	10	-12	-9
4	0	4	7	-11	-13	-10
5	0	4	13	-16	-18	-15
6	0	4	14	17	-19	16
7	195	4	-1	-2	-5	-8
8	0	3	-14	11	8	
9	-2	1	-17			
10	-183	1	19			

Line Data Input

Line No.	Hazen-Williams Constant, C	D Diameter (inches)	L Length (feet)	Estimated Flow, Q (gpm)
1	100	24	9,000	3,634
2	100	8	2,000	356
3	100	28	5,000	4,000
4	100	24	5,000	3,000
5	100	18	5,000	3,548
6	100	10	9,000	722
7	100	16	2,000	3,000
8	100	18	6,000	7,000
9	100	24	2,000	3,000
10	100	10	2,000	444
11	100	10	2,000	730
12	100	18	9,000	2,267
13	100	10	2,000	1,233
14	100	20	6,000	7,225
15	100	14	6,000	1,200
16	100	24	6,000	7,000
17	100	12	6,000	0
18	100	18	2,000	922
19	100	20	6,000	8,912

Note: Limit = 2 ft Loops = 10 Lines = 19.

Table 20 (concluded)

	Line Data Output				
Line No.	Calculated Flow (gpm)	k	Head Loss (feet)	Loop No.	Error (feet)
1	422.9	3.618×10^{-6}	18.4	1	-1.59
2	334.3	1.657×10^{-4}	7.7	2	-1.55
3	3,406.9	9.518×10^{-7}	3.3	3	-0.77
4	3,610.6	2.010×10^{-6}	7.7	4	-0.94
5	3,526.3	8.113×10^{-6}	29.6	5	-0.91
6	495.4	2.527×10^{-4}	24.4	6	-0.48
7	4,374.1	5.746×10^{-6}	31.3	7	-0.74
8	7,394.9	9.736×10^{-6}	139.9	8	-1.52
9	2,633.5	8.041×10^{-7}	1.7	9	-0.30
10	-546.2	5.615×10^{-5}	-6.5	10	-0.66
11	-227.5	5.615×10^{-5}	-1.3		
12	1,900.5	1.460×10^{-5}	17.0		
13	1,457.5	5.615×10^{-5}	40.0		
14	9,756.2	5.840×10^{-6}	140.2		
15	-381.2	3.294×10^{-5}	-2.0		
16	8,349.2	2.412×10^{-6}	43.4		
17	-235.1	6.957×10^{-5}	-1.7		
18	-659.2	3.245×10^{-6}	-0.5		
19	11,247.3	5.840×10^{-6}	182.3		

Water Network Developments

In water network analysis, a saving in time and money can be achieved if the computer is used to its fullest capacity to encompass the more comprehensive water network problems, from data preparation to optimizing among alternatives. The network computer programs are a carryover from the hand computation schemes and should be redesigned because in recent months, a number of developments have occurred which broaden computer use as well as accelerate previous methods. The faster network computer programs, with their easier data preparation methods, are going into the design for new network distributions that yield optimum costs.[13] A list of analytical areas that are being developed or should be developed in water network analysis is given below.

- More rapid convergence to a solution is most important to handle large networks.
- The initial flows are being estimated by the computer program in terms of the known inputs and takeoffs.
- More floxible data inputs in a form easiest to prepare should be available, with the computer doing as much internal preparation as possible.
- It is essential to develop the ability to handle all types of facilities, such as pumping stations, storage tanks, booster pumps, etc., in a realistic manner.
- The computer output listings should be in a form most useful to the user, giving the pressures at all points in the system.
- A dynamic network analysis of the changing water demands over a period of a day is necessary to show the true conditions of the water system.
- There should be computer drawings showing the flow diagrams with labeled lines giving values of flow, pressure, and relative elevations.

- A computer sketch that gives pressure contours over a schematic of the water network would be quite helpful.

One of the most important modifications that can be made to network analysis is a method for a quick solution. For a large network, the computer time would be too expensive without fast and consistent convergence. Some modifications to the Hardy-Cross method have proved successful in reducing the number of iterations necessary to reach solutions. One method to reduce the number of oscillations of correction factors, as manifested by a sign change, is to reduce the correction by one-half, which compensates for over-corrections. Under-corrections, which can be seen by no change in sign in three iterations, can be increased by some factor, say 1.2 times the correction. Another device used to increase convergence is to concentrate on the terms that are most out of balance, and to ignore the terms that are within the specified limits. Still another method to speed convergence is to include the quadratic terms of the correction factor q in the binomial of the loop equations rather than just the linear terms used in the Hardy-Cross method. A feature which has aided in speeding up the convergence is to include additional control loops of the main lines of the system.[3] Although these control loops are redundant, they keep the important lines on a more consistent track toward convergence.

One of the tedious chores in the Hardy-Cross system is the requirement of initial estimates. In the past, good estimates were essential because of the long computer time required to reach a solution; however, with the modification to speed the convergence, it requires only ten or so iterations more to reach values as good as can be estimated. The computer costs are small compared to the man-hours required to do the estimating, and depending on the computer and the size of the network, the extra costs could be less than a minute of computer time.

When the initial estimates are eliminated, the data preparation is also simplified by removing the requirement that the direction of the flow be specified. The flow directions can be inferred by defining pipelines in terms of their two nodes, and thus the signs in the upper portion of Table 20 would be eliminated. The data preparation should be arranged in terms of the basic network properties, with the computer doing further preparation and checking. It has proved advantageous not only to have the properties of each pipeline given, but also to have the data prepared to include the lines at each node as well as the known inputs or takeoffs, and, if known, the ground elevation. Although the lines at a node can be determined from the input-line data which give its two nodes, this extra information is easy to obtain and allows for the computer to crosscheck the input information to catch human errors.[9]

In the network analysis, the water input from a well pump is taken as constant, but in fact, the flow from a well varies with the pressure. The booster pump must strain more to add water when the pressure is high, and using a constant flow can give misleading results. The variations of water input from a pump with pressure can be included in the Hardy-Cross calculation with the introduction of a table or an equation. Other water facilities such as booster pumps can be handled in a more realistic manner.

The output from the computer should be in a form most convenient to the user so that no more calculations are necessary. The usual practice is to think in terms of pressure in psi, and the data should be given in this form. The relative elevations, in terms of head loss, are also useful items to be included in the data output.

If the user is interested in picking the strong and weak points of the network in terms of pressure, the listing should be prepared to arrange the nodes in ascending order of their pressures. The ranking of the network points by pressure will prove both interesting and helpful in quickly identifying danger points.

Currently, to more fully understand the water network, the information given by the computer is transcribed onto a sketch of the network. The computer can neatly draw a schematic of the network with the pertinent values and save these hand steps. To have the computer make a sketch would require a grid to be superimposed over the network, and the x, y coordinates of each node would be included with the data preparation. Actually, finding the coordinates of the nodes would not be difficult since pipelines usually run along streets, and since scaled street maps are readily available. Also, a saving of time with improved accuracy would be derived from not having to measure the pipeline lengths, since the computer could calculate the lengths from the given coordinates. The nodes could be identified by their coordinate numbers rather than by an arbitrary set of numbers, and would thereby allow greater flexibility in analyzing two networks together, without the requirement of renumbering the nodes. The node coordinates are found only once, whereas transcribing the values to a schematic must be done every time the network is calculated with a variation in demands.

To obtain an overall view of a network, pressure contours are overlaid on the network schematic. The contour lines are currently estimated and drawn by hand, but the computer not only can plot the network schematic, but also can calculate and draw pressure contour lines at the same time, since all of the information is already in the computer after inclusion of the node coordinates. The user could immediately evaluate the network as it comes from the computer, with no need for further manipulation.

VII CONCLUSIONS AND DISCUSSION

Water Supply System

As a result of our analysis of the water supply system in San Jose, we concluded that the San Jose Water Works is highly dependent upon electric power and that without such power, its ability to deliver water is limited to about 90 percent of the total service area where it could deliver normal demand for about 2 days. After this initial 2 day period, it could then only deliver 25 percent of normal demand for about 47 days. In this power-off situation, the capacity of the water works is limited by the amount of water stored in distribution reservoirs and the amount of water that is able to be released from impoundment reservoirs.

It is clear, therefore, that without electric power the ability of the water system to satisy postattack water needs is limited to probably at most, the water needed for human consumption.

Any attempt to use water for the fighting of mass fires would rapidly deplete the water stored in the distribution reservoirs. Once the distribution storage was depleted, it appears improbable that use of water for firefighting or any other high rate consumption would be possible because of the limited gravity capability of the water system.

The assumption of areawide power failure in the immediate postattack period is our unconfirmed considered opinion, and therefore further investigation is needed to confirm or deny the possibility of power failure and determine the length of time that such failure would last.

If no power failure occurred, or if power were restored, we further concluded that the Water Works would be capable of supplying approximately 125 percent of normal demand without depleting available distribution storage. In other words, we concluded that the physical damage sustained by the water works was minimal and that after several days to at most a few weeks following the attack, full preattack production capacity and distribution would be available.

The preceding conclusion is based upon the operation of the system as of August 24, 1965. At that time the system was operated semiautomatically by the use of preset controls, which required the facilities to be visited at least once daily. Since the physical damage sustained by the system was limited to disruption of the functioning of these controls and no radioactive fallout was present, we assumed that the postattack operation of the system would be by manual control until the limited damage could be repaired.

Recently, the San Jose Water Works has begun fully automatic operation of the water system. The operation is controlled by computer and utilizes 16 leased telephone trunk lines to transmit data and commands between the computer control and approximately 116 remote telemetering installations.

Therefore at present, in addition to its dependence upon the power system, the water system is also dependent upon the telephone system.

Under the 1965 conditions of semiautomatic operation, we concluded that manual operation of the system after attack would not degrade the postattack capability significantly. If the same attack were to occur in the future, however, it would be much more difficult for the operating personnel to return to manual operation of the system, and loss of the automatic computer control would result in a more serious degradation of the postattack capability of the water system.

Since postattack manual control of the water system requires personnel to visit or be stationed at the various facilities periodically, the presence of fallout could seriously hamper and complicate manual control of the water system and significantly increase the ramifications of the light damage.

The San Jose Water Works is a large complicated system obtaining its water supply from both gravity surface water and pumped groundwater supply sources. Both the gravity and pumped water supplies are distributed geographically throughout the system. Because of this, the system is able to withstand light damage quite well. As the intensity of attack increases, the postattack capacity would decline. Also, as the location of the attack was varied, keeping the intensity constant, the results would remain relatively constant. This would result in a vulnerability distribution for the system.

If, on the other hand, the system relied on a single source for its water supply, the results of an attack would be highly dependent upon the relative locations of the attack and the source of supply. An analysis of a system of this type could easily result in a vulnerability which would be represented by a step function.

The above considerations may be useful for analysis of other cities in the FIVE CITY STUDY. Can the results provide a point on a vulnerability distribution which may then be applied to like cities, or are the results merely one end of a step function unique to the city in question?

During the course of conducting transattack and postattack analyses, analysts postulate the containment of mass fires and the decontamination of radioactive fallout. One method of accomplishing this would require large volumes of water, and hence the capability of the water system to deliver water becomes important. In our analysis, we concluded that in the event of power failure, the San Jose Water Works would not be able to deliver the required water for such high consumption rate purposes. In the event of no power failure, we stated that approximately 125 percent of normal demand with a normal pattern of distribution could be satisfied without depleting available distribution storage. Whether sufficient water would be available for high consumption rate usage with a nonnormal demand pattern is unknown.

Even in a completely no damage situation, it is doubtful that the normal water supply system for the average city could supply the water required for the large scale firefighting that uses water. The systems are designed and sized for handling the normal frequency of fires encountered in average cities of their size and are not designed to deliver large volumes of water in numerous locations simultaneously. The same is true for decontamination. The normal system could probably supply small decontamination projects in sequence but not many large projects simultaneously.

It would appear fruitful for future research to investigate this problem. One method for accomplishing this would be to obtain estimates of the water demand (required supply rates and locations of demand) and use a rapid method of network analysis of the type discussed in Chapter VI to determine if these demands could be satisfied.

Sewage System

As a result of our analysis of the San Jose sewage system, we concluded, as we did with the water system, that the postattack functioning of the system is highly dependent upon electric power. The postattack problem, however, is somewhat different. With water, we could not deliver it without power. With sewage, we could collect it with no significant problems but we could not accomplish treatment of the sewage.

Therefore, as far as the City of San Jose is concerned, there is no sewage collection and disposal problem after attack. Postattack operation simply bypasses the sewage treatment plant and disposes of the sewage in San Francisco Bay.

Regionally, however, the postattack sewage problem is quite different. The sewage treatment plants of Menlo Park, Palo Alto, Mountain View, Sunnyvale, Milpitas, as well as the San Jose-Santa Clara plant, all form a semicircle around the postulated nuclear burst. Therefore, all these treatment plants will be inoperable postattack and will be dumping raw sewage into the southern end of San Francisco Bay. The postattack sewage problem, then, is not what problems are encountered within the city as a result of the attack but rather what problems are encountered regionally as a result of the attack. Are the regional problems of pest-vector control, water pollution, and odor control significant after attack, or will they take care of themselves until the sewage treatment plants are repaired? In terms of regional considerations, is postattack sewage treatment a nicety or a necessity?

The problem of the availability of power to operate the sewage treatment plant is also different from that encountered in the water supply system. With water, the power is supplied by another utility. With sewage, however, the treatment plant generates its own power. The loss of power, therefore, is strictly a sewage problem and not an interaction between the sewage and power systems.

Drainage System

As a result of our analysis of the San Jose Drainage System, we concluded that the vulnerability of this system to the nuclear attack postulated for this first iteration of the FIVE CITY STUDY is not a significant problem because no serious damage is expected.

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Appendix A

HARDY-CROSS WATER NETWORK ANALYSIS WITH THE METHOD OF BALANCED FLOWS

Besides the method of balanced-heads, another method called balanced-flows was developed by Hardy-Cross. The balanced-flows method has been found to give higher accuracy and is being used more. The method of balanced-heads starts with the initial flow values chosen so that the water flow at the junctions is balanced, and corrections are made to the flow of each. However, in the method of balance-flows, the initial head loss values are chosen so that the head loss of the line of each loop is in balance, and corrections are made to the head loss of each line by using the node relationships.

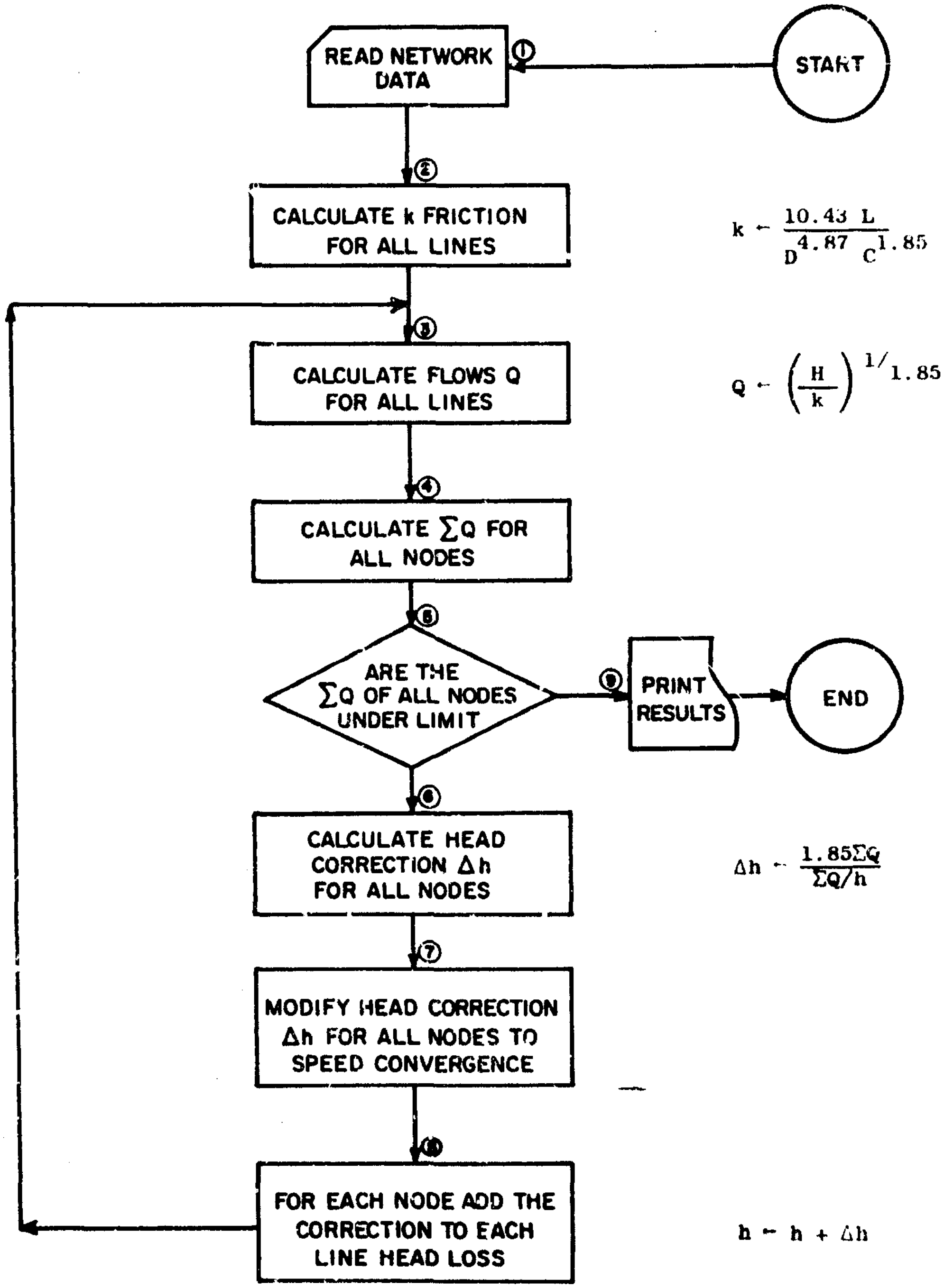
The correction of head loss ΔH at a node is

$$\Delta H = 1.85 \frac{\Sigma Q}{\Sigma h/Q} .$$

The flow chart for the method of balanced flow is shown in Figure A-1.

Figure A-1

PROCEDURE FOR BALANCED FLOW METHOD



Appendix B

DAVIDON MINIMIZATION METHOD

In recent years, a number of iterative techniques have been developed to solve an equation with numerous variables. A method based on the properties of a quadratic function is one of the more successful approaches, and this generalized minimization technique is described from a method developed by Davidon,[1] who applied it for least squares fitting to parameters of nuclear physics equations. The method was modified by Fletcher[11] and Powell,[12] who provided the proofs of convergence.

To use the powerful Davidon method, the water network equations must be described in terms of a single minimizing function which could be formed in numerous ways, including cost figures and other important considerations involving the water network if desired. The method has been applied to small networks with good results, but when the networks become larger, the convergence slows down and more development is required before the Davidon method will compare favorably to the modified Hardy-Cross method for water network analysis.

The steps and symbols of the Davidon method are shown in Figure B-1 and Table B-1. The Davidon method begins as the steepest descent method by taking the correction or step size for each variable proportional to its gradient. The subsequent step sizes are modified by a matrix A which embodies information learned from previous iterations and hence has a huge advantage over other methods that treat each iteration independently. If the function F to be minimized were in quadratic form, the solution would be found in N or less iterations where N is the number of variables. Also, the matrix A tends to be the reciprocal of the second derivative matrix G, where $G_{ij} = \partial^2 F/\partial Q_i \partial Q_j$.

Figure B-1

PROCEDURE FOR DAVIDON MINIMIZATION METHOD

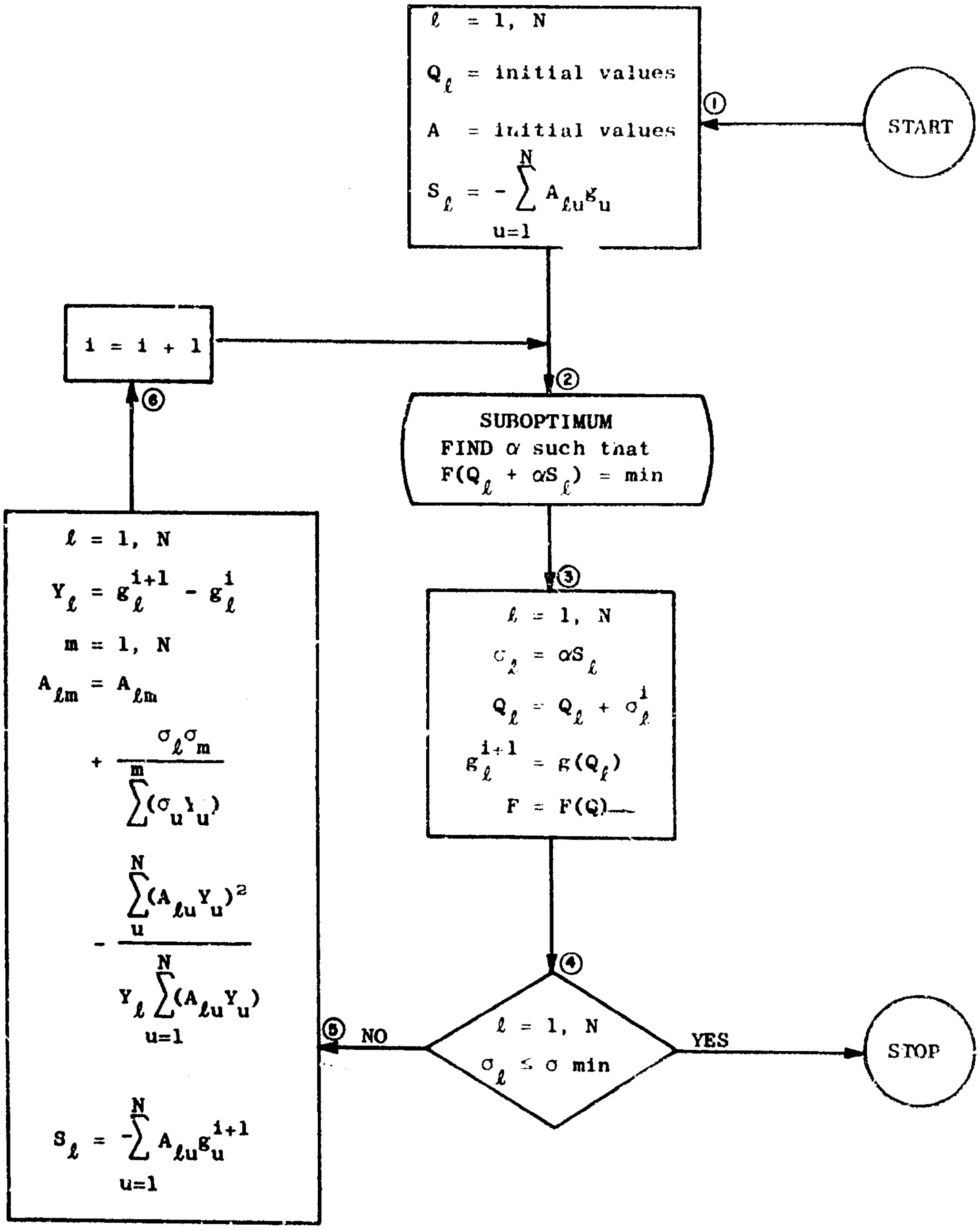


Table B-1

SYMBOLS FOR DAVIDON METHOD

U = number loops in the network

V = number nodes in the network

N_i = number of lines in the ith loop

M_j = number of lines in the jth node

g_i = $\partial F/\partial Q_i$, is partial derivative of the function F with respect to the line Q_i

F = minimizing function

σ_i = the error in head loss for the i loop

δ_j = the error in flow for the j node

h_{i_ℓ} = is the head loss of the ℓth line in the ith node

Q_{j_ℓ} = is the flow of the ℓth line in the jth node.

In the first box of Figure B-1, it is assumed that the data are read and all checking and initialization of the flows in each line are made. The A matrix is initially taken as the identity matrix and carries the effect of previous iterations. The values S_ℓ gives the direction and relative magnitude of the correction to be added to the flow Q_ℓ of the ℓ-th line. To find the value of the correction ($\sigma_\ell = \alpha S_\ell$) to each line ℓ, a suboptimum routine gives the value α such that $F(Q_\ell + \alpha S_\ell)$ is a minimum. Any one-dimensional suboptimum routine can be used to find α. In box 3 of the figure, the new value of the flow in each line is given by adding a correction to the old value. The derivative is also calculated along with the new value of the function F. Box 4 of the figure indicates whether the network has been solved to the degree of accuracy desired, and if all the flow corrections are less than a preset minimum. If the test is not satisfied, then the A matrix is modified (Box 5) and a new relative magnitude and direction for the flow in each line is calculated. Box 6 increments the iteration counter and the process continued until the test is satisfied.

The water network loop and node equations can be combined into one function to be minimized. One way to formulate the function is similar to a least-squares-fitting approach.

$$F = \sum_{i=1}^{U}(\epsilon_i)^2 + \sum_{j=1}^{V}(\delta_j)^2$$

where ϵ_i is the error in the i loop equation and δ_j is the error of the j-th node equation:

$$\epsilon_i = \sum_{\ell=1}^{N_i} h_{i_\ell}$$

$$\delta_j = \sum_{\ell=1}^{M_j} Q_{j_\ell}$$

The function F is zero only when both the loop and node equation are satisfied, and thus when the water network is solved. Care must be taken that all the loop and node equations are considered. The basic number of loop and node equations must equal the number of lines plus one for a true solution.

For a network where the elevations are given, imaginary lines between these elevation points are drawn so that new loops are obtained to account for the added information, similar to the Hardy-Cross method. In these imaginary lines, however, the head loss is taken as a constant equal to the difference of elevation at the ends of the line.

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13. ABSTRACT

The report examines the facilities of the water supply, sewage, and drainage systems in the City of San Jose; assesses their vulnerability to the effects of the nuclear attack postulated for the first iteration of the FIVE CITY STUDY; and presents a preliminary estimate of the postattack capability of these systems and their interaction with the electric power system. Additional data presented are: guides for analyzing the vulnerability of water, sewage, electric power, and natural gas facilities to the effects of a 5-MT nuclear burst, and methods for performing rapid network analysis of water supply systems.

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SRI Project 4949-390, Contract No. OCD-PS-64-201
OCD Subtask No. 39

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VULNERABILITY OF THE WATER, SEWAGE,
AND DRAINAGE SYSTEMS IN SAN JOSE

by
David W. Goodrich, E. Patrick Webster, Jr.,
C. A. Kamradt, and F. Howard Merrick
Stanford Research Institute

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DETACHABLE SUMMARY

Scope

The FIVE CITY STUDY is an iterative process. This report deals with the first iteration of the FIVE CITY STUDY in San Jose, California, and reports the expected damage that would result from an assumed 5-MT nuclear weapon detonation 14,500 feet over the southern end of San Francisco Bay north of the City of San Jose (Latitude 372735N, Longitude 1220329W) at 8:52 pm PDT on August 24, 1965.

This report describes and analyzes the vulnerability of the water, sewage, and drainage systems facilities in San Jose as they existed on August 24, 1965, with civil defense preparedness and countermeasures that existed at that time. No attempt is made to analyze postattack recovery; this is the subject of another OCD work unit. The transportation and communications systems are to be analyzed and reported separately.

Objectives

The objectives of this work unit for the water, sewage, and drainage systems were to:

1. Determine the extent of damage and service interruptions to be faced by local utilities in the event of nuclear attack.

2. Review and codify emergency countermeasures that may be employed to modify the interruption of utility services following nuclear attacks.
3. Determine the interactions among the various separate utilities and the effects of these interactions upon the ability of the utility system as a whole to maintain service after a nuclear attack.
4. Provide damage information to facilitate future study of the cost and effort required for the recovery of local utilities following nuclear attack.
5. Develop a methodology by which the effects of nuclear attacks upon local utility systems may be rapidly and comprehensively analyzed, taking into account the interactions among the various separate utilities.
6. Provide information to enable study of the interactions between the local utilities system and other segments of the economy.

Since the FIVE CITY STUDY is an iterative process, these objectives will not be completely achieved until more than one iteration has been performed in each of the FIVE CITIES. However, this report presents an initial effort toward fulfilling the above objectives.

The report presents the damage to the facilities of, and the associated service interruption of, the water, sewage, and drainage systems in San Jose as a result of the assumed attack. Some emergency countermeasures that may be employed to modify the interruption of service are discussed but further work is required in this area. The interactions between the water, sewage, and drainage systems and the electric power system are analyzed, but additional research concerning interactions will be required when the work units studying electric power and natural gas complete their research.

This report and the FIVE CITY STUDY Working Papers* associated with it provide damage information to facilitate future study of the cost and effort required for recovery of the water, sewage, and drainage systems in San Jose and also provide information allowing study of the interactions between these utilities and other segments of the economy in San Jose. This report also presents the basis for development of a methodology to analyze the effects of nuclear attack upon local utility systems and discusses methods for rapidly performing network analyses of water supply systems.

Summary

Water Supply

The water supply system in San Jose is highly dependent on electric power for well and booster pumping. However, since the San Jose Water Works obtains its water supply from both groundwater and surface water sources, some residual supply capability will exist in the event that the supply of electric power is interrupted.

Immediately after attack, if power is interrupted, the water supply system will be able to supply about 2 days' normal demand in 90 percent of the service area. This will deplete available distribution storage, and after 2 days, the capability would drop to 25 percent of normal demand for an additional 47 days. This will deplete impoundment storage. Without

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* "San Jose Water Supply System--Station Damage Reports," FIVE CITY STUDY Working Papers 5S-11101-4334A-01 to -19, Stanford Research Institute, TN-OAP-101 to -119, October 1966.
"San Jose Water Supply System--General System Description Report," FIVE CITY STUDY Working Paper 5S-11101-4334A-20, Stanford Research Institute, TN-OAP-120, November 1966.
"San Jose Drainage System," FIVE CITY STUDY Working Paper 5S-11101-4334A-21, Stanford Research Institute, TN-OAP-121, December 1966.
"San Jose Sewage System," FIVE CITY STUDY Working Paper 5S-11101-4334A-22, Stanford Research Institute, TN-OAP-122, January 1967.
"San Jose Water Supply System--System Degradation Report," FIVE CITY STUDY Working Paper 5S-11101-4334A-23, Stanford Research Institute, TN-OAP-123, January 1967.

power for well and booster pumps, water for sustained fighting of mass fire or for other high consumption rate uses would not be expected to be available at the required volumes or pressures.

In the event electric power is not interrupted or after the initial power failure was corrected, the water supply system would be able to supply 125 percent of the average August 1965 demands without depleting available distribution storage. The availability of excess pumping capacity and distribution storage would be expected to permit limited firefighting, provided that firefighting flow did not withdraw water to such an extent as to degrade the water pressure below required minimums. This provision could present a major problem in the sustained fighting of mass fire even with an undamaged water system.

After several days to, at most, a few weeks following the attack, full preattack production capacity and distribution would be expected to be available.

The lack of fallout will be a deciding factor in the postattack capability of the water system. If fallout were present, postattack manual control of the system would be difficult at best, with a resulting decrease in capability.

Sewage

The sewage collection system in San Jose was found to be only slightly dependent upon electric power, since the collection system is predominantly a gravity collection system. No significant damage is expected to occur to the collection system as a result of the attack, and therefore no postattack problem is expected to hinder the collection of sewage in the City of San Jose.

The sewage treatment plant, which performs both primary and secondary treatment, is highly dependent on electric power for its operation. The problem is different, however, from that encountered with the water supply system, since the San Jose-Santa Clara Water Pollution Control Plant produces its own power and has no provision for the importation of outside power.

The sewage treatment plant, in addition to using large amounts of power, requires large volumes of process air. Extensive damage is expected to occur to the power generation and air production equipment and the auxiliary equipment necessary for power distribution and plant control. As a result of the damage, no sewage treatment will be possible, and the sewage will therefore have to bypass the plant through an existing bypass line and discharge directly to San Francisco Bay. After some postattack emergency repair, perhaps on the order of several man-days, chlorination to attempt disinfection of the bypassed sewage may be performed.

Sufficient repair to permit primary treatment before bypassing the sewage to the bay would require perhaps on the order of a few man-years. Restoring the treatment plant's ability to perform full primary and secondary treatment and sludge handling would demand extensive reconstruction, requiring perhaps on the order of several man-years of repair and reconstruction effort.

Since no problem is expected regarding the collection of sewage in the City of San Jose, only the treatment of this collected sewage will be of concern in the postattack period. All the sewage treatment plants serving the cities of Menlo Park, Palo Alto, Mountain View, Sunnyvale, and Milpitas form a semicircle around the postulated nuclear burst; therefore the postattack sewage problem is one of regional concern, comprising water pollution control and pest-vector-odor control in the southern end of San Francisco Bay. Whether this is a significant postattack problem remains to be determined and is beyond the scope of this work unit.

Drainage

The drainage system in the City of San Jose is essentially 182 separate, predominantly gravity systems tied together by improved and unimproved natural drainage ways. No significant damage is expected from the effects of the postulated attack, hence no significant postattack problems are expected to occur with regard to the drainage system in San Jose.