CITY STUDY

JULY 1971

SD 11101 4334C 03

City of
DETROIT, MICHIGAN

VULNERABILITY OF GAS UTILITIES TO NUCLEAR ATTACK

UNITED STATES
DEPARTMENT
OF THE
INTERIOR

OFFICE OF OIL AND GAS

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C.

Work Order OCD-PS-66-100
Work Unit 4334C

Approved for Public Release:
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OOG 9/30/71

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Office of Oil and Gas Department of the Interior Washington, D. C. 20240	2a. REPORT SECURITY CLASSIFICATION 2b. GROUP

3. REPORT TITLE

Vulnerability of Gas Utilities to Nuclear Attack
City of Detroit, Michigan

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*

Maurice A. Richford

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1970	225	12

8a. CONTRACT OR GRANT NO. OCD-PS-66-100	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 4334C	OOG-103
c. 5S-11101-4334C-03	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Civil Defense Department of the Army Washington, D. C. 20310

13. ABSTRACT

Purposes of the report are: (1) to determine nuclear attack effects on facilities and capability of the gas system supplying Detroit, Michigan; and (2) describe normal system operation and give a functional inventory of buildings, transportation and other support equipment.

Gas distribution facilities in 227 sq. mi. of Detroit area, formerly serving 592,900 customers (86.5% of preattack total), are shut down indefinitely by the Company. Service is returned to 92,323 customers.

Principal damage to Company facilities is to buildings and contents of regulating stations and storehouses.

Postattack transmission system capacity, physical operating personnel, vehicles, communication and supplies are adequate for immediate postattack repair and operation.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nuclear Attack						
Vulnerability						
Damage						
Gas facilities						
Gas System						
Emergency measures						
Repair of gas system						
Repressuring of gas system						
Restoration of gas service						

SUMMARY

The effects of a hypothetical, 5 MT surface burst, nuclear attack on the supply and distribution of natural gas by the Michigan Consolidated Gas Company to 685,200 customers in its Detroit District are investigated and evaluated.

Following the warning of an impending attack, the Company activates its Emergency Plan. Principal provisions of the Plan to prepare the system for a nuclear attack are:

(1) Valve off, shut down and leave unmanned three of the four City Stations normally supplying the Detroit District distribution system. The purpose is to delegate further control of gas entry into the distribution system to a single, manned station.

(2) Reduce normal operating pressures in specified high pressure distribution mains. The purpose is to minimize gas volume inventory in the distribution system.

(3) Relocate trucks and major mobile equipment to designated, less vulnerable points outside of Detroit. This element of the Plan is completed several weeks prior to the attack.

One hour after the detonation, supply to Detroit District distribution is shut off by the Company at the City Gate Station. The shutdown is made to stop gas leaking at a 16 MMCFH rate from damaged gas facilities in the distribution area. After shutdown, distribution pressure declines to zero pounds gauge in about 85 minutes.

In the immediate post-attack period, a part of the Detroit District distribution system surrounding and extending out from ground zero and formerly serving 592,900 customers is not restored to service. It is isolated from the balance of the system and left shut down indefinitely, because most buildings and residences therein and need for gas fuel are wiped out by the blast and fire. The area covers 227 square miles, comprising the City of Detroit and all or substantial portions of adjoining communities.

Gas distribution operations are fully restored in two separate areas, east and west of Detroit, containing a total of 92,323 customers or 13.5% of the preattack number. Gas appliances therein are progressively returned to use by Company personnel beginning nine (9) days after start of emergency repairs; completion is thirty-nine (39) days later.

The separation boundaries between the distribution system parts restored and not restored to gas service follow, in general, the outer limits of severe, secondary fire damage.

Principal damage to Michigan Consolidated aboveground facilities is to buildings of regulating stations and storehouses. Losses in supplies and incapacitation of operating stations is not critical in the postattack period because the amount of system remaining to be operated is small.

The underground distribution "grid" mains in the vulnerable area are cast iron employing cement packed joints. High pressure "feeder" mains interlacing the area are either steel or leak clamped cast iron.

It is expected that the grid mains (unclamped and most vulnerable) will remain operational to at least the 20 psi overpressure radius. Distribution regulator vaults begin to experience damage at 16 psi. As an area operational limit, neither value has significance in the immediate postattack period. Both represent distances deep within the shutdown area, where need for gas service no longer exists.

Natural gas supply available for the Detroit area in the postattack period will be more than adequate. Three of the four incoming transmission systems are undamaged and capable of resuming normal deliveries. In addition, by late August, the amount of gas placed in underground storage by Michigan Consolidated will supply the reduced system for months if, for some reason, transmission [illegible]ies cannot be resumed immediately.

The number of Detroit District uninjured personnel is ample to handle the system in the postattack period, except for a temporary shortage of certain skills during the emergency repair and repressuring operations. It is likely, although not pursued in the study, that help from other Michigan Consolidated Gas Co. districts would offset the deficiency.

The number of undamaged vehicles is adequate at all times in the postattack period. Less than 7 percent of the truck fleet is damaged. Gasoline is not a problem in view of a nearby undamaged refinery.

Mobile radio is the sole means of communication for directing and coordinating recovery operations. Telephone facilities emanating from the General Office are damaged beyond short term repair. The two surviving base radio stations of the Company and 485 mobile, two-way radios in vehicles provide adequate coverage of the area. Adding to the flexibility is a Company-owned base station, mounted in a van type vehicle, which enables the station to be moved to any location in the area.

Gas supply to the Company's adjoining Ann Arbor District and its 43,775 customers is unaffected and uninterrupted by the Detroit attack.

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City of
DETROIT MICHIGAN

VULNERABILITY OF GAS UTILITIES TO NUCLEAR ATTACK

FIVE CITY STUDY

Prepared by: M.A. Richford and W.E. Davis

Under the Direction of: Office of Oil and Gas

JULY 1971

OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

Prepared for:

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Work Order OCD - PS - 66 - 100
Work Unit 4334C

UNITED STATES
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WASHINGTON, D.C. 20240

FOREWORD

Under Work Order No. 4334S-OCD-PS-66-100, the Office of Civil Defense, Department of the Army, engaged the Office of Oil and Gas, Department of the Interior, to determine the vulnerability of selected gas utility systems to hypothetical nuclear attacks.

This is a report of the vulnerability of the Detroit gas system, the third in the "Five-City" series.

It describes normal preattack conditions and gas operations, evaluates damage to gas facilities and casualties to employees and the effects thereof, and outlines the area in which gas will be served in the immediate postattack period.

It is hoped that the information contained herein will further stimulate all gas utility systems throughout our Country to achieve an optimum state of readiness in the event of such an attack.

John Ricca
Acting Director

ABSTRACT

The portion of the Michigan Consolidated Gas Company gas distribution system formerly serving 592,900 customers (86.5% of the preattack total) in the City of Detroit and substantial parts of adjoining communities totaling 227 square miles of built up area is shut down indefinitely by the Company. Gas service is not restored because most of the buildings and households therein and need for gas service are wiped out by the 5 MT nuclear blast and ensuing fire.

Gas distribution operations are restored in two separated areas, east and west of Detroit, containing 92,323 customers. Gas appliances in buildings and households therein are progressively returned to use by Company personnel beginning nine (9) days after start of repair work. Completion is thirty-nine (39) days later.

Principal damage to Michigan Consolidated facilities is to buildings and contents of distribution regulating stations and storehouses. Losses in supplies and incapacitation of station operating equipment is not critical in the postattack period because of the small amount of the former system returned to service.

Postattack transmission system capacity is ample. Three of the four incoming systems are undamaged and capable of resuming normal deliveries.

Physical system operating personnel, vehicles, and mobile radio communication facilities are adequate for postattack repair and routine operation.

Gas supply to the Company's adjoining Ann Arbor District and its 43,775 customers is unaffected and uninterrupted by the Detroit attack.

ACKNOWLEDGMENT

A study of this complexity required the help of many individuals. Not only are the principles and mechanics of gas transmission and distribution in a large system involved, but also the appraisal of nuclear attack effects thereon.

The advice and guidance of George F. Divine, Economist, Systems Evaluation Division (Research), Office of Civil Defense, and members of the Office of Oil & Gas, Department of the Interior, were particularly helpful in conducting the study.

Appreciation is expressed to Messrs. Karl E. Schmidt, Vice President–Engineering, and A. E. Browning, Director of Marketing and Research of American Natural Gas Service Company and to A. H. Cramer Manager, and Wilfrid Robinson, Technical Coordinator, Operation Services Department; A. R. Ford, Superintendent, and Arthur Resowski, Assistant Superintendent, Street Department; and Preston B. Thompson, Executive Engineer, and R. D. Kempner, Manager, Distribution Design Department, of the Michigan Consolidated Gas Company, for the time and help generously given during the progress of the study.

The contribution to the study of my associate, Mr. W. E. Davis, until illness forced his retirement is gratefully acknowledged.

In addition, the information supplied by Mr. D. P. Green, Assistant Manager, Gas Production and Transmission, Consumers Power Company, relative to gas operations of that Company in areas adjoining Detroit assisted in establishing area boundary limits of the study.

M. A. Richford

CONTENTS

	Page
Foreword	ii
Preface	iii
Abstract	iv
Acknowledgement	v
Contents	vi
Illustrations	x
Tables	xii
Purpose of Study	1
Scope of Study	2

Section I—General Description of the Detroit Gas Supply System

Historical	5
General	7
Natural Gas Systems Supplying the Detroit Area	7
Natural Gas Distribution in the Detroit Area	14
Transfer System	17
Grid System	21
Typical Piping Layout Detroit City Distribution	21
Valves	22
Vaults	25
Regulators	26
Meters	27
Services	28

	Page
Mileage of Mains in Detroit District	28
System Operation	30

Section II—Vulnerable Locations and Damage Appraisals

Introduction	35
Underground Gas Facilities and Damage Appraisals	36
Aboveground Gas Facilities and Basis of Damage Appraisals	38
Damage Appraisals	45

Section III—Gas System Support Facilities and Damage Appraisals

General	93
Electric Power	93
Truck and Major Portable Equipment	94
Michigan Consolidated Storehouses and Supplies	99
Michigan Consolidated Communication Facilities	103

Section IV—Organization and Personnel

Michigan Consolidated Organization	111
Personnel Casualties	111

Section V—Emergency Measures, Postattack Repairs and Restoration of Service in the Detroit Area

General	121
Preattack Emergency Measures	121

	Page
Post-attack Emergency Measures	124
Post-attack Repairs and Restoration of Gas Service in Detroit District	125
Restoration of Service to Individual Establishments in the Postattack Area Shut Down Indefinitely	129
Michigan Consolidated Distribution Facilities in Detroit Area Not Shut Down	130
Countermeasures	130

Section VI—Summary

Summary	137

APPENDICES

Appendix A

Analysis Gas Regulator Vault Damage by Overpressure	143
Discussion of Bell and Spigot Joints	148
Analysis of Chimney at Coolidge Station	151
Analysis of Low Pressure Holder at Coolidge Station	153

Appendix B

Normal Distribution of Mobile Equipment of Department of Production, Transmission and Supply	159

Appendix C

Gas System Restoration Personnel at Attack Warning Time	163

Page

Appendix D

Derivation of Pressure Decline Equation 173

Appendix E

Time to Restore Immediate Postattack Distribution Grid System in Detroit District 181

Time to Restore Gas Service to Eight Hospitals in Shutdown Area 183

Appendix F

Discussion of Proposal that Householders Turn Off Gas Supply to Their Premises 187

Appendix G

Glossary of Terms 201

References 202

ILLUSTRATIONS

Figure		Page
1.	Lower Michigan Showing Transmission Mains Serving Michigan Consolidated Gas Company	9
2.	Office–River Rouge Station (photograph)	8
3.	Gas Processing Equipment–Willow Run Station (photograph)	12
4.	Gas Scrubbers–Northwestern Station (photograph)	13
5.	Gas Supply System–Detroit Area	15
6.	Gas Distribution System–City of Detroit	19
7.	Typical Downtown Gas Distribution Facilities	23
8.	Indoor Meter and Regulator Set in Basement (photograph)	27
9.	Outdoor Meter and Regulator Set Enclosed in Plastic Case (photograph)	28
10.	Locations of Damage Appraisals	41
11.	Regulator Building with Master Valve and Office Building–River Rouge Station (photograph)	45
12.	Interior of Regulator Room–River Rouge Station (photograph)	47
13.	Interior of Master Valve Building–River Rouge Station (photograph)	47
14.	Station Building and Meter Runs–Northeastern Station (photograph)	51
15.	Storehouse and Garage–Allen Road Station (photographs)	54
16.	Storehouse at Coolidge Station (photographs)	58
17.	Regulator Building and Interior–Coolidge Station (photographs)	60
18.	Service and Regulators Buildings at East Jefferson Station (photographs)	64
19.	Regulator Building–Evergreen Station (photograph)	68
20.	Views at Lynch Road Station (photographs)	74
21.	Views at Tireman Station (photographs)	80
22.	Interior Views at Station A and E (photographs)	84
23.	Edsel Ford Freeway–Livernois Avenue Crossing (photograph)	88

Figure		Page
24.	Pipeline Bridge River Rouge–Zug Island (photograph)	89
25.	Radio Communication Facilities	106
26.	Organization Chart Michigan Consolidated Gas Company	112
27.	Postattack Gas Supply in Detroit Area	127
28.	Standard Vaults for Emco and Fisher Regulators	145
29.	Locations of Gas Operations Personnel at Attack Warning Time	165
30.	Average Percent Casualties from Blast Effects Detroit Area	167
31.	Time Required to Restore Immediate Postattack Distribution Grid System in Detroit District	181
32.	Duration of Postattack Gas Leakage in Buildings and Fire Development—Detroit Area	191

TABLES

Table		Page
i	Gas Volumes Transported by Transmission Mains, Sendout and Number of Customers, Year 1965	11
ii	Gas Deliveries to Detroit District, August 24, 1965 and Peak Day 1965	17
iii	Detroit District Distribution Mains, Operating Pressures and Miles of Main	29
iv	Electric Generating Units and Damage Appraisals Michigan Consolidated Gas Company	95
v	Normal Distribution of Trucks and Mobile Equipment	96
vi	Emergency Distribution of Trucks and Mobile Equipment	97
vii	Truck Locations at H Hour and Damage Appraisals	98
viii	Storehouse Supplies, Gas System and Customer Service	101
ix	Postattack Gas System Restoration Personnel by Occupation Categories, Michigan Consolidated Gas Company Detroit District	114
x	Casualties Among Gas System Restoration Personnel by Occupational Categories Detroit District	116
xi	Casualty Distribution—Gas System Restoration Personnel Detroit District	117
xii	Postattack Areas and Numbers of Customers Restored to Service	126
xiii	Gas Main Overcrossings Where Overpressure is Greater than 2.5 psi—Detroit District	154
xiv	Normal Distribution of Mobile Equipment Department of Production, Transmission and Supply	159
xv	Details of Casualty Distribution Among Gas System Restoration Personnel--Detroit District	169
xvi	Time Required to Restore Gas Service to Eight Hospitals in Shutdown Area	183
xvii	System Pressures and Volumes Immediately Prior to Attack and to Shutdown at Northwestern Station	195

SECTION I

GENERAL DESCRIPTION
OF THE
DETROIT GAS SUPPLY SYSTEM

HISTORICAL

In September of 1851, the Detroit Gas Light Company began serving manufactured gas in the City of Detroit. Twenty years later, the Mutual Gas Light Company also secured a franchise to serve in the same area. Woodward Avenue, after a time, became the boundary separating the service areas of the two companies. The gas, made from coal, was used mainly for illumination.

This arrangement continued until 1889 when a third company, the Michigan Gas Company, brought natural gas to a part of Detroit from a field near Findlay, Ohio; and, a few years later, from another source in Canada. The three companies combined in 1893 to form the Detroit Gas Company, which was renamed the Detroit City Gas Company in 1898.

In 1902, the natural gas supplies failed, forcing a complete return to manufactured gas. This second era of manufactured gas operation continued until 1935 when Panhandle Eastern Pipeline Company, an interstate supplier, began a long term, annual delivery of 46.4 billion cubic feet of natural gas to Detroit. The supply originated in the Hugoton Field of the Texas-Oklahoma Panhandle; delivery point was the River Rouge Station in the Detroit area.

Meanwhile, in 1906, the Company became a member of the American Light and Traction Company—later to become today's American Natural Gas System. By doing so, it became affiliated with the Michigan gas companies of Grand Rapids Gas Light and Muskegon Traction and Lighting in that organization.

Following reentry of natural gas into the Detroit system, supply mains were extended to Grand Rapids and Muskegon and to new service areas and recently discovered natural gas fields in the central part of the State. An interconnected network resulted which, in 1938, was renamed the Michigan Consolidated Gas Company to reflect the integration.

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By 1945, when Panhandle Eastern supply began to approach inadequacy to meet the expanding load, a new supplier—the Michigan-Wisconsin Pipeline Company—was organized by Michigan Consolidated. It built an interstate pipeline, also tapping the Hugoton Field. The facility, for alternate supply reasons, entered the State on the Lake Michigan side, reinforcing supply to Grand Rapids and Muskegon while enroute to the underground storage fields (depleted native gas fields) in the Six Lakes area of Central Michigan. Each year during warm months, part of its annual 53 billion cubic feet delivery is stored therein for withdrawal during winter to help supply the Detroit area.

In the early fifties, Detroit needed additional gas again. A second interstate pipeline—this time from the Gulf Coast of Louisiana to Willow Run in the Detroit area—was built in 1956 by the American-Louisiana Pipeline Company, later to be merged into Michigan-Wisconsin. Its initial annual delivery of 110 billion cubic feet approximately doubled existing incoming supply.

Similarly, during summer months, part of its annual delivery is placed in underground storage.

Subsequently, both Michigan-Wisconsin pipelines have been paralleled and compressor stations added. In conjunction with gas withdrawn from storage, the peak day deliverability of the Detroit area system in 1965 to its 698,000 customers was about 1.6 billion cubic feet per day.

At the time of the change to natural gas in 1935, four manufacturing plants, having a total rated capacity of 77 million cubic feet per day of 530 Btu gas, were operating in Detroit. Customers numbered 385,548 and the peak day sendout of record was 73.4 million cubic feet. During this time, in common with prevailing practice, cast iron pipe was used in the Detroit distribution system.†
Today, within the limits of the same service area, the system remains cast iron except for steel feeder mains added for reinforcement after 1935.

*In 1969, customers and deliverability had risen to 702,000 and 2.0 billion respectively.
†Except service pipes which were wrought iron or steel.

GENERAL

The State of Michigan is divided into two parts by the Straits of Mackinac. Locally, the northern part is called the Upper Peninsula (or U.P.); the southern part is the Lower Peninsula. The City of Detroit is in the lower Peninsula, see Figure 1.

Seven utilities serve natural gas in Lower Michigan. However, only two companies—Consumers Power and Michigan Consolidated—operate integrated, area-wide systems.

Lower Michigan is an oil and gas producing region, but many fields have been depleted and the remaining reserves are limited. In 1965, local gas production contributed 5.8 billion cubic feet to Michigan Consolidated's statewide sendout of 291.6 billion. The deficit is balanced by importation from out-of-state sources. Reached through interstate pipelines, these sources are: (1) the Hugoton and Laverne Fields of Texas and Oklahoma, (2) the Louisiana-Texas Gulf Coast area, and (3) the fields of Western Canada through interconnection with other pipelines.

Fourteen depleted fields with a total current capacity of 150 billion cubic feet have been converted to underground storage reservoirs and are tied into the Michigan Consolidated and affiliated Michigan-Wisconsin Pipeline systems as shown in Figure 1. Net working volume of the storage fields applicable to Michigan Consolidated use is 69 billion cubic feet. The availability of storage space enables the incoming transmission systems from out-of-state to be operated at high load factors by storing surplus gas underground during low sendout days. As a result, up to 900 MMCF per day is available from storage in winter to supplement the maximum 650 MMCF daily incoming from out-of-state transmission.

NATURAL GAS TRANSMISSION SYSTEMS SUPPLYING THE DETROIT AREA

Natural gas is delivered to Michigan Consolidated in the Detroit area by the four transmission systems shown in Figure 1.* Monthly deliveries, additions and withdrawals from storage are given

*The Michigan-Wisconsin Pipeline, which enters the State on the Lake Michigan side from the Hugoton Field, is not pertinent to this study.

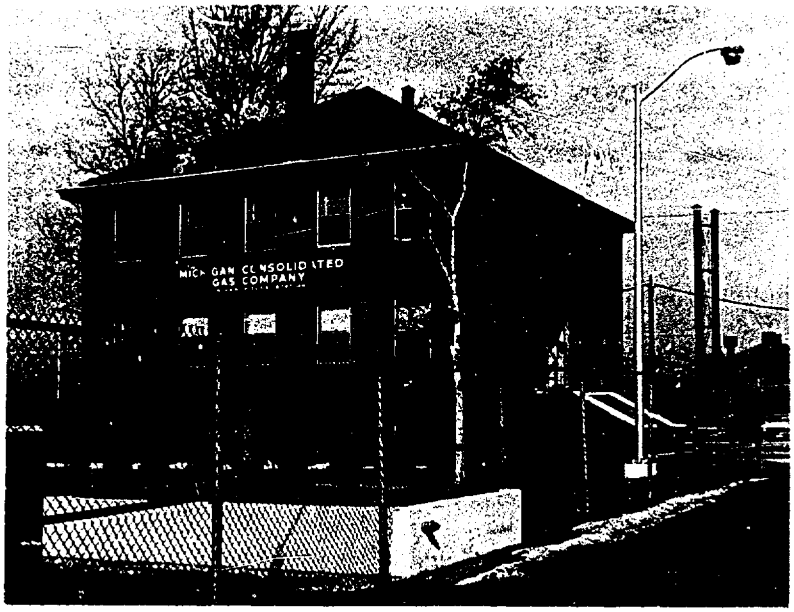

Figure 2. Station Office, River Rouge Michigan Consolidated Gas Company

in Table 1. Two of the systems are long-distance interstate pipelines entering the area from the south:

1. *Panhandle Eastern Pipeline Company, 22 and 26 inch Mains.* This independently owned system originates in the Hugoton Field of Texas and Oklahoma. It delivers gas into Michigan through parallel mains branching off in Indiana from the Panhandle trunk system. The branch system connects to both Consumer Power and Michigan Consolidated.

Connection is made at Michigan Consolidated's River Rouge City Gate Station, see Figure 5. On adjoining property, Panhandle maintains flow control and measurement equipment; terminal pressure is controlled by Panhandle at its Pelham Station, six miles upstream.

Contractual arrangements with Michigan Consolidated specify delivery of 46.4 billion cubic feet annually at 150 psi at River Rouge Station, spread over the seven month period of April through October or an average day rate of 217 MMCF. During other months, Panhandle has no obligation, except to make up any deficiency in annual commitment.

Panhandle also connects with the Windsor, Canada system and its 29,000 customers by means of a 16 inch lateral crossing under the Detroit River. It is one of several companies supplying that system.

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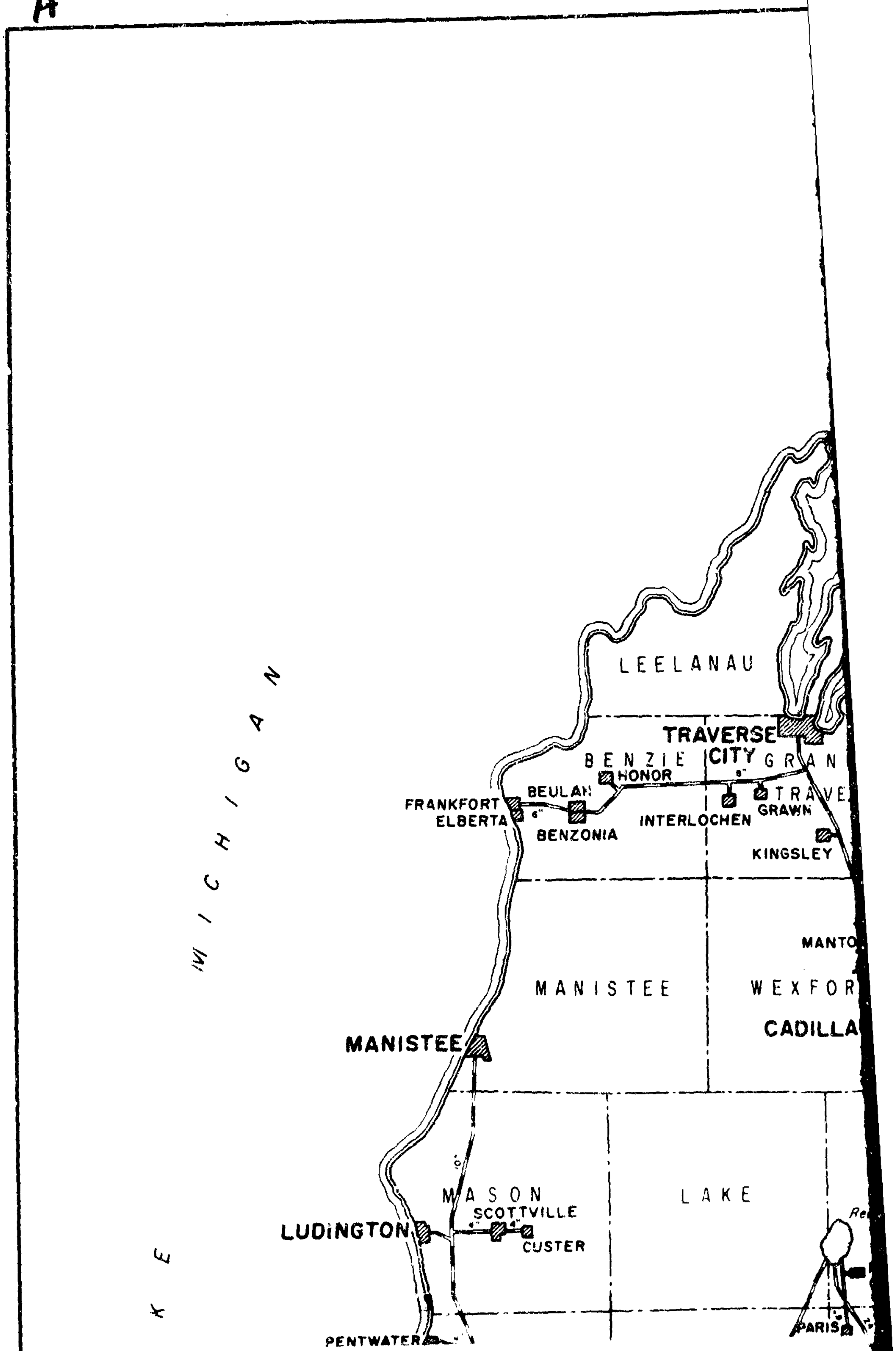

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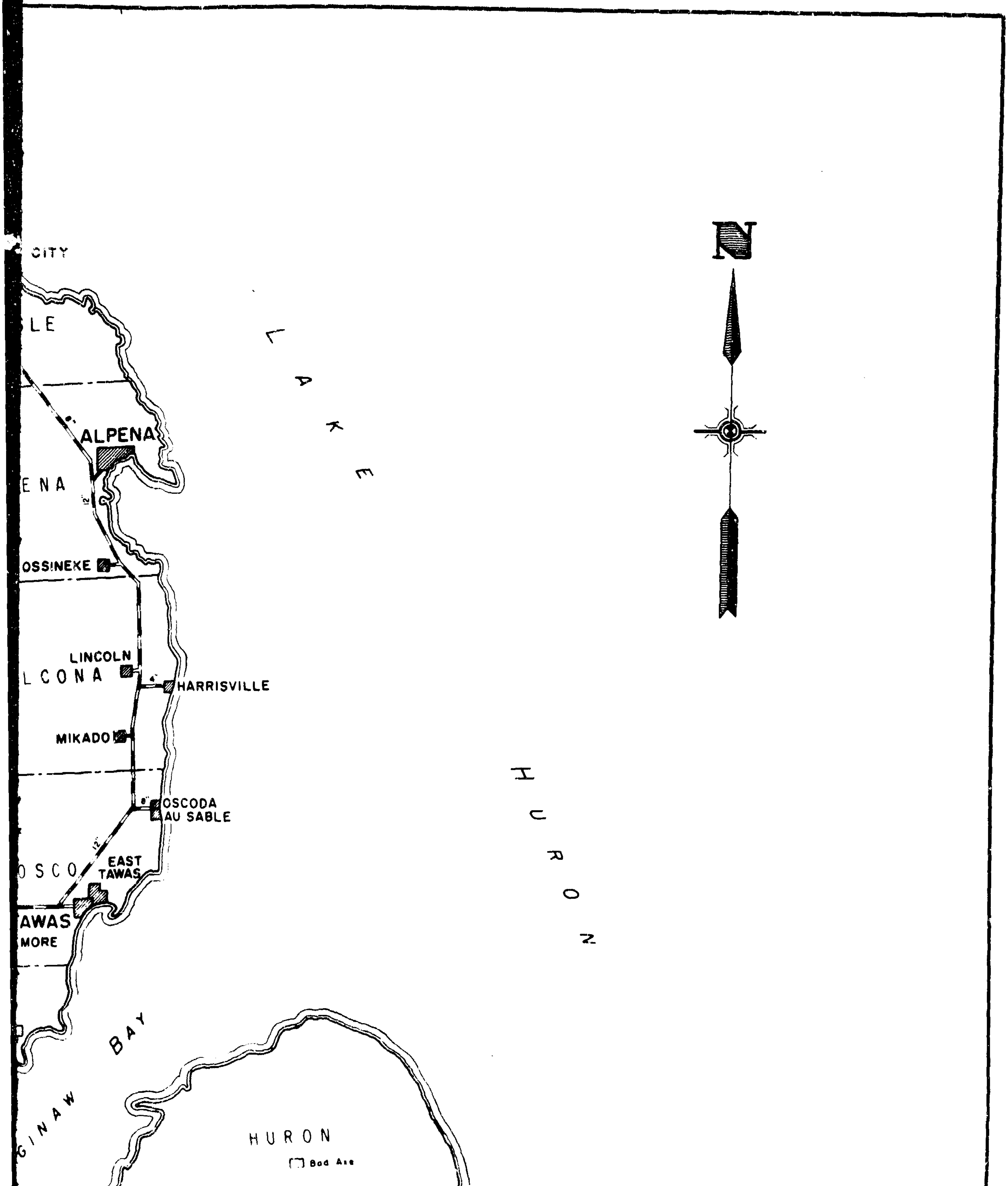
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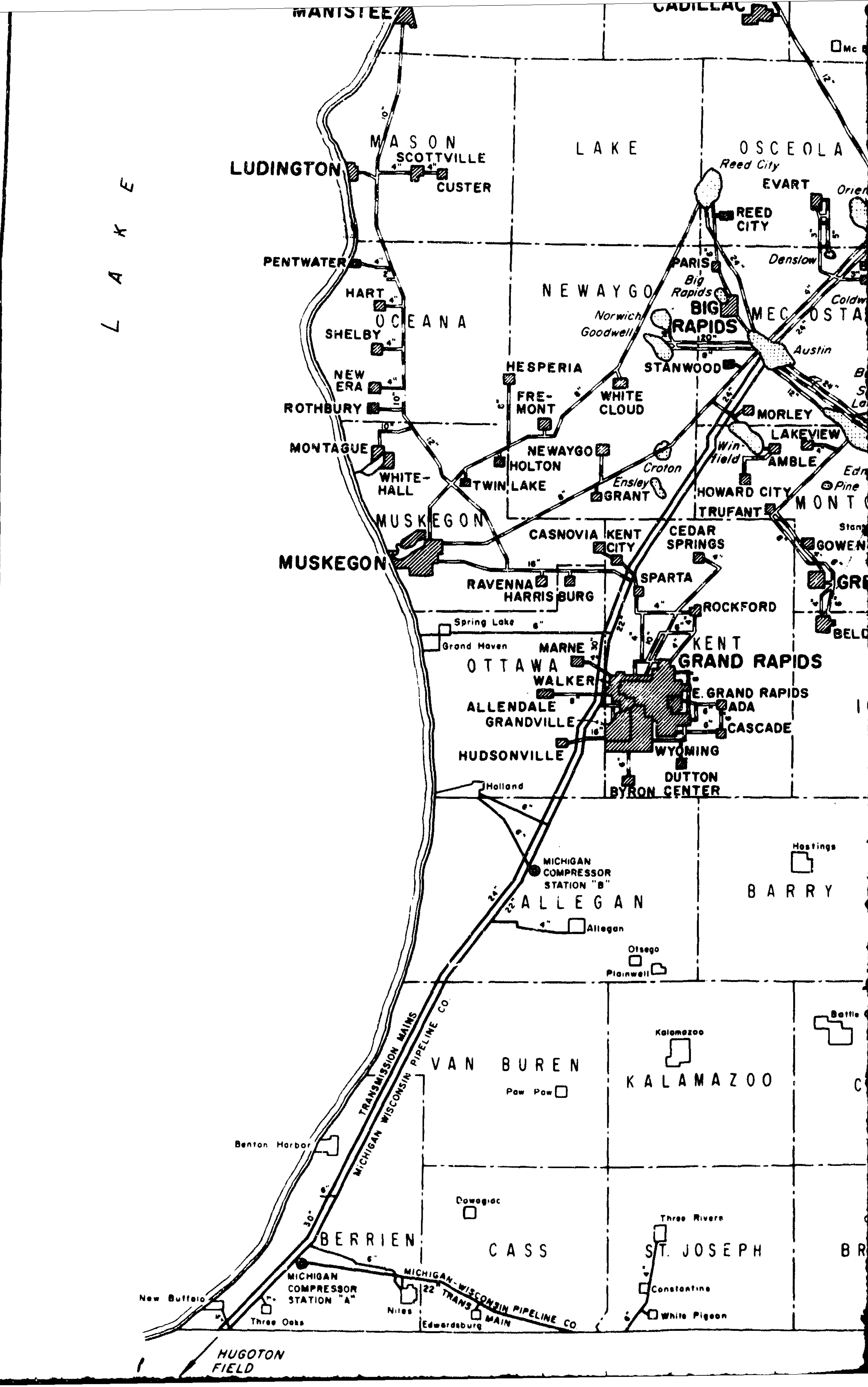

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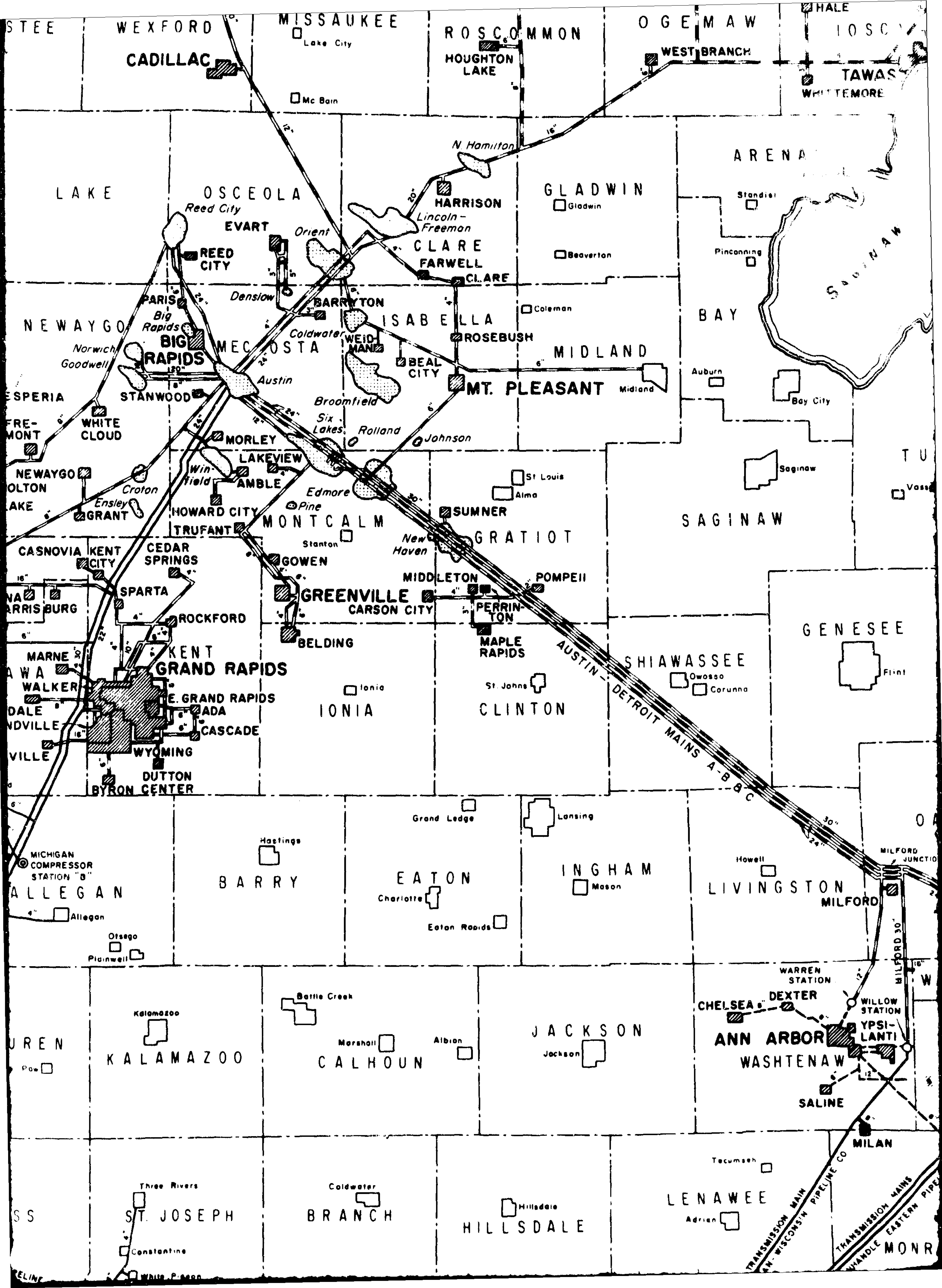

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BAY
NEWAYGO
Big Rapids
BIG RAPIDS
ISABELLA
ROSEBUSH
Coldwater
WEIDMAN
MECOSTA
Norwich
Goodwell
BEAL CITY
MIDLAND
Austin
Auburn
Midland
STANWOOD
MT. PLEASANT
Broomfield
Bay City
HESPERIA
FREMONT
WHITE CLOUD
Six Lakes
Rolland
Johnson
MORLEY
NEWAYGO
LAKEVIEW
Winfield
AMBLE
Croton
Edmore
St Louis
Alma
Ensley
Pine
GRANT
HOWARD CITY
SUMNER
Saginaw
Vassar
MONTCALM
TRUFANT
Stanton
New Haven
GRATIOT
SAGINAW
CASNOVIA
KENT CITY
CEDAR SPRINGS
GOWEN
SPARTA
MIDDLETON
POMPEII
GREENVILLE
CARSON CITY
PERRINTON
ROCKFORD
GENESEE
BELDING
MAPLE RAPIDS
MARNE
KENT
GRAND RAPIDS
SHIAWASSEE
AUSTIN - DETROIT MAINS A-B & C
WALKER
Ionia
St. Johns
Owosso
Corunna
Flint
E. GRAND RAPIDS
ADA
CASCADE
IONIA
CLINTON
WYOMING
DUTTON CENTER
BYRON CENTER
Grand Ledge
Lansing
Hastings
MICHIGAN COMPRESSOR STATION "B"
MILFORD JUNCTION
Howell
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
Mason
Charlotte
MILFORD
Allegan
Eaton Rapids
Otsego
Plainwell
MILFORD 30"
WARREN STATION
Battle Creek
Kalamazoo
CHELSEA
DEXTER
WILLOW STATION
Marshall
Albion
JACKSON
ANN ARBOR
YPSILANTI
KALAMAZOO
CALHOUN
Jackson
WASHTENAW
Paw Paw
SALINE
MILAN
Tecumseh
Three Rivers
Coldwater
Hillsdale
LENAWEE
ST. JOSEPH
BRANCH
HILLSDALE
Adrian
TRANSMISSION MAINS
PANHANDLE EASTERN PIPELINE
TRANSMISSION MAIN
MICHIGAN-WISCONSIN PIPELINE CO
Constantine
White Pigeon
MONROE

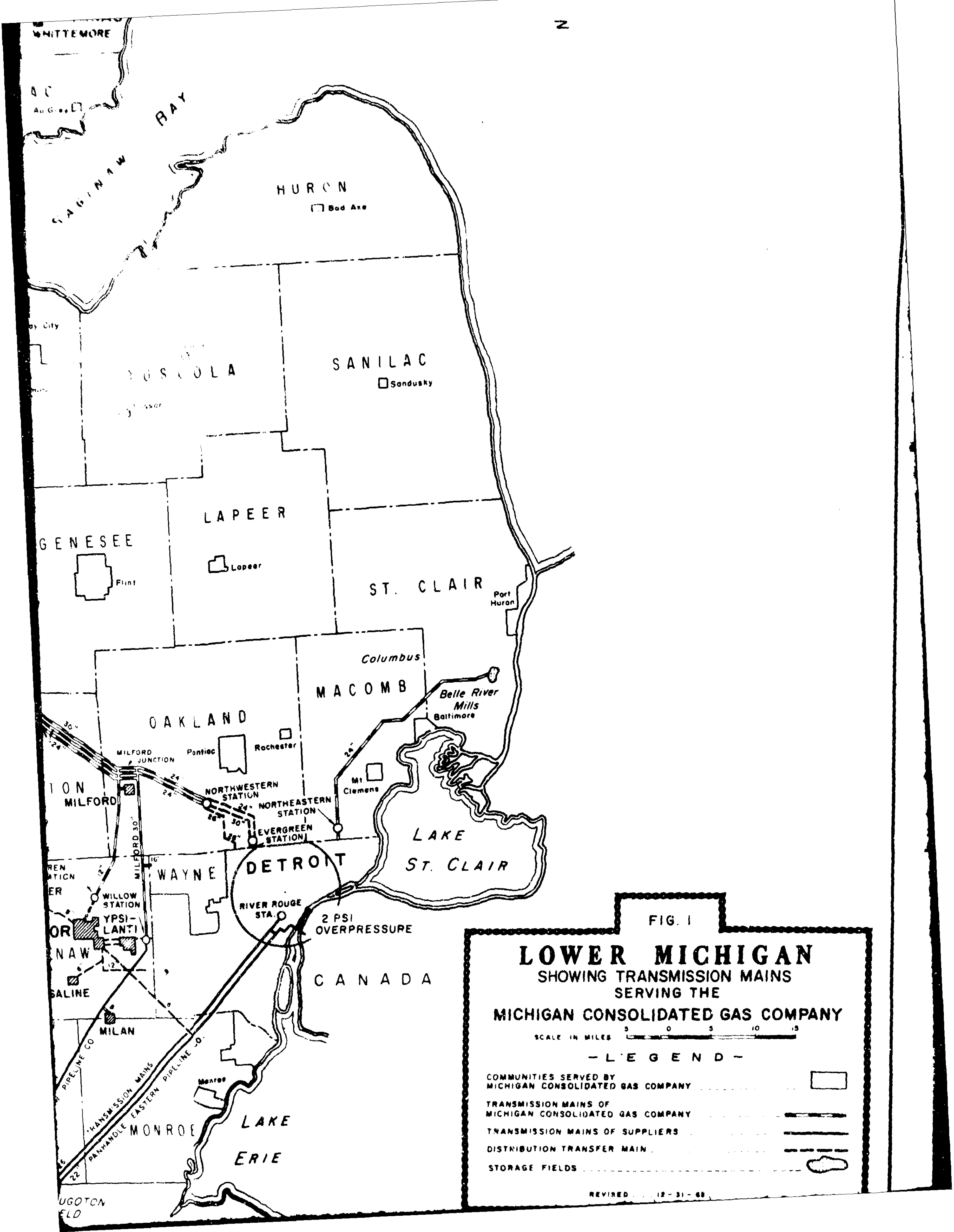

FIG. 1

LOWER MICHIGAN
SHOWING TRANSMISSION MAINS
SERVING THE
MICHIGAN CONSOLIDATED GAS COMPANY

Table I—Gas Volumes Transported by Transmission Mains, Sendout and Number of Customers
Detroit Area, Michigan Consolidated Gas Company
Year 1965

Month	Volumes to Detroit Distribution: Michigan-Wisconsin Willow Station MMCF	Panhandle Eastern @ River Rouge Station MMCF	Michigan Consolidated Northeast Station MMCF	Michigan Consolidated Northwest Station MMCF	To Storage MMCF	From Storage MMCF	Sendout MMCF	Customers Detroit District Number
Jan.	15,774	780	1,337	13,506	–	13,239	31,397	694,669
Feb.	13,345	229	1,118	13,243	–	13,251	27,935	694,980
Mar.	16,352	28	1,448	9,786	–	9,786	27,614	695,139
Apr.	11,633	6,299	–	1,870	1,476	–	19,802	693,651
May	4,533	6,802	–	166	4,684	–	11,501	690,371
June	742	6,442	29	2,896	7,487	–	10,109	687,469
July	69	6,654	–	2,511	9,763	–	9,234	685,564
Aug.	63	6,662	–	2,998	13,038	–	9,723	685,220
Sept.	4,169	5,700	–	405	8,628	–	10,274	686,823
Oct.	9,352	5,663	–	1,847	3,547	–	16,862	692,402
Nov.	12,107	2,142	–	7,101	2,445	5,788	21,350	696,040
Dec.	14,317	–	2,264	9,223	–	11,487	25,804	697,969
Total	102,456	47,401	6,196	65,552	51,068	53,531	221,605	

Std. cu. ft. @ 14.73 psia & 60°F.

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2. *Michigan-Wisconsin Pipeline Company—Gulf Coast System.* This system, built in 1955 by the American-Louisiana Pipeline Company—now merged into Michigan-Wisconsin Pipeline, an affiliate of Michigan Consolidated—originates in the Gulf Coast area of Louisiana and terminates at Willow Station. Constructed originally as a single 30 inch pipeline employing three (3) compressor stations, more than 400 miles,* as of 1965, have been looped and eleven (11) compressor stations totalling 141,000 HP have been spaced along the pipeline's 1100 mile length.

Maximum operating pressure is 858 psi. Normal daily delivery at Willow is 525 MMcf at 675 psi terminal pressure, which can be increased to 650 MMcf by lowering terminal pressure to 525 psi.

At Willow Station, the gas is processed for heavy hydrocarbons, yielding an average of 0.125 gallons of propane and heavier liquids per Mcf of gas.

Heating value after processing averages 1025 Btu/cubic feet, dry basis.

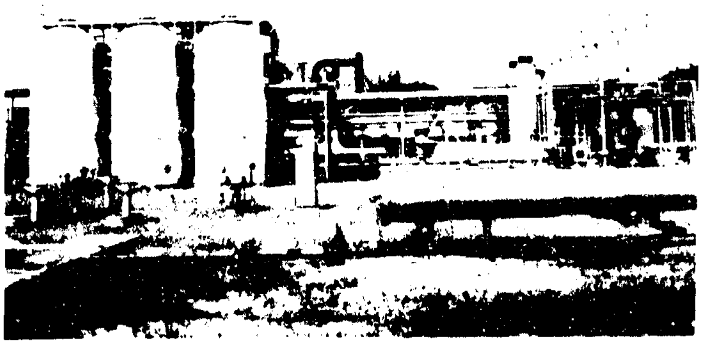
Figure 3. Gas Processing Equipment Willow Station.

The Panhandle supply, stripped to methane before transmission, averages 980 Btu/cubic foot, dry basis.

During summer months, when Panhandle supplies more than one half of Detroit's requirements, Michigan-Wisconsin's deliveries to distribution are minimal amounts as shown in Table 1. Most of its volume flows through Willow Station to the Austin-Detroit system via the 30 inch Milford main, principally to storage but partly for current Detroit distribution via Northwestern Station.

*The last 30 miles of looping is scheduled for completion in 1969.

The two intrastate systems, owned and operated by Michigan Consolidated, which enter Detroit District from the north are:

A. *Austin-Detroit System—Six Lakes to Detroit.* This 130 mile long system, originating in the storage fields of central Michigan, consists of three parallel mains, two 24 inch and one 30 inch. All three mains are operated in parallel throughout the year for maximum deliverability to Detroit in winter and maximum inlet pressure to the storage injection compressors in summer.

Delivery control point to Detroit is at continuously manned Northwestern Station.

Hourly capacity to deliver storage gas to Detroit ranges from 41.7 MMcf when storage is full at 685 psi well head pressure to 29.2 MMcf at the end of the season when field pressures have declined to a minimum of 335 psi and the higher compression ratio reduces Six Lakes compressor capacity to deliver into the 970 psi Austin-Detroit system.

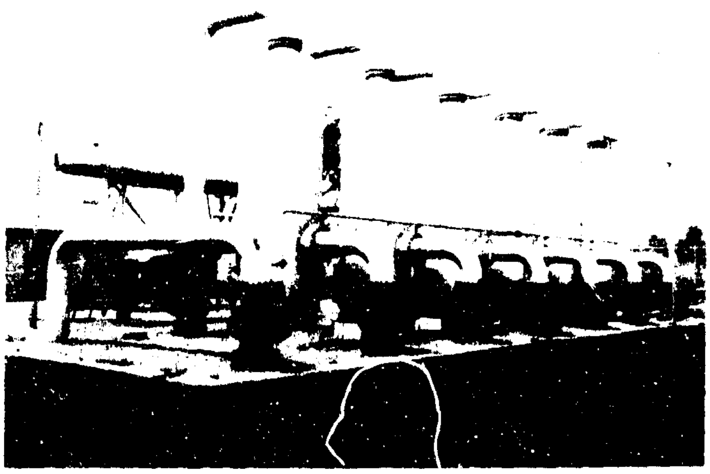

Figure 4. Gas Scrubbers Northwestern Station.

B. *Belle River Mills System, 24 inch Main to Northeast Station.* This system transports gas to and from storage fields in the Belle River area. Storage field operating pressures range from 500 to 1200 psi enabling 24 billion cubic feet to be placed underground. Withdrawn gas is processed for condensate recovery before transmission to Detroit at 450 psi. Maximum deliverability to Detroit is about 28 MMCFH at start of the season.

Mains in both systems, including the 30 inch Milford leg connecting with Willow Station, are protected by automatic valves.* Normal spacing is approximately 15 miles except in the 25 mile long Milford main, where the valves are eight miles apart.

NATURAL GAS DISTRIBUTION IN THE DETROIT AREA

Gas enters the Detroit distribution area through the four City Gate stations of Willow, River Rouge, Northwestern and Northeastern. Seasonally, two schedules are employed in their operation:

1. From November through March, Willow Station is the primary distribution point for the area sending out incoming Michigan-Wisconsin Pipeline gas, supplemented as needed at Northwestern and Northeastern stations with gas drawn from storage. During these months, Panhandle Eastern has no obligation to supply Michigan Consolidated and receipts at River Rouge are either small or nil.

2. From April through October, River Rouge Station is the primary distribution point sending out incoming Panhandle Eastern gas, supplemented as needed at Northwestern and Willow. During these months, the bulk of the incoming Michigan-Wisconsin supply is diverted to storage.

Statistically, these seasonal changes in operating practice are shown in Table 1. Thus in August, the month of the hypothetical attack, 68.5 percent of the area's gas requirements were delivered by River Rouge Station with the remainder coming from Northwestern.

Shown in Table II are comparable statistics for August 24th (the day preceding the strike) and February 3, 1965, the peak sendout day of the year. No "interruptible" gas was curtailed on the peak day. Interruptible curtailment depends on the amount of gas in storage rather than system flow capacity. Curtailment, if exercised, is most likely to occur late in March when the volume of

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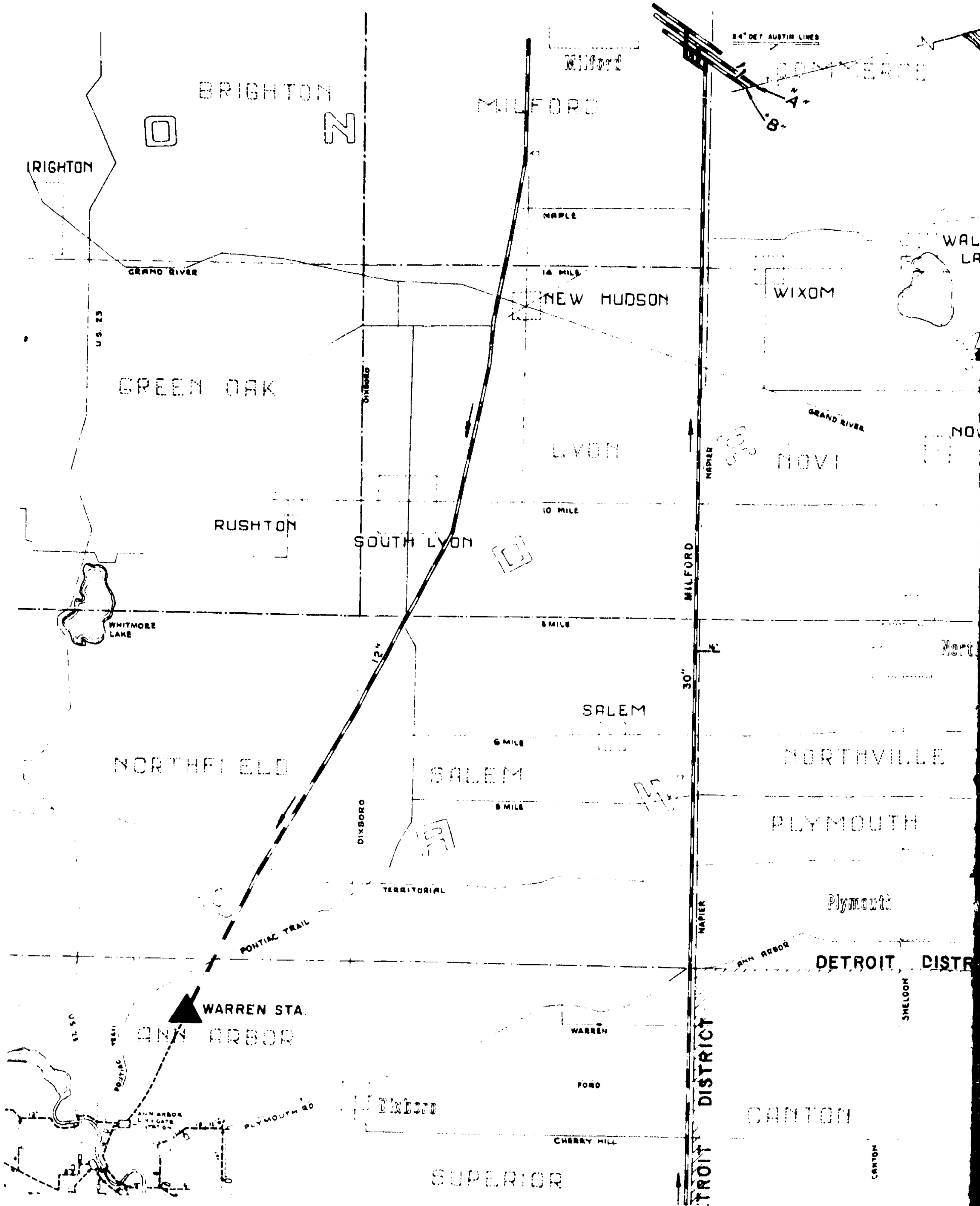
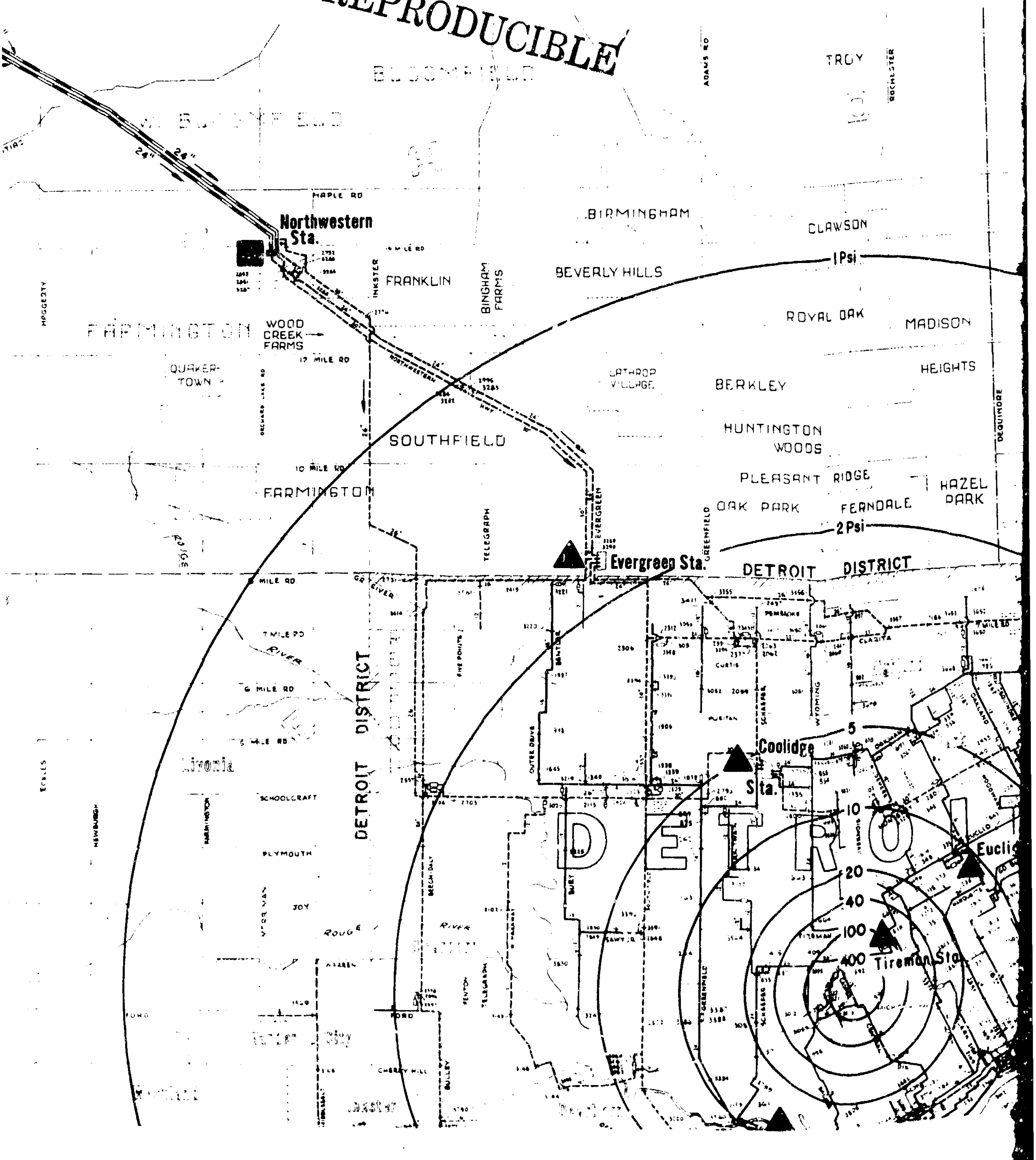
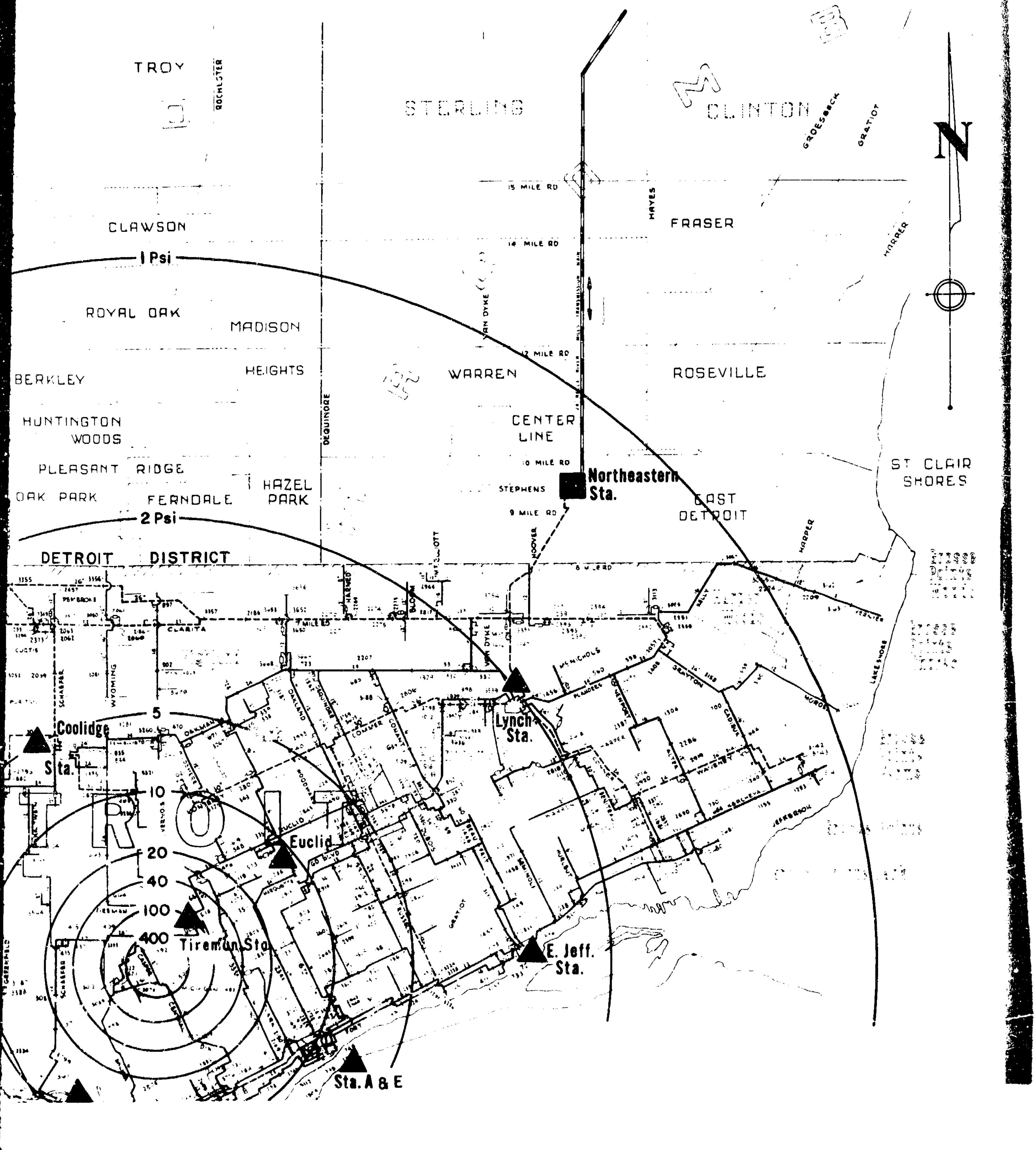
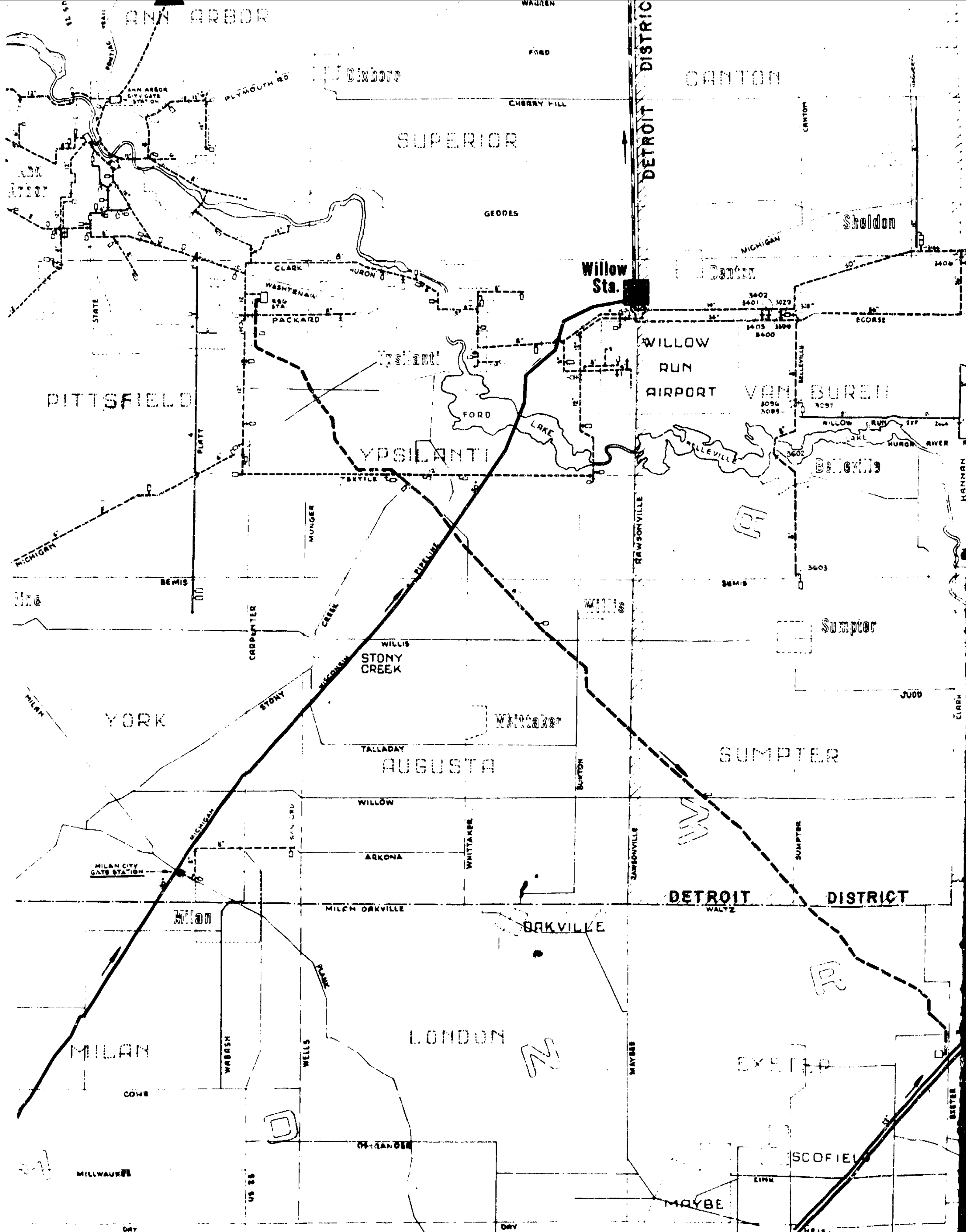
*Mainline valves which automatically close under excessive flow rates from pipe rupture or other catastrophic damage.

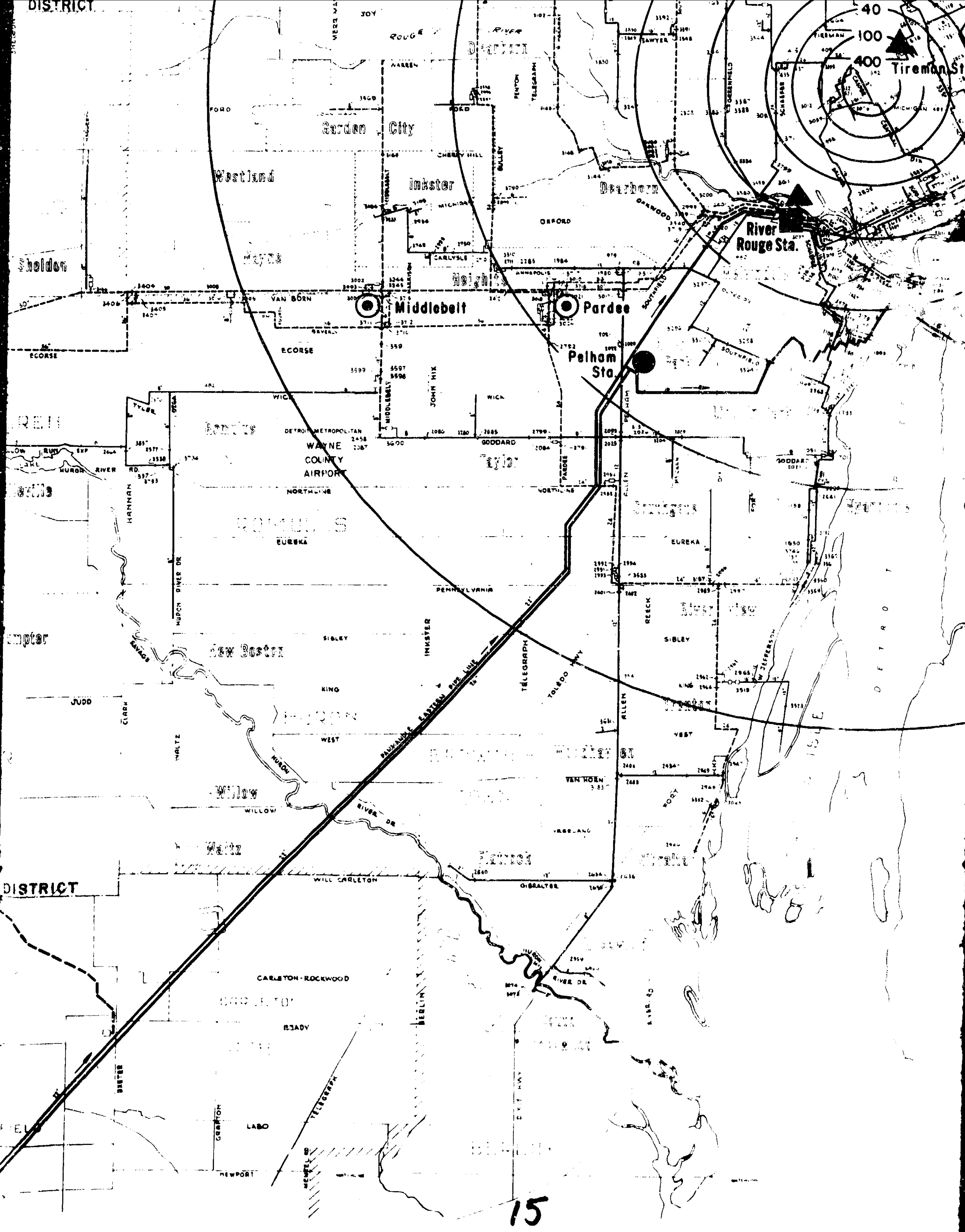


24" DET AUSTIN LINES
Milford
BRIGHTON
MILFORD
COMMERCE
"A"
"B"
BRIGHTON
MAPLE
WIXOM
GRAND RIVER
14 MILE
NEW HUDSON
U.S. 23
GREEN OAK
DIXBORO
GRAND RIVER
LYON
NAPIER
NOVI
10 MILE
RUSHTON
SOUTH LYON
MILFORD
WHITMORE LAKE
8 MILE
12"
30"
SALEM
6 MILE
NORTHFIELD
SALEM
NORTHVILLE
5 MILE
DIXBORO
PLYMOUTH
TERRITORIAL
Plymouth
NAPIER
PONTIAC TRAIL
ANN ARBOR
DETROIT DISTRICT
WARREN STA.
ANN ARBOR
SHELDON
WARREN
FORD
PLYMOUTH RD
Dixboro
DISTRICT
CANTON
CHERRY HILL
SUPERIOR
TROIT
CANTON


Northwestern Sta.
Evergreen Sta.
Coolidge Sta.
Tireman Sta.
Euclid
1 Psi
2 Psi
5
10
20
40
100
400
24"
26"
30"
BLOOMFIELD
TROY
BIRMINGHAM
CLAWSON
BEVERLY HILLS
FRANKLIN
BINGHAM FARMS
ROYAL OAK
MADISON HEIGHTS
FARMINGTON
WOOD CREEK FARMS
QUAKER-TOWN
LATHROP VILLAGE
BERKLEY
HUNTINGTON WOODS
SOUTHFIELD
PLEASANT RIDGE
HAZEL PARK
OAK PARK
FERNDALE
DETROIT DISTRICT
DETROIT
Livonia
MAPLE RD
17 MILE RD
10 MILE RD
7 MILE RD
6 MILE RD
5 MILE RD
SCHOOLCRAFT
PLYMOUTH
JOY
WARREN
FORD
CHERRY HILL
INKSTER
TELEGRAPH
EVERGREEN
GREENFIELD
ADAMS RD
ROCHESTER
DEQUINDRE
ORCHARD LAKE RD
NEWBURGH
ECKLES
FARMINGTON
HAGGERTY
River
Rouge
NORTHWESTERN HWY


N
TROY
STERLING
CLINTON
GROESBECK
GRATIOT
15 MILE RD
CLAWSON
HAYES
FRASER
14 MILE RD
1 Psi
ROYAL OAK
MADISON
HEIGHTS
VAN DYKE
12 MILE RD
WARREN
ROSEVILLE
BERKLEY
HUNTINGTON
WOODS
DEQUINDRE
CENTER
LINE
10 MILE RD
ST CLAIR
SHORES
PLEASANT RIDGE
HAZEL
PARK
STEPHENS
Northeastern
Sta.
OAK PARK
FERNDALE
EAST
DETROIT
9 MILE RD
2 Psi
DETROIT DISTRICT
HARPER
LAKESHORE
Coolidge
Sta.
Lynch
Sta.
5
10
20
40
100
400
Euclid
Tireman Sta.
GRATIOT
E. Jeff.
Sta.
Sta. A & E


ANN ARBOR
CANTON
SUPERIOR
DETROIT DISTRICT
Dixboro
CHERRY HILL
PLYMOUTH RD
ANN ARBOR CITY GATE STATION
GEDDES
Sheldon
MICHIGAN
Willow Sta.
Denton
CLARK
HURON
WASHTENAW
PACKARD
ECORSE
WILLOW RUN AIRPORT
VAN BUREN
Ypsilanti
PITTSFIELD
FORD LAKE
BELLEVILLE
Belleville
YPSILANTI
TEXTILE
STATE
PLATT
MUNGER
HURON RIVER
WILLOW RUN EXP
BEMIS
Willis
Sumpter
CARPENTER
CREEK
WILLIS
STONY CREEK
PIPELINE
JUDD
YORK
STONY
Whittaker
TALLADAY
AUGUSTA
SUMPTER
BUNTON
WILLOW
ARKONA
WHITTAKER
MILAN CITY GATE STATION
DETROIT DISTRICT
WALTZ
Milan
MILAN OAKVILLE
OAKVILLE
PLANK
LONDON
MILAN
EXETER
WABASH
WELLS
MAYBEE
COHB
MILLWAUKEE
US 23
SCOFIEL
DRY
MAYBE
HEISS


DISTRICT
Garden City
Westland
Inkster
Dearborn
Wayne
Sheldon
Heights
Middlebelt
Pardee
Pelham Sta.
River Rouge Sta.
Tireman St
40
100
400
FORD
CHERRY HILL
MICHIGAN
OXFORD
CARLYSLE
ANNAPOLIS
VAN BORN
ECORSE
WICK
DETROIT METROPOLITAN
WAYNE COUNTY AIRPORT
GODDARD
NORTHLINE
EUREKA
PENNSYLVANIA
SIBLEY
KING
WEST
JUDD
WILLOW
Willow
Waltz
WILL CARLETON
GIBRALTAR
VAN HORN
CARLETON-ROCKWOOD
LABO
NEWPORT
TELEGRAPH
INKSTER
JOHN HIX
MIDDLEBELT
HANNAN
HURON RIVER DR
ALLEN
REECK
TOLEDO HWY
SOUTHFIELD
OAKWOOD
Taylor
River View
Trenton
Flat Rock
GRAFTON
BERLIN
SIBYTER
CLARK
WALTZ
PANHANDLE EASTERN PIPE LINE
RIVER DR
HURON
JEFFERSON
FORT
DISTRICT

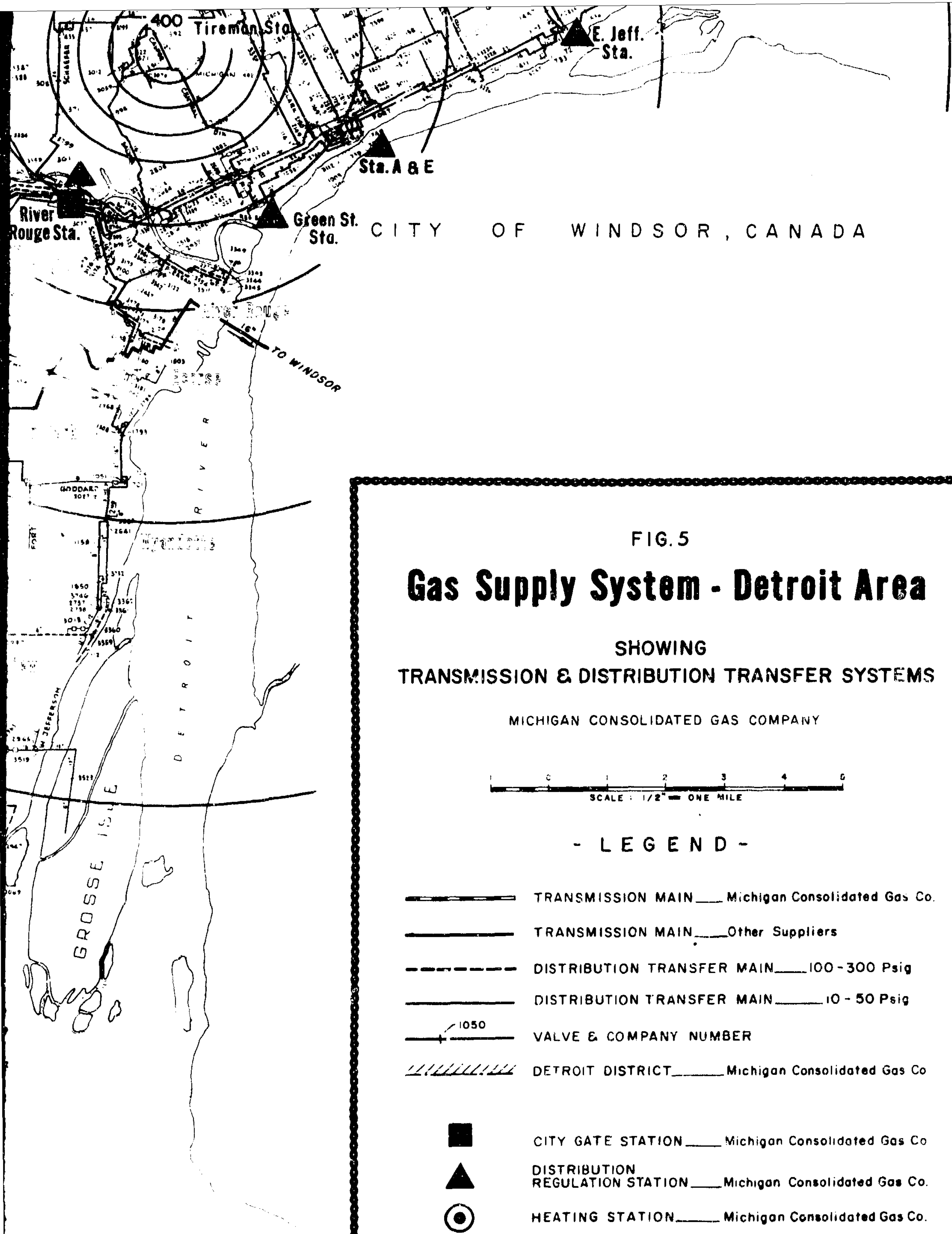


FIG. 5

Gas Supply System - Detroit Area

SHOWING
TRANSMISSION & DISTRIBUTION TRANSFER SYSTEMS

MICHIGAN CONSOLIDATED GAS COMPANY

1 0 1 2 3 4 5
SCALE : 1/2" = ONE MILE

- LEGEND -

- TRANSMISSION MAIN ___ Michigan Consolidated Gas Co.
- TRANSMISSION MAIN ___ Other Suppliers
- DISTRIBUTION TRANSFER MAIN ___ 100 - 300 Psig
- DISTRIBUTION TRANSFER MAIN ___ 10 - 50 Psig
- 1050 VALVE & COMPANY NUMBER
- DETROIT DISTRICT ___ Michigan Consolidated Gas Co
- CITY GATE STATION ___ Michigan Consolidated Gas Co
- DISTRIBUTION REGULATION STATION ___ Michigan Consolidated Gas Co.
- HEATING STATION ___ Michigan Consolidated Gas Co.
- PELHAM STATION Panhandle Eastern Pipeline Co.

gas remaining in storage is low. The purpose is to prevent storage field pressures from being drawn below established minimums.

Table II—Gas Deliveries to Detroit District Distribution

August 24, 1965 and Peak Day 1965

Stations	August 24, 1965 MCF*	Peak Day MCF*
Willow	—†	508,547
River Rouge	199,961	—
Northwestern	168,441	756,464
Northeastern	(39,614)‡	70,355
Totals (including interruptible)	328,788	1,335,366
Interruptible	131,388	186,200

*Standard cubic feet @ 60°F and 14.73 psia.
†On this date, Willow delivered 527,400 MCF to the Detroit-Austin system for storage.
‡To storage at Belle River Mills.

Distribution Systems in the Detroit Area

Two integrated systems distribute gas in the Detroit area. Locally, one is termed the Transfer Main system;* the other is called the Distribution Grid System.*

Transfer Main System. The principal facilities of this system are shown in Figure 5. The overall function of the system, as the name implies, is to transfer gas from the City Gate stations to the various parts of the distribution area.

*See Glossary for definitions.

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The system operates in two general ranges of pressure:

1. *Pressure Range 100–300 psi.* Mains operating in this range are steel. They are identified in the legend of Figure 5 and by pressures noted near individual mains in Figure 6.

The function of those operating at 300 psi* is to move large volumes from the City Gate stations to the major distribution regulating stations of Evergreen, Coolidge, Lynch and River Rouge (the latter when supplied from Willow). A heavy industry may be supplied directly by a 300 psi main, for example the 16 inch, River Rouge, Zug Island main, to Great Lakes Steel.

From the major regulating stations, 100–200 psi facilities deliver gas to the secondary regulating station, for example the 24 inch–100 psi main between River Rouge and Station A and others. They may, in addition, supply branch mains and, in many instances support nearby trunks operating at lower pressure levels.

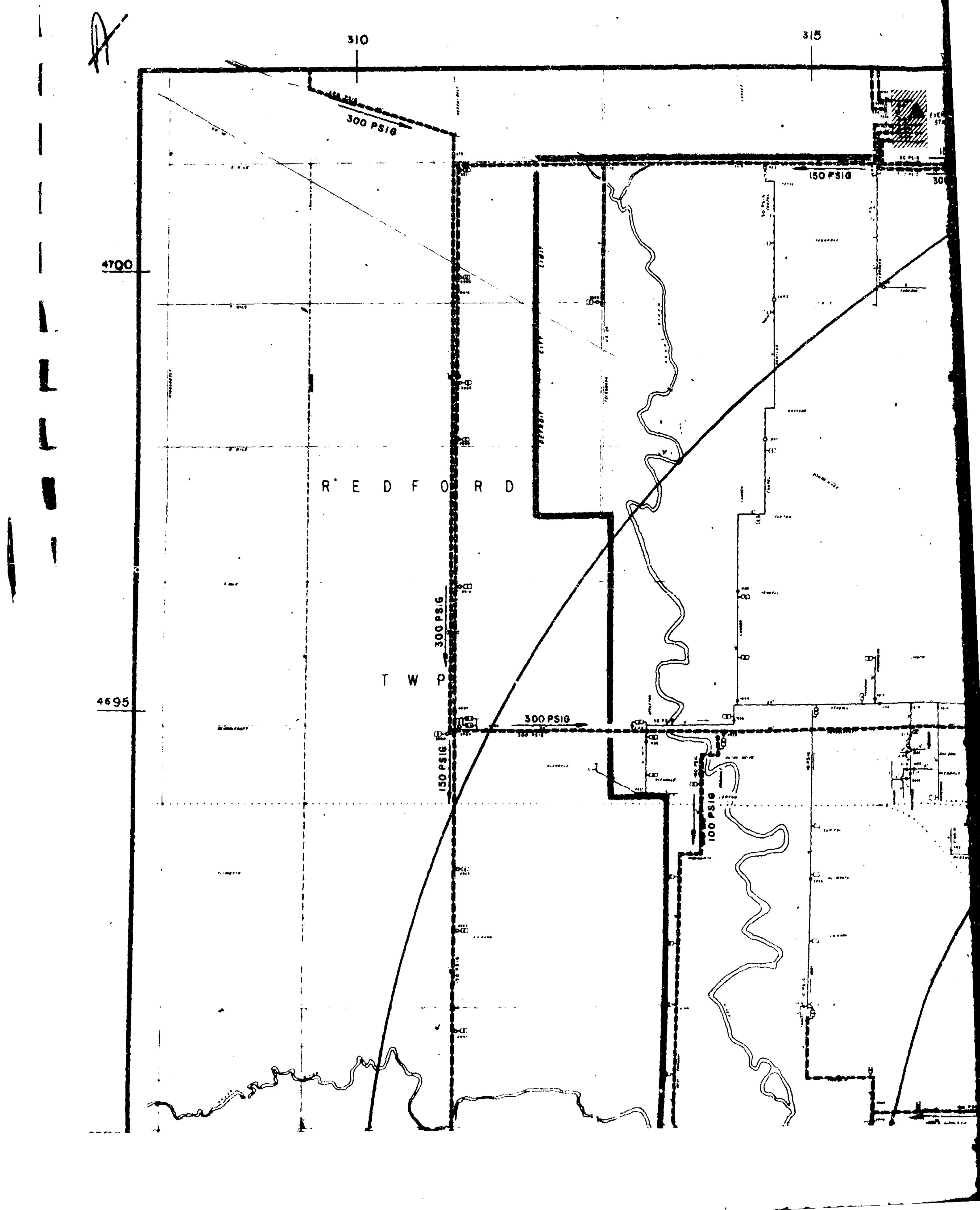
2. *Pressure Range 10–50 psi.* These mains, also shown and identified in Figures 5 and 6, either originate at the regulator stations where distribution regulators control outgoing pressures, or are pressure controlled branches from higher pressure facilities.

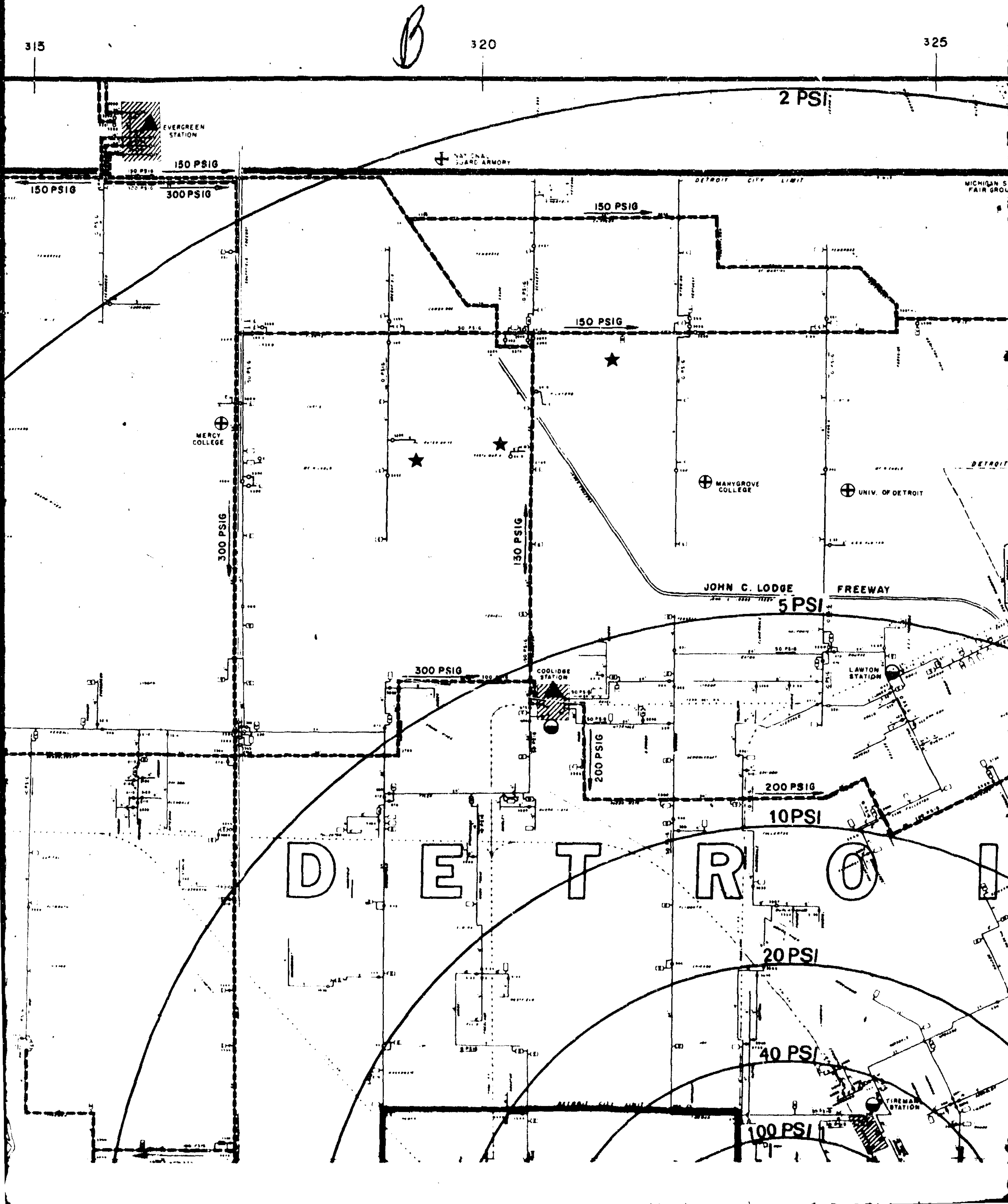
Their primary function is to supply approximately 800 district regulators in the Detroit District of which about 575 are in the area encompassed by Figure 6. The district regulators in turn deliver pressure controlled volumes to the Grid System.

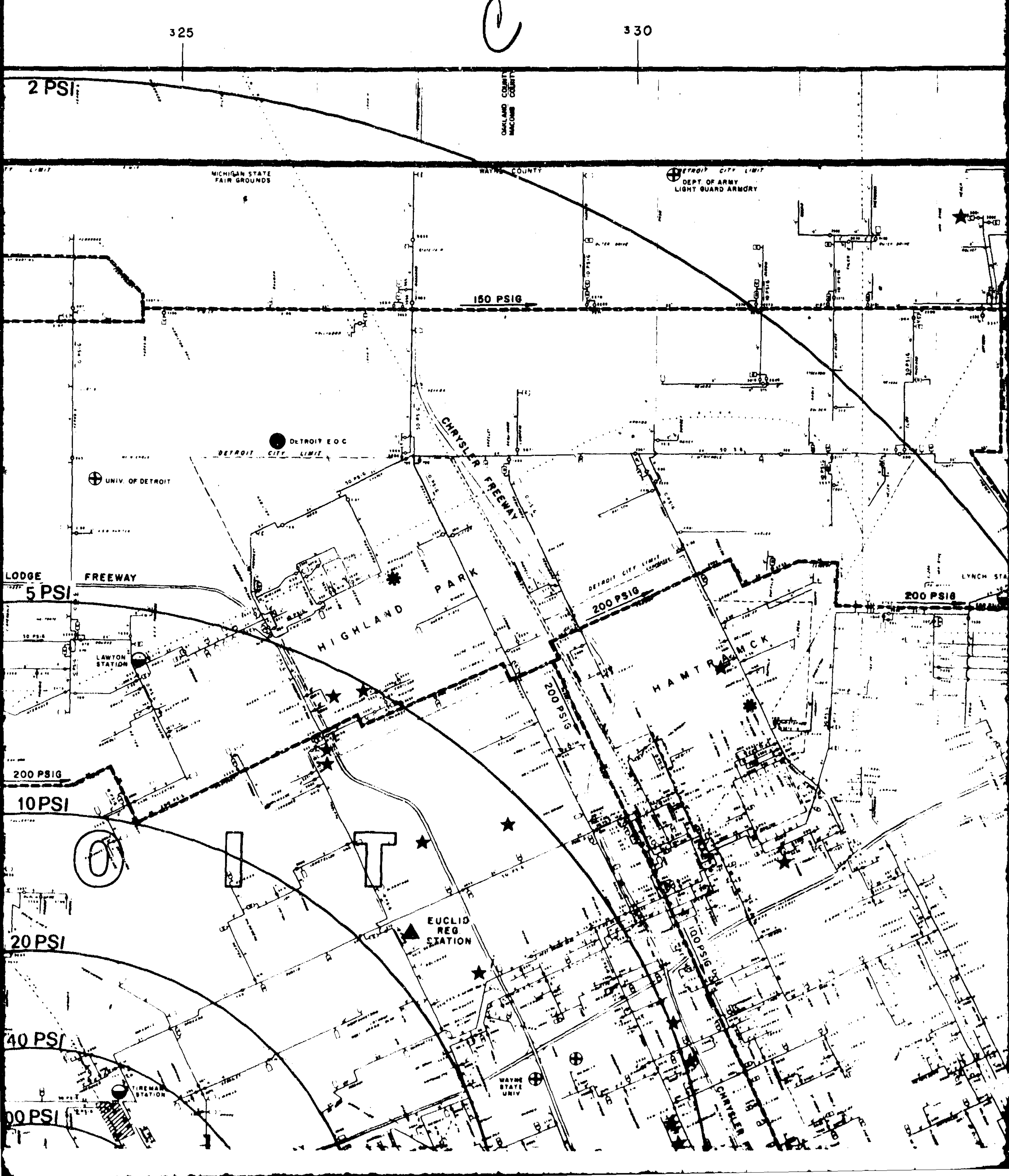
A secondary function is to directly supply individual service lines where a grid system main is not nearby.

In the older parts of the system, transfer mains not exceeding 10 psig in operating pressure are usually cast iron, originally installed for manufactured gas distribution.

*Except in special instances, services are not supplied from Transfer Mains operating above 150 psig.


310
315
4700
4695
300 PSIG
150 PSIG
REDFORD
TWP
300 PSIG
300 PSIG
150 PSIG
100 PSIG

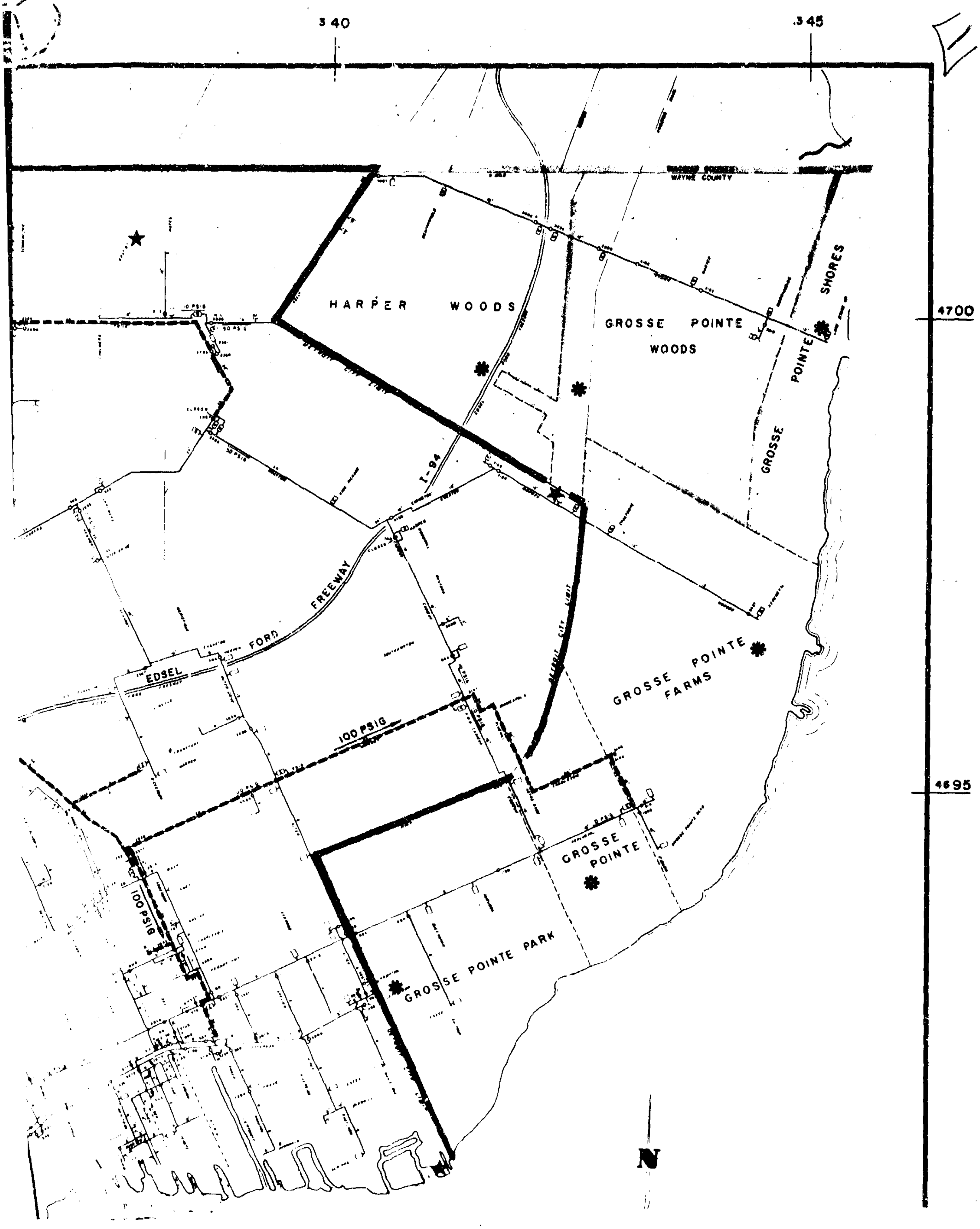

B
315
320
325
2 PSI
EVERGREEN STATION
150 PSIG
150 PSIG
300 PSIG
NATIONAL GUARD ARMORY
DETROIT CITY LIMIT
MICHIGAN STATE FAIR GROUNDS
150 PSIG
150 PSIG
MERCY COLLEGE
MARYGROVE COLLEGE
UNIV. OF DETROIT
300 PSIG
150 PSIG
JOHN C. LODGE FREEWAY
5 PSI
300 PSIG
COOLIDGE STATION
LAWTON STATION
200 PSIG
200 PSIG
10 PSI
DETROI
20 PSI
40 PSI
TIREMAN STATION
100 PSI

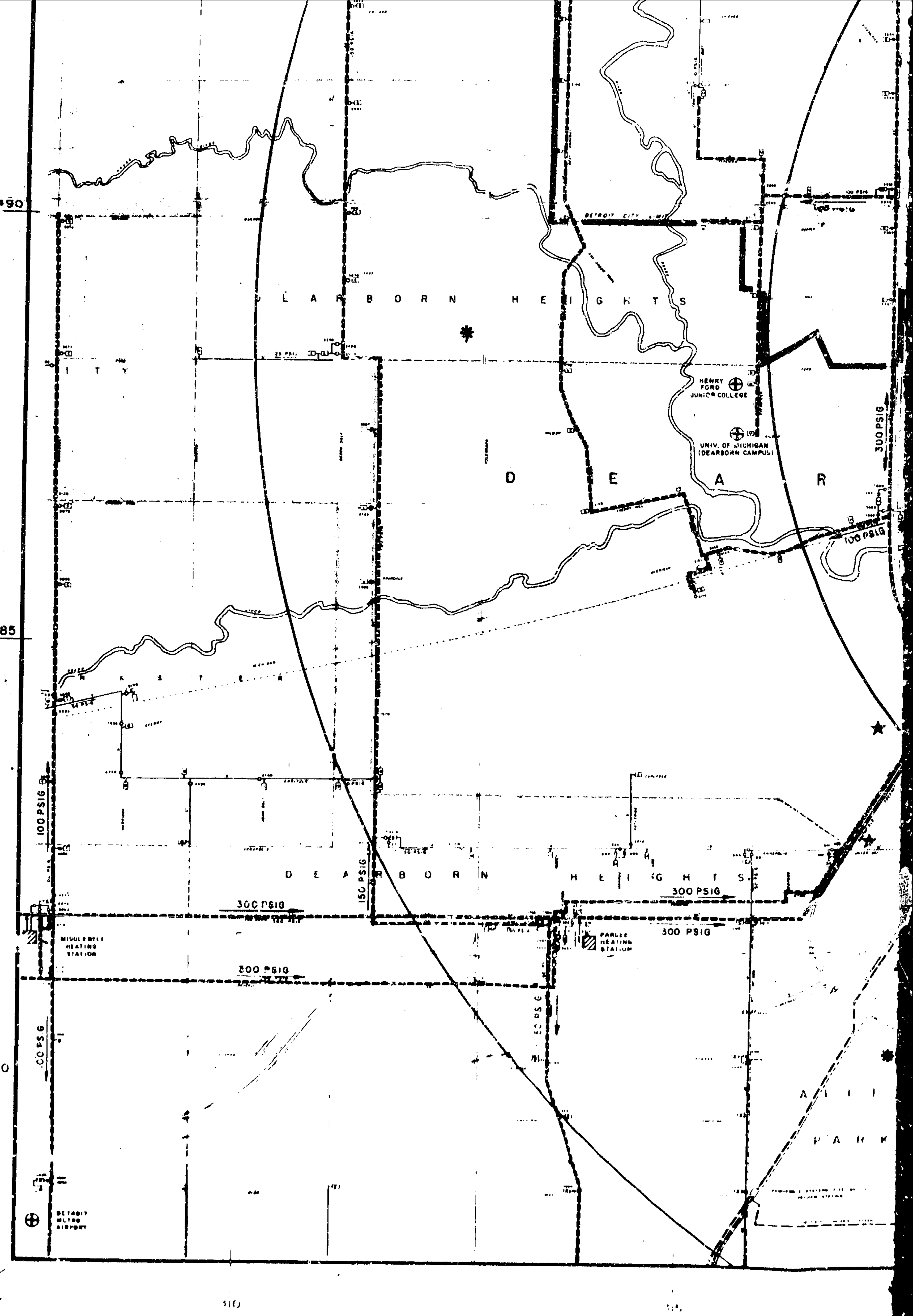


325
330
2 PSI
OAKLAND COUNTY
MACOMB COUNTY
MICHIGAN STATE FAIR GROUNDS
WAYNE COUNTY
DETROIT CITY LIMIT
DEPT. OF ARMY LIGHT GUARD ARMORY
150 PSIG
DETROIT E O C
DETROIT CITY LIMIT
UNIV. OF DETROIT
CHRYSLER FREEWAY
LODGE FREEWAY
5 PSI
HIGHLAND PARK
200 PSIG
LYNCH
200 PSIG
LAWTON STATION
HAMTRAMCK
200 PSIG
200 PSIG
10 PSI
D I T
EUCLID REG STATION
100 PSIG
20 PSI
40 PSI
WAYNE STATE UNIV
CHRYSLER
00 PSI

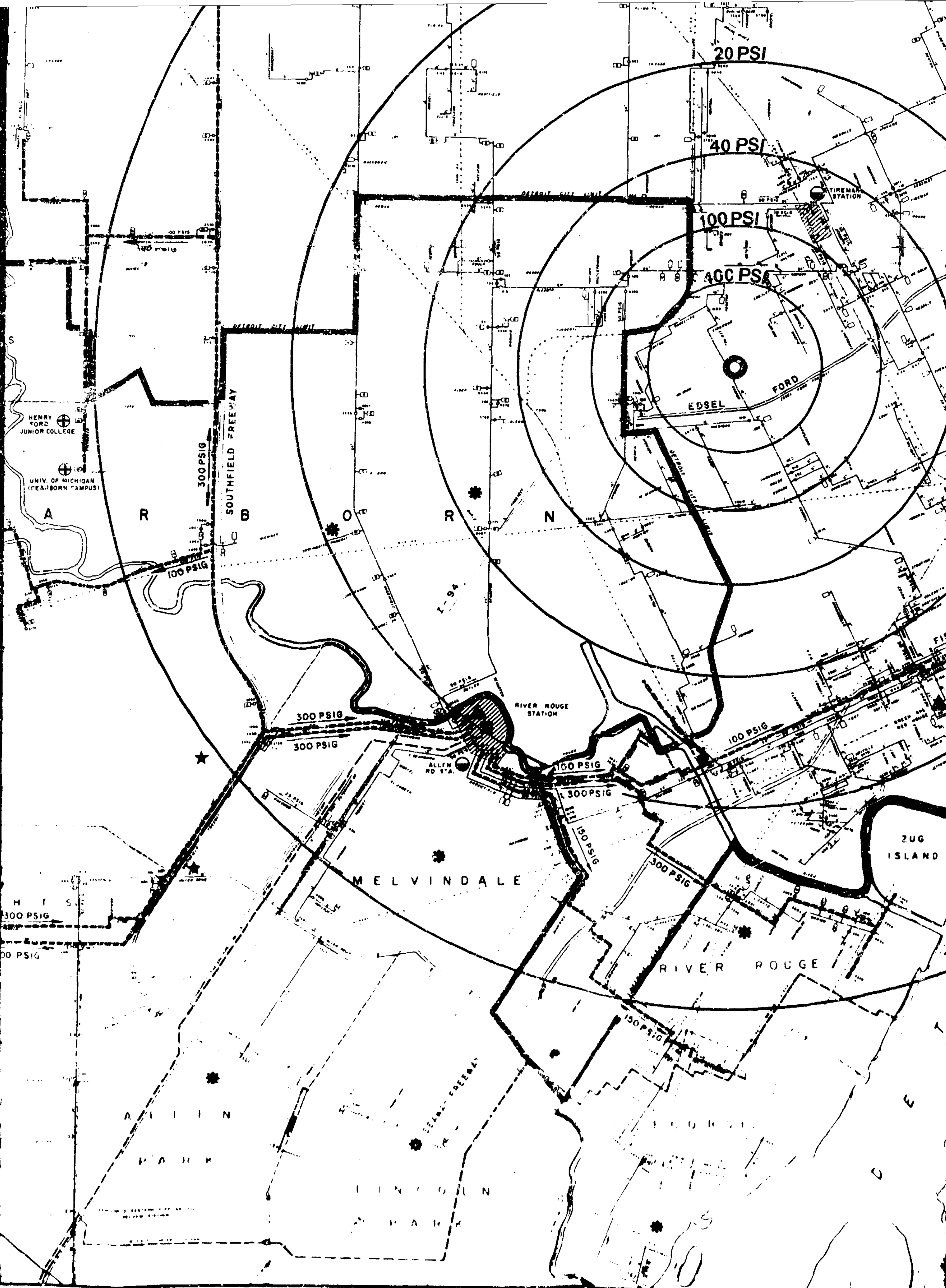
D

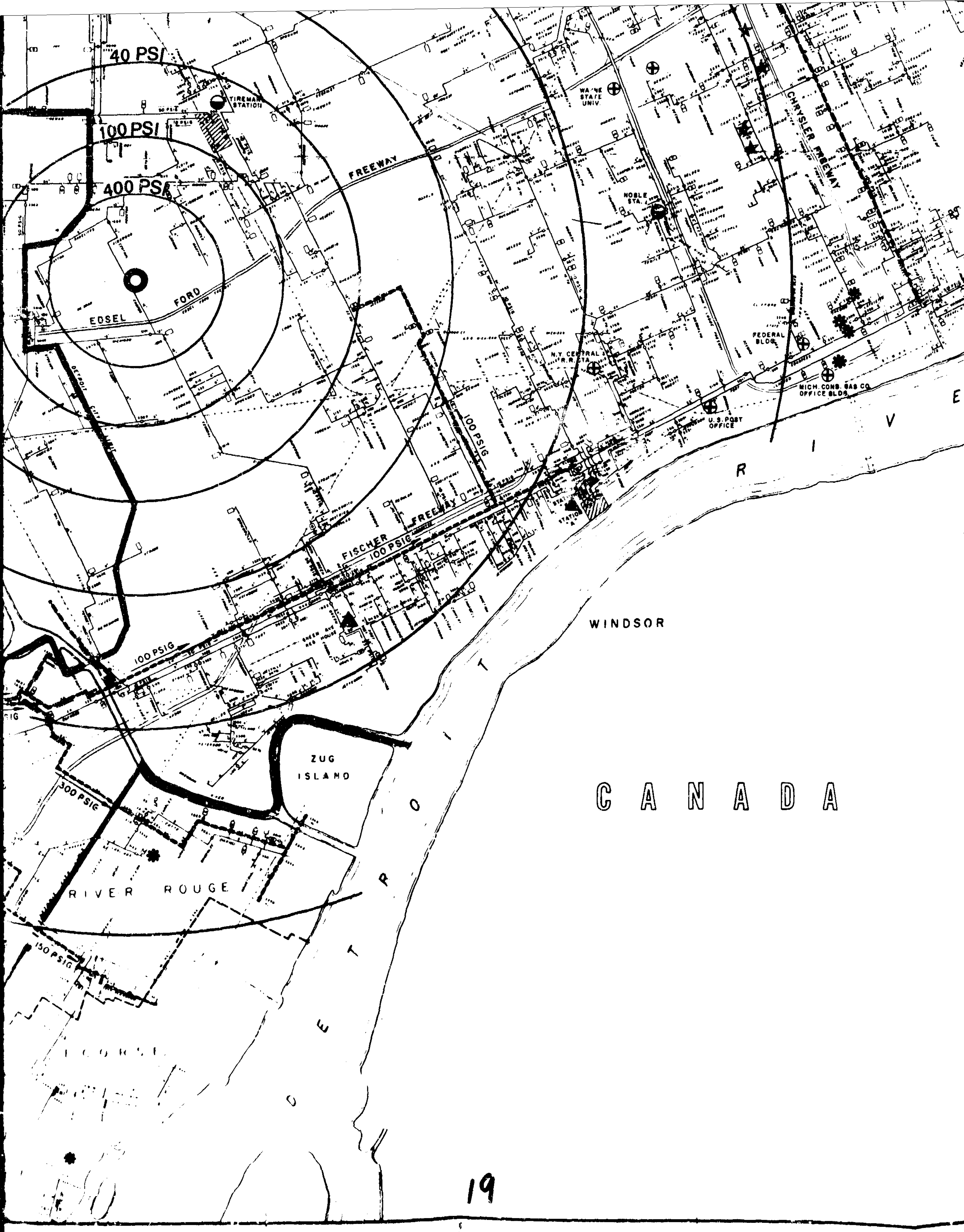

335
340
300 PSIG
150 PSIG
HARPER WOODS
I-94
300 PSIG
LYNCH STATION
200 PSIG
DETROIT CITY AIRPORT
100 PSIG
EDSEL
FORD
FREEWAY
100 PSIG
100 PSIG
GROSSE POINTE PARK


340
345
4700
4695
WAYNE COUNTY
HARPER WOODS
GROSSE POINTE WOODS
GROSSE POINTE SHORES
I-94
FORD FREEWAY
EDSEL
100 PSIG
100PSIG
GROSSE POINTE FARMS
DETROIT CITY LIMIT
GROSSE POINTE
GROSSE POINTE PARK
N



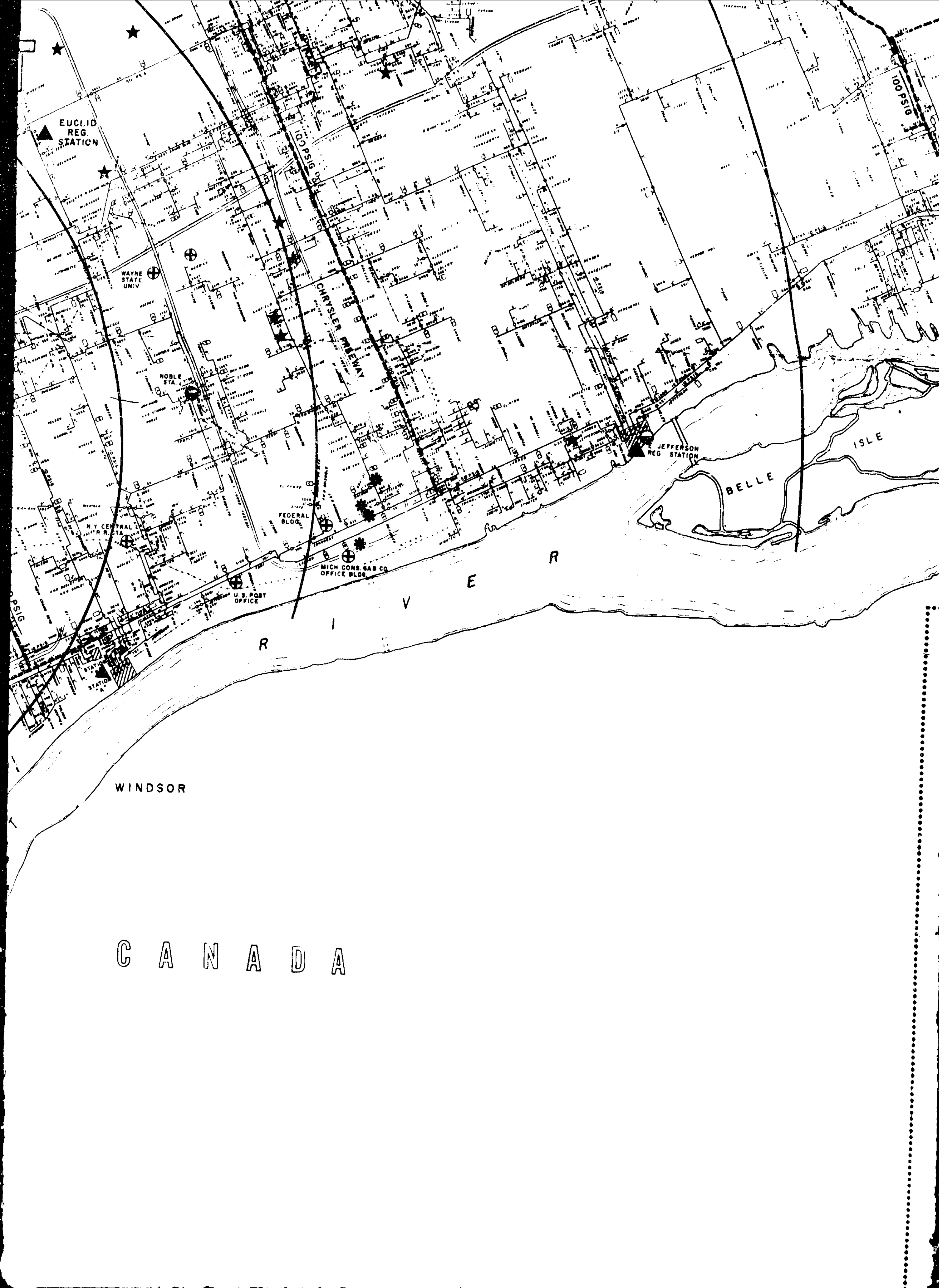
390
385
D E A R B O R N H E I G H T S
DETROIT CITY LIMIT
HENRY FORD JUNIOR COLLEGE
UNIV. OF MICHIGAN (DEARBORN CAMPUS)
300 PSIG
D E A R
100 PSIG
100 PSIG
150 PSIG
D E A R B O R N H E I G H T S
300 PSIG
300 PSIG
300 PSIG
300 PSIG
MIDDLEBELT HEATING STATION
HEATING STATION
PARK
DETROIT METRO AIRPORT


20 PSI
40 PSI
100 PSI
400 PSI
TIREMAN STATION
EDSEL FORD
DETROIT CITY LIMIT
DETROIT CITY LIMIT
HENRY FORD JUNIOR COLLEGE
UNIV. OF MICHIGAN (DEARBORN CAMPUS)
300 PSIG
SOUTHFIELD FREEWAY
A R B O R N
100 PSIG
I-94
RIVER ROUGE STATION
300 PSIG
300 PSIG
ALLEN RD STA.
100 PSIG
300 PSIG
150 PSIG
100 PSIG
300 PSIG
ZUG ISLAND
M E L V I N D A L E
300 PSIG
R I V E R R O U G E
150 PSIG
FIS
L I N C O L N
P A R K



40 PSI
100 PSI
400 PSI
TIREMAN STATION
FREEWAY
EDSEL
FORD
WAYNE STATE UNIV.
NOBLE STA.
CHRYSLER FREEWAY
FEDERAL BLDG.
N.Y. CENTRAL R.R. STA.
MICH. CONS. GAS CO. OFFICE BLDG.
U.S. POST OFFICE
100 PSIG
FISCHER FREEWAY
100 PSIG
100 PSIG
WINDSOR
ZUG ISLAND
CANADA
300 PSIG
RIVER ROUGE
150 PSIG
R I V E R

H


EUCLID REG. STATION
WAYNE STATE UNIV
NOBLE STA.
100PSIG
100PSIG
CHRYSLER FREEWAY
N.Y. CENTRAL R.R. STA.
FEDERAL BLDG.
MICH. CONS. GAS CO OFFICE BLDG.
U.S. POST OFFICE
JEFFERSON REG. STATION
BELLE ISLE
R I V E R
WINDSOR
CANADA

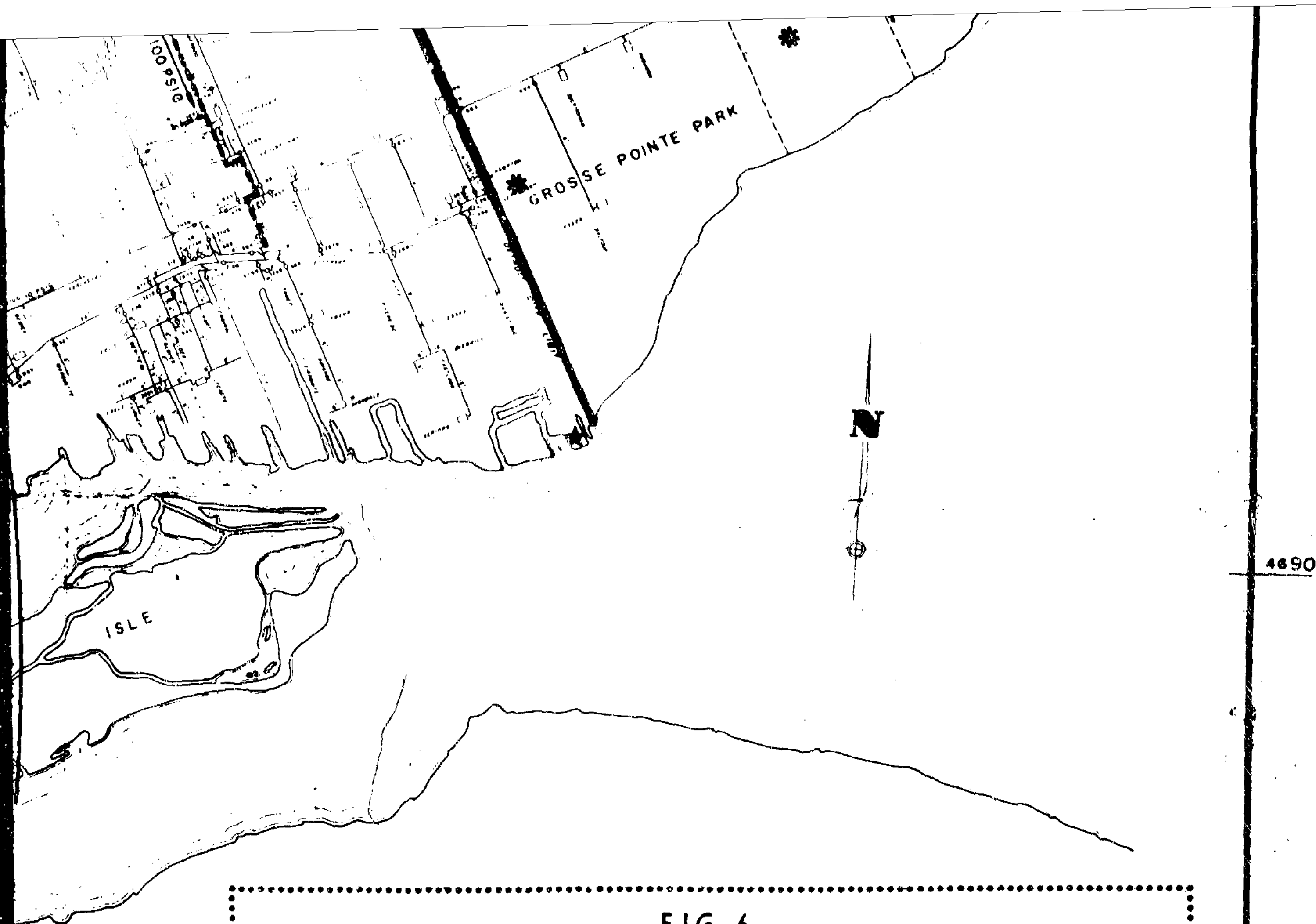


FIG. 6

Gas Distribution System – City of Detroit

SHOWING
TRANSFER MAINS and OPERATING STATIONS

MICHIGAN CONSOLIDATED GAS COMPANY

1 MILE — 1/2 — 0 — 1 MILE

SCALE — 1" = 0.738 MILES

LEGEND

(heavy solid line)	DETROIT CITY LIMITS	
(heavy dashed line)	TRANSFER MAIN . 100 psi and ABOVE	Mich. Cons. Gas Co
(thin line)	TRANSFER MAIN ... 10 to 100 psi	Mich. Cons. Gas Co.
⊖	SERVICE and MAINTENANCE STATION	Mich. Cons. Gas Co.
■	CITY GATE STATION	Mich. Cons. Gas Co
▲	REGULATING STATION	Mich. Cons. Gas Co
—o—	VALVE	Mich. Cons. Gas Co
—□—	DISTRICT REGULATOR, (see footnote)	Mich. Cons. Gas Co.
●	DETROIT EMERGENCY OPERATING CENTER (Civil Defense)	
★	HOSPITAL	
✱	CITY OR COUNTY OFFICE	
⊕	U.S. GOVERNMENT BUILDINGS	

Letters in regulator symbol mean a protective feature is included as follows: S and M represent Series and Monitoring arrangements; C and HL indicate a Closure or Hi – Low device.

Grid System. This system is composed of a highly interconnected network of headers and laterals receiving gas from the Transfer System through district regulators. The grid system directly supplies services of customers in built up areas street by street. Figure 7 is a typical grid arrangement.

Grid system pipe is cast iron except in the suburban areas west and south of the Rouge River where steel is employed. Thus, cast iron pipe predominates in the area most pertinent to this study. The bell and spigot joints, every 10–12 feet, are sealed by jute packing held in place by an annular ring of cement in the bell section. However, all cast iron joints operating above 10 psi and about 10 percent operating at or under 10 psi have been leak clamped, representing an estimated 12 percent of total cast iron joints in the system.

Two pressure schedules are used for the grid system—1.5 psi in summer and 2 psi in winter, except in:

(1) suburban areas where grid mains are steel and pressures up to 50 psi may be used.*

(2) a 12.5 square mile area extending out approximately 2 miles on each side and 3 miles up from the foot of Woodward Avenue in downtown Detroit where pressure is 7 inches of water column.

Typical Piping Layout, Detroit Gas Distribution

Figure 7 is a map of a one-third square mile portion of the gas distribution system in the City of Detroit. It shows a typical arrangement of underground gas facilities in streets. A series of similar maps in fireproof files at One Woodward cover the balance of the Detroit District system.

The area portrayed by this map surrounds ground zero. Distribution component parts typical of Detroit's cast iron system shown by the map are:

1. *A Transfer System 12 inch, 10 psi Cast Iron Main.* The dashed line along Casper Street identifies this main which, also, is the principal supply into the area. The portion of the main between Dresser couplings under the Edsel Ford freeway is steel.

*There are also two small 2 psi pressure areas in downtown Wyandotte and Trenton.

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2. *A grid system 8 inch, 2 psi cast iron header main* shows as a solid line along McGraw Street. A district regulator at McGraw and Casper taking gas from the 10 psi, 12 inch main supplies the header with 2 psi gas.

3. *A series of grid system 4 inch, 2 psi, cast iron lateral mains crossing McGraw.* Each lateral is connected to and receives 2 psi gas from the header at street intersections along McGraw.

Also shown is an example of load balancing in the area. In this instance, the boiler load of the school on Larkins Street is supplied from a branch main purposely extended 700 feet along Wagner from a transfer main 3,000 feet east of Casper. The intent is to avoid overloading the 2 psi system in the vicinity of the school.

Not shown by distribution section maps are services pipes supplying customers. Terminal locations of services in the streets and at meter sets on customers' premises, size and kind of pipe and other data are kept in Service Order fireproof files on the eleventh floor at One Woodward.

The need for distribution section maps is to fix with reasonable accuracy locations of operating and non-operating (dead or abandoned) underground gas facilities. Nearby foreign underground facilities such as telephone ducts, high voltage electric cables, for example the 120 KV cable in 7 inch pipe conduit along Casper Street, are often identified and located in distribution maps.

Valves

For sectionalizing and pressure control purposes, the Detroit District Transfer System contains approximately 1,250 valves. In general, distances between sectionalizing valves vary from one mile or less for mains operating in the range of 10–49 psi to five miles or less for 300 psi facilities. Valve spacing in Figure 6 are typical. All valves are accessible without digging by being installed in boxes, pits or vaults.

Grid systems generally do not contain sectionalizing valves. Rivers, freeways, railroad right-of-ways or other natural boundaries such as wide streets with mains on both sides and a minimum of cross ties, or adjoining areas operating at different pressures are relied on if isolation of blocks of customers should be necessary. Shutting down regulators feeding the area to be isolated and the valving or cutting of cross-ties are required. Areas with these characteristics are present in Detroit, for example the 7 inch W.C. low pressure part of the system in downtown Detroit and other sections separated by freeways, except for relatively few interconnecting transfer or header mains.

Distribution System Vaults

Excluding regulators installed in City Gate and named regulating stations (see Figure 5), all distribution regulators in the field are located in underground concrete vaults. There are 413 vaults within a six psi overpressure radius around ground zero.

Four sizes of vaults are used, see Appendix A. The concrete roof slabs, usually at or close to ground level, are 12 inches thick and reinforced with mats of 5/8 inch bars and two or three 10 inch I beams depending on vault size. Design criteria is a 15,600 pound concentrated wheel load including impact and maximum stresses of 20,000 psi for steel and 3,000 for concrete in compression. This loading on the top slab is equivalent to a blast overpressure of 13 psi.

The 12 inch walls and 4 inch floor slabs are not reinforced and thus are vulnerable to fracture by the lateral component of overpressure and by ground motion.

In the cast iron portion of the system all piping in vaults, including 15–25 foot lengths approaching and leaving, are steel. Entrance and exits of pipe from the vault are through the end walls. Concrete is poured around the pipe in place resulting in rigid anchorage.

Regulators

Distribution regulators in the field employ pilot loading. In stations, both pilot loading and instrument control are used. Regulator bodies are cast iron and generally are supported by adjustable stands bearing on a concrete floor.

Company policy is to design protective features into regulator sets where regulator malfunction could subject downstream facilities to unsafe pressures.

In distribution stations, each outgoing Transfer main is protected from over-pressure by a Hi-Low Operator, a device attached to and capable of turning a plug valve immediately ahead of the regulator. The device automatically counteracts regulator malfunction by alternately closing and opening the valve to hold pressure within set, safe limits.

In distribution vaults in the cast iron area, the grid system is provided protection at each supply point where regulator inlet pressure exceeds 10 psi by:

(1) an Over-Under Operator, a device for turning a plug valve. It acts to automatically close the valve if pressure exceeds or falls under preset values. Manual reopening is required.

(2) series, triple or monitoring* arrangements of two or more regulators. Redundancy of equipment provides the protection.

Locations of regulators in vaults and kinds of installed protective equipment are shown in Figure 6 and identified in the legend.

For customer protection in his premises, relief type service regulators or other approved devices are installed where inlet pressure to the service regulator exceeds 2 psi.

---

*In this arrangement, two regulators in series have a common downstream pressure control point. One regulator is adjusted to control at a pressure slightly higher than the "working" regulator. If the "working" regulator fails to close, the second one takes control.

Meters and Services

When Detroit was supplied with manufactured gas, meters on customers' premises were always installed indoors, usually in basements, to avoid low temperature exposure in winter. During this same period, service regulators in meter sets were unneeded because grid system pressure was only slightly higher than the standard 7 inches W.C. pressure delivered to houselines.

The subsequent raising of grid pressure to 2 psi required the addition of a service regulator to each meter set.

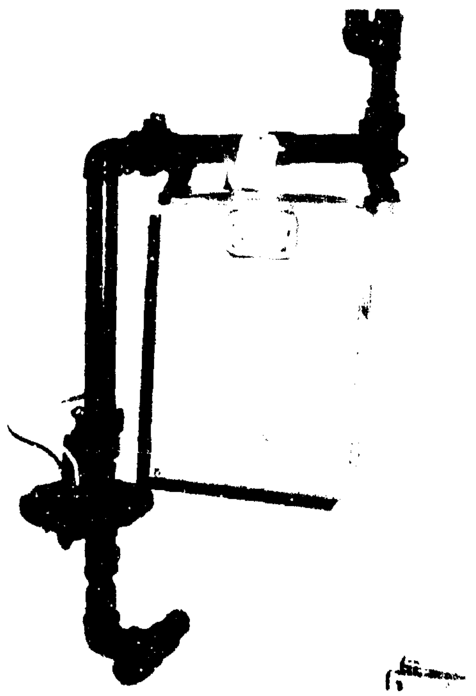

Figure 8. Indoor Meter and Regulator Set in a Basement.

Figures 8 and 9 show typical current indoor and outdoor meter installations in the Detroit area. The former is a basement location dating back to manufactured gas distribution. The 1-1/4 inch service enters the basement below grade. The regulator, added after introduction of natural gas, is 1 inch and meter is a 10:300 tinned steel case.

The service regulator was fitted in the assembly by cutting the inlet piping ahead of the meter and inserting the regulator equipped with compression type, rubber wedge seal couplings. The vulnerability of this arrangement to piping breakage from floor collapse appears less than meter sets in Operation Teapot (Reference 5). Meters in Detroit are strengthened by meter bars and, in addition, the flexible couplings can absorb movement, features not present in above test.

Figure 9 is an outdoor meter and regulator set enclosed in a plastic case to enhance appearance. Where not prominently visible from the street, plastic enclosures are not included.

Within the area enclosed by 6 psi overpressure of this hypothetical attack, 170,604 installed meters, or 97.5%, are tinned steel case, 3501, or 2%, are hardcase and the balance of 593 are rotaries. Except for 2842 hardcase meters installed outdoors, the balance amounting to 98.4% of the total are located indoors.

Figure 9. Outdoor Meter and Regulator Set Enclosed in Plastic Case.

Meter Test And Repair

Gas meter test and repair operations for Detroit District are conducted in a modern, overhead conveyor, automated shop located at Tireman Station.

The shop, presently employing 61 persons, has a nominal capacity to repair and test 600 meters per 8 hour day.

Service Lines

The average length of service pipe from the street main to meter sets on customers' premises in the cast iron area is 70 feet. During the manufactured gas period, the minimum size steel service pipe for residential and commercial installations was 1-1/4 inches. Comparable sizes now with natural gas are 1 inch steel or 7/8 inch OD copper or plastic tubing. Service pipe replacement in the grid area is usually made by pulling copper or plastic tubing through the existing steel service.

Mileage of Mains in Detroit District

Mileage of gas mains supplying the 562 square mile Detroit District are given in Table III, listed by operating pressure and pipe materials. Not included is piping in (1) distribution operating stations and (2) services to customers.

Table III—Detroit District Distribution Mains Operating Pressures and Miles of Main

August 1965

Steel Mains	
Operating Pressure	**Miles**
10 psig or less*	1,690.27
25 psig	1.02
40 psig	47.02
50 psig	79.27
100 psig	45.08
150 psig	52.64
200 psig	20.76
300 psig	89.63
	2,025.69
Cast Iron Mains	
Operating Pressure	**Miles**
10 psig or less*	2,850.73
25 psig	.42
50 psig	60.09
	2,911.24
TOTAL DETROIT DISTRICT	4,936.93

*Principally 2 psi

As of January 1968 amounts of pipe were:

Steel	2300 miles	44.4%
Cast Iron	2885	55.6%
Plastic	0 2	

All pipe lis ·d is classed as distribution. Michigan Consolidated's nearby transmission such as the Milford-Detroit-Austin, Northwestern and Northeastern systems are outside of Detroit District.

Panhandle Eastern transmission in Detroit District totals 31 miles of 22 and 26 inch and 8.5 miles of 16 inch.

Based on an average of 70 feet per customer, service pipe total is approximately 9,250 miles, allowing for joint services. Principal sizes are 1 and 1-1/4 inch steel and 7/8 inch O.D. copper and plastic tubing.

Customer Service In Detroit District

Gas appliance adjustment and related services to customers are provided by a mobile force of 582* servicemen, helpers and trainees.

To minimize driving time and truck mileage in covering the area, the force is divided into eight groups working out of the seven Service Stations shown in Figure 6 plus Eureka Station located in Southgate outside of the area shown.

Typical summer night schedules are 38 on duty from 8:00 p.m. to midnight and 11 thereafter from midnight to 8:00 a.m.

During August 1968, an average force of 576 servicemen worked 78,000 service and 23,500 meter orders. For the year ending August 1968, annual totals were 1,050,000 and 316,000 respectively or a total of 1,366,000.

SYSTEM OPERATION—SUPPLY AND PRESSURE

To the extent of arranging for gas supply to meet daily requirements and the maintenance of proper pressures, operation of the system is assigned to the Company's Gas Dispatcher. The

*Year 1968

principal duties involved in this responsibility are (1) forecasting of daily loads, (2) arranging for delivery of forecast volumes from suppliers, and (3) supervision and adjustment of operating pressures such that adequate supply is available in all parts of the system.

The Dispatcher and his staff are part of the Company's Department of Production, Transmission and Storage. Dispatch headquarters, which are continuously manned, are located in the main office at One Woodward Avenue, Detroit.

The Dispatcher arranges for gas supply:

(1) by consultation with the Michigan-Wisconsin Pipeline Dispatcher, also located at One Woodward. This pipeline operates at a substantially constant rate in excess of 500 MMcf per day throughout the year.

(2) by assuming, during the contract months, that the standard 217 MMcf is available from Panhandle Eastern. Either party, however, for operational reasons can temporarily change the rate. A telephone call to or from Panhandle headquarters in Kansas City via Michigan Bell long distance facilities is required in that event.

(3) by ordering the injection or withdrawal of gas from underground storage to balance incoming supply with forecast load. Being part of the Department which operates the storage facilities and associated connecting transmission pipelines with Detroit, the Dispatcher has direct jurisdiction over this segment of system supply.

For pressure conditions in both the Detroit distribution and the transmission mains owned and operated by Michigan Consolidated, the Dispatcher exercises direct supervision by observation of telemetered values from 53 pressure and 16 volume rate points in the system, supplemented by hourly readings telephoned from City Gate and the manned regulating stations. He exercises direct control in Detroit distribution by means of 17 regulators in the field remotely controlled from his office or by requesting station operators to make changes in station regulators.

SECTION II

VULNERABLE LOCATIONS AND DAMAGE APPRAISALS

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INTRODUCTION

The area in Metropolitan Detroit wherein the blast effects of the hypothetical surface strike can cause significant damage to gas supply facilities is divided in this study into two zones:

1. One is the crater area—0.42 miles in diameter and 500 feet maximum depth. All surface and sub-surface gas facilities therein are considered without qualification to be totally destroyed (Reference 1, page 202).

2. The second area, which surrounds the crater, extends out about seven and one-half miles from ground zero to where overpressure is about 2.5 psi and damage, if any, to gas facilities ceases to be significant. In the intervening area towards ground zero, system damage (facilities and buildings) grades from light to severe.*

The determination of severity of damage requires consideration of the magnitudes of the physical products of the detonation: (1) thermal radiation, (2) dynamic pressure, (3) airborne debris, (4) overpressure, and (5) ground shock.

In the case of underground gas facilities, thermal radiation (including secondary fires), dynamic pressure and associated airborne debris have little or no means to effect damage. The remaining two, ground shock (ground motion) and overpressure, can cause major damage to underground gas facilities and structures.

Ground motion, as the transmitter of ground shock, is considered to develop from a nuclear explosion in two ways:

1. from pressure waves directly generated in the earth's crust by the jar of the explosion. The waves travel from the crater outwardly through the earth producing a motion similar to waves

*Light damage requires minor repair only to return the item to its original condition. Severe damage represents damage so extensive that repair is uneconomical.

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on water. The potential to damage underground objects does not extend much beyond the crater's rupture zone (Reference 1, page 202) because of large energy losses therein. Potential damage to underground gas regulator vaults and cast iron pipe is further diminished by wave lengths of this type of ground motion long enough for the gas facilities to "roll" (Reference 1, page 202) with the motion.*

2. from air blast overpressure acting on the ground surface as it moves radially outward from ground zero. The effect is to momentarily depress the level of the surface followed by decompression and return to or near the original level as the blast front moves on. Simultaneously, a horizontal displacement takes place resulting in the two displacements producing a wave-like motion.

Damage to underground gas facilities will be greater from ground motion produced by overpressure than from directly generated motion (Reference 1, page 202).

In addition to producing ground motion with its wracking effect on underground structures, overpressure force is transmitted downwardly through the soil subjecting such structures to externally applied force.

The mechanics of load application on the structure is the same as though it is aboveground except that reflection pressure buildup does not take place and the horizontal force component varies in intensity with soil properties.

UNDERGROUND GAS FACILITIES AND DAMAGE APPRAISAL

Underground gas facilities in Detroit vulnerable to damage are steel and cast iron piping, concrete vaults and gas pressure regulators therein. These facilities are stressed in varying degrees by

*Blasting and bombs set up earth vibrations (waves) similar to seismic disturbances. Harmful vibrations from earthquakes rarely have frequencies exceeding 10 cycles per second. A range of earthquake periods frequently used in seismic design is from 0.1 to 2.5 seconds. Using 1400 (Reference 3,page 202)feet per second wave velocity in the near surface soil in Detroit, corresponding wave lengths vary from 140 to 3100 feet. Half wave lengths exceed vault dimensions and the maximum 16 foot cast iron pipe lengths, enabling these facilities to roll with the motion and escape damage.

ground movement and externally applied forces from overpressure transmitted through the ground cover.

Available data on underground gas facility damage is too general for application in Detroit. A table (Reference 1, page 202) gives a minimum distance of three crater radii from ground zero to points where damage to flexible pipe and small, heavy, buried structures is classified as light (minor). However, the distance concerns directly induced ground shock and is further inappropriate for Detroit because of the major amount of inflexible, cast iron pipe making up the gas system.

Three elements, characteristic of the Michigan Consolidated underground system, any one of which can limit the surface overpressure that the buried system can absorb and remain operational are (1) underground concrete regulator vaults designed for local conditions, (2) unclamped, cement packed, bell and spigot joints, and (3) cast iron pipe.

Computed stresses in vaults from external loading imposed by surface overpressure transmitted through the soil indicate a light damage limit of 16 psi for the vault size most vulnerable, see Appendix A. Coincident ground motion components are 1.2 inches vertical and 0.6 inch horizontal. It is not expected that these movements will increase vault damage to the extent that rebuilding is required, nor consistently damage bell and spigot joints, the condition of the latter being measured by gas leakage rather than physical damage. This conclusion regarding joints is based on the minuteness of the transient angularity (1/2 degree) developed momentarily between the longitudinal axes of the parts making up the joint, see Appendix A. Horizontal motion, it is felt, will be absorbed by pipe slack and ground slippage.

Remaining, however, is damage from circunferential fracturing of the cast iron pipe, particularly at connections and service tees where differential movements are involved since fractures occur from time to time under normal conditions from stress resulting from ground settlement, traffic loading and other local causes, numerous fractures are expected. These breaks will occur not only near ground zero where damage is expected from high overpressures, but also in areas more distant where ground motion alone might not cause damage but when superimposed on pipe already under stress from local causes produces overloading.

In the absence of test data equating overpressure and cast iron pipe damage applicable to Detroit, it is the opinion of this study that cast iron pipe, light damage, limiting overpressure (absence of dangerous leakage) should be set no closer to ground zero on the average than the 16 psi established for Detroit vaults. This value is approximately 50 percent of the 30 psi found undamaging to cast iron pipe in the Nevada test (Reference 5).

A reduction of the Nevada overpressure is reasonable for Detroit in view of Detroit's older pipe imbedded in soil more dense and cohesive than soil surrounding the newly laid pipe in the Nevada test. Isolated instances of significant leakage are expected, however, in Detroit areas of lower overpressure. Extensive precautionary testing by the utility for underground leakage will be required as a cast iron system in the area affected by the blast is progressively returned to service.

The frequency of fractures and degree of damage increases, of course, as ground zero is approached. There is, presently, no information nor could any be derived in Detroit which would permit prediction of a severe damage overpressure limit.

ABOVEGROUND FACILITIES AND DAMAGE APPRAISAL BASES

Most Michigan Consolidated aboveground facilities employed in operation are station buildings and their contents. Exceptions are overhead gas main crossings in the field, radio masts, a gas holder, boiler chimneys and other miscellaneous items.

In station buildings, principal indoor contents employed in operating the physical system are supplies* and tools, meters, vehicles being repaired and distribution operating equipment such as regulators, compressors and accessories. The assortment of supplies and equipment maintained in a particular station depends on the function of the station.

Station buildings, as a rule, are single story, cement floor, 12 inch unreinforced wall, load bearing, brick structures. Roofs are gypsum slab, waterproofed with roofing paper and tar or interlocking tile and supported by steel trusses or I beams whose ends are either bolted to the tops of or are anchored in the walls. Window frames and outside doors are metal.

No significant quantities of combustible materials are used in the construction of operating buildings except in two locations where the operations are relatively unimportant. In addition, no fuel arrays were observed within or adjacent to buildings containing operating gas equipment.

In non-operating buildings, for example offices in service† buildings, wood studs may be used in metal lathe partitions, but furniture is metal. In storehouses, partitions are either metal or masonry and all furniture and counters are metal.

Based on building construction definitions listed in Reference 10, the single story, low profile, industrial type Michigan Consolidated station buildings are equivalent to Item 3, Load Bearing Monumental Type. Severe damage from overpressure is taken to begin in the range of 8.5 to 9.5 psi. Unusual features of each building and exposure to nearby massive missiles are taken into account in the damage appraisal.

Damage to operating supplies in buildings depends on what happens to the building. Damage to operating equipment in buildings such as regulators, as it effects gas delivery, is related

*Pipe, large fittings, vehicles in service and most portable equipment are stored outdoors.
†Partitioned office space in front portions of Garages used by Customer Service and Street Departments.

to the strength of the functional parts of the item, building damage and exposure to missiles generated within or external to the building. Evaluation requires on-site appraisal.

Possibility of fire is evaluated by on-site inspection for fuel arrays, ignition of leaking gas, if any; and, if in the fire spread area, the degree of isolation of the building from sources of firebands.

For trucks and mobile equipment, degrees of damage and associated overpressures are given under Trucks and Mobile Equipment in Section III.

ABOVEGROUND GAS FACILITIES AND DAMAGE APPRAISALS

In the area shown in Figure 6, there are 130 locations where gas mains or operating buildings and equipment are aboveground and exposed to blast effects and fire. Including three City Gate Stations located outside of the area but pertinent to the Study, the facilities by groups are:

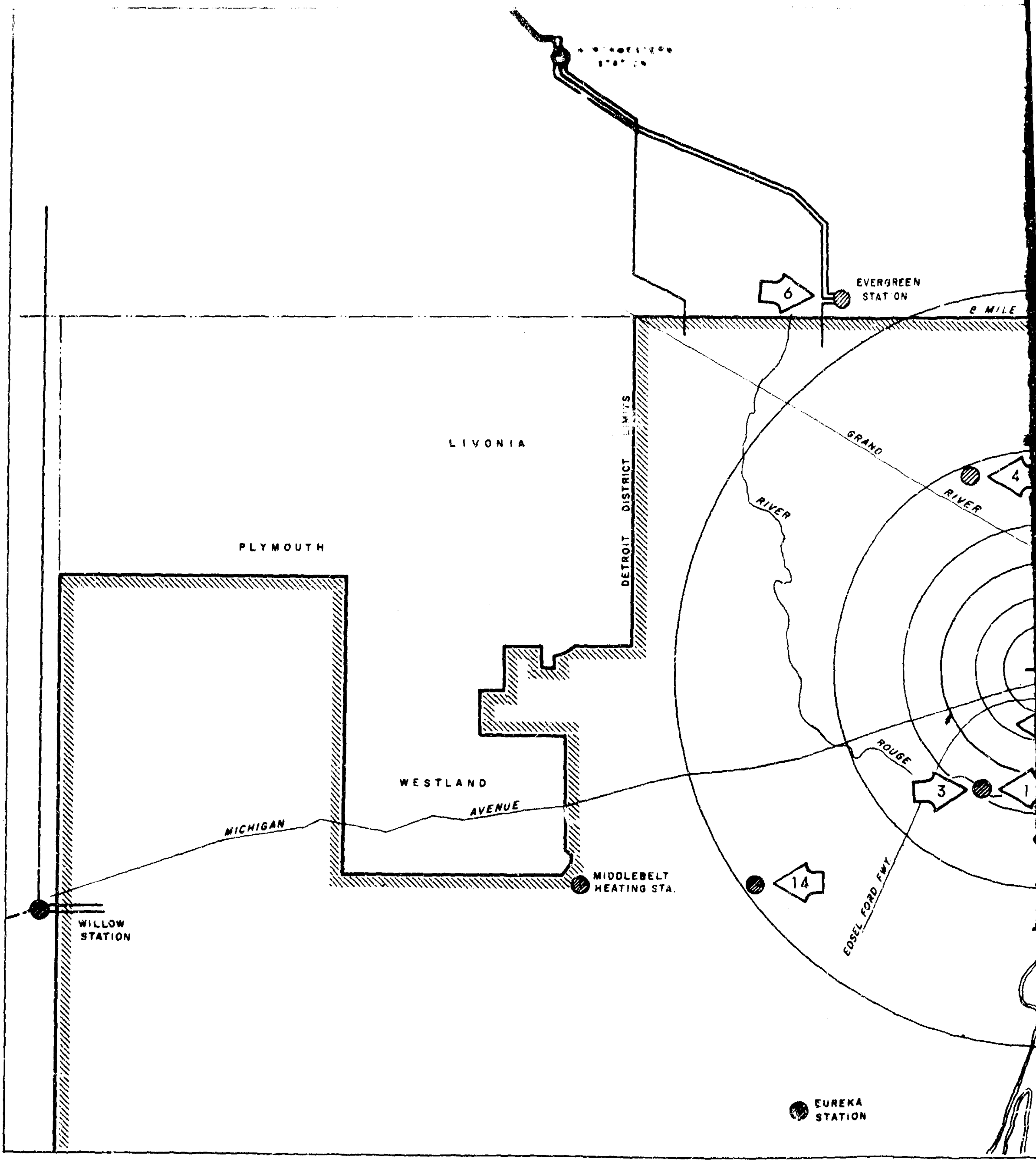
1. *City Gate Stations.* Distances from ground zero and attack environmental data are:

Station	Dist. from G. Z. (Km)	Overpressure (psi)	Wind Speed (mph)
River range	5.6	8.8	295
Northeastern	19.6	1.2	<60
Northwestern	27.6	0.7	<60
Willow Run	43	0.4	<60

NOTE: < = "less than" symbol.

River Rouge Station is exposed to major damage from blast; Northeastern is in the fire spread area (Reference 8). For descriptions of the facilities and expected damage, see Damage Appraisals Nos. 1 and 2. For locations, see Figure 10 wherein corresponding identification numbers are used.

Both Northwestern and Willow Run Stations are outside of the fire spread area. The above environmental data show the improbability of significant blast damage at either station.


EVERGREEN STATION
6
8 MILE
LIVONIA
DETROIT DISTRICT
GRAND
RIVER
RIVER
4
PLYMOUTH
WESTLAND
MICHIGAN
AVENUE
ROUGE
3
1
MIDDLEBELT HEATING STA.
WILLOW STATION
14
EDSEL FORD FWY
EUREKA STATION

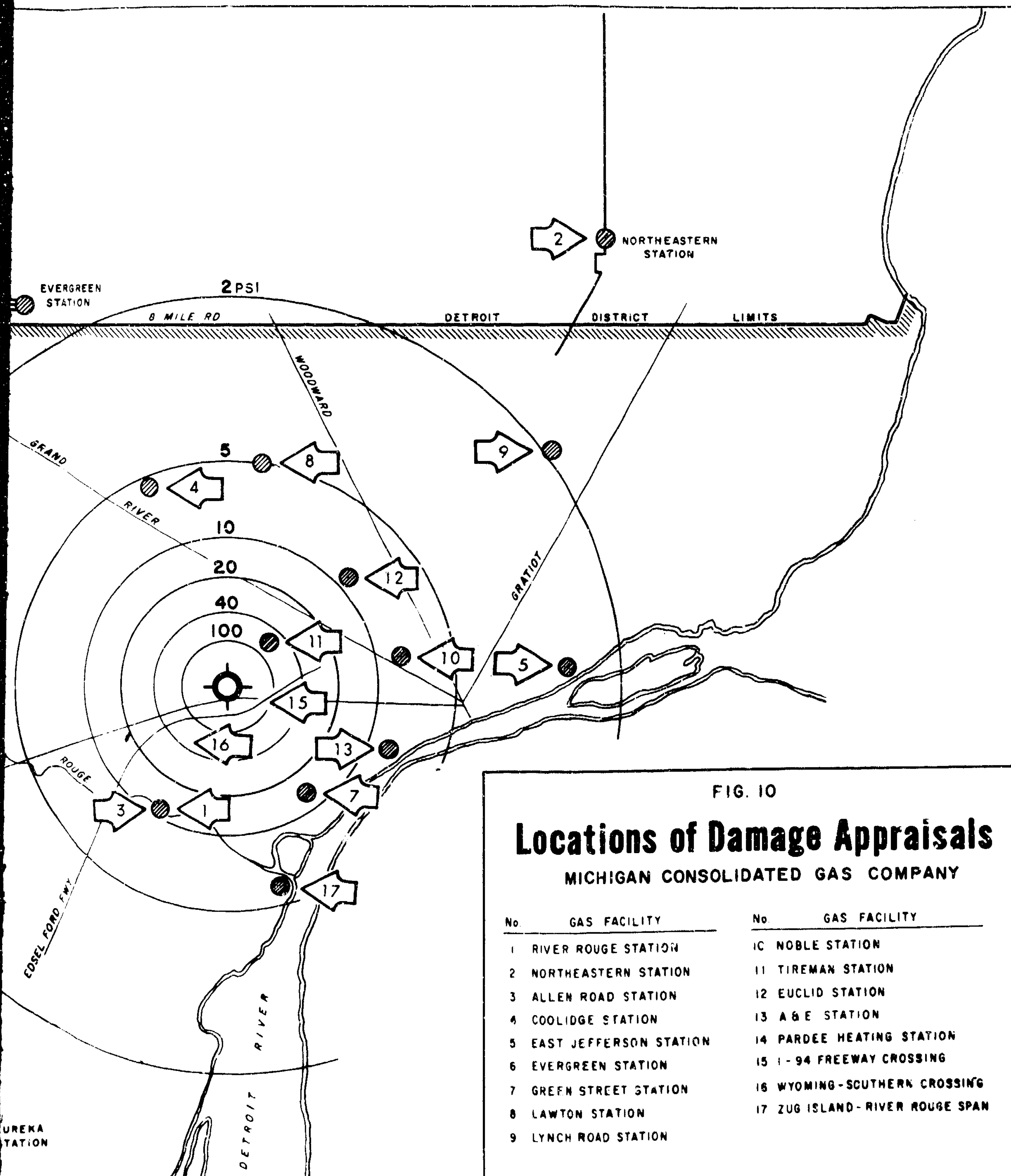


FIG. 10

Locations of Damage Appraisals

MICHIGAN CONSOLIDATED GAS COMPANY

No.	GAS FACILITY	No.	GAS FACILITY
1	RIVER ROUGE STATION	10	NOBLE STATION
2	NORTHEASTERN STATION	11	TIREMAN STATION
3	ALLEN ROAD STATION	12	EUCLID STATION
4	COOLIDGE STATION	13	A & E STATION
5	EAST JEFFERSON STATION	14	PARDEE HEATING STATION
6	EVERGREEN STATION	15	I - 94 FREEWAY CROSSING
7	GREEN STREET STATION	16	WYOMING - SOUTHERN CROSSING
8	LAWTON STATION	17	ZUG ISLAND - RIVER ROUGE SPAN
9	LYNCH ROAD STATION		

2. *Distribution Regulating, Maintenance and Service Stations.* There are eleven stations in this category. All were inspected and damages appraised, see Damage Appraisals Nos. 3–13 inclusive, except for Eureka Station which is outside of the Figure 6 area.

Eureka is a service operating center and a minor storehouse. It performs no distribution regulating operations. Overpressure and wind velocity are 1.7 psi and 60 mph respectively.

3. *Heating Stations.* Two stations are in the category: Pardee and Middlebelt, see Figure 6. Distances from ground zero and environmental data are:

Station	Dist. from G. Z. (Km)	Overpressure (psi)	Wind Speed (mph)
Pardee	12.1	2.4	80
Middlebelt	17.2	1.4	60

Pardee is in the fire spread area, see Damage Appraisal No. 14.

Middlebelt is outside of the fire area.

4. *Gas Mains Crossing Freeways, Rivers and Railroads via City Street Bridges.* There are 116 installations in this grouping. In most instances, the steel gas mains are carried on hangers under the bridges. Figure 23 shows a typical crossing structure.

The gas mains are not exposed in the sense that they are visible in a horizontal line of sight at ground level. Instead, they are concealed by deep web I beam stringers which provide shielding from airborne missiles and thermal radiation. Open field locations of the crossings afford protection from fire except where debris might pile up and become ignited; pipe damage, however, is more likely to result from overstrain as a result of bridge failure and lateral displacement of the deck.

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Lateral displacement of the deck sufficient to over stress the pipe is considered to occur when dynamic pressure in the range of 6–15 psi* is applied under steady flow conditions normal to a vertical side of the structure. The specific lateral pressure required to damage a particular overcrossing depends on its size and design.

The structures, slender in profile and open underneath, are affected mainly by aerodynamics loading. Diffraction loading from overpressure is minor. The time for the blast wave to envelop the structure is so short that overpressure differential between the front and back faces of the structure is neutralized almost instantaneously.

The analytical procedure (Reference 1, page 202) indicates that a peak dynamic pressure in the range of 8–9 psi normal to the side of the structure is required to exert a 6 psi average lasting for the duration of the dynamic positive phase, a length of time probably short of duplicating windstorm conditions.

Two overcrossings and attached piping, which are damaged, are discussed in Damage Appraisals Nos. 15 and 16.

The remaining overcrossing of this group and applicable environmental data are listed in Table XIII. Inspection of the Table indicates that no other crossing is in danger of significant damage.

Whether or not pipeline crossings in Detroit are damaged is not material in the immediate postattack period. If damaged, they are located in the area purposely shut down by the utility because of vast destruction of aboveground structures and the ensuing absence of need for gas service. If needed in the immediate postattack period, replacement would be comparatively easy, even to the extent of constructing a temporary span not dependent on a bridge for support.

*Recommended by Mr. P. Epstein, Assistant Engineer of Design-Structure of Wayne County, Michigan.

Not included in Table XIII are thirty-six (36) crossings located in the area of Figure 6 where overpressures are less than 2.5 psi. The less than 85 mph winds at these locations are incapable of inflicting significant damage.

5. *Pipeline Bridge Over River Rouge.* This is a Michigan Consolidated bridge supporting a 16 inch gas pipeline. It will be damaged, see Damage Appraisal No. 17.

DAMAGE APPRAISAL NO. 1—RIVER ROUGE CITY GATE STATION

I. Attack Data:

Distance from G. Z.	5.6 km	Wind speed	295 mph
Overpressure	8.9 psi	Thermal radiation	120 cal/cm^2
Dynamic pressure	1.9 psi	Residual nuclear radiation	200 R/hr

II. Description of Facility:

This station, occupying 15 acres of land, is situated near the south bank of the River Rouge. About one-half mile of open space intervenes between the station and the Ford Motor River Rouge Plant located along the north bank of the river towards ground zero.

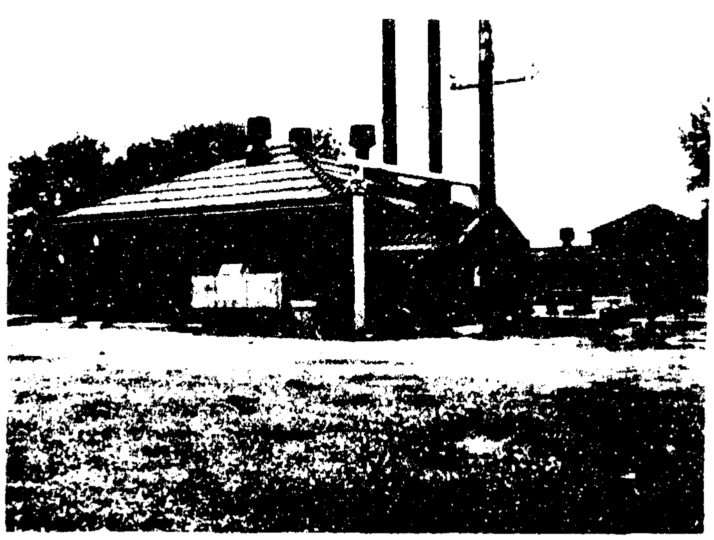


Figure 11. Regulator Building with Master Valve and Office Buildings in background looking away from direction of G. Z.

A 240 foot radio mast, supporting two antennae remotely operated by Dispatchers at One Woodward and guyed at four levels, is located in the yard. There are no transmitting consoles in the station.

Activities handled by or from the station are:

1. Receives transmission gas from (a) Panhandle Eastern Pipeline at 150 psi and (b) from Willow and/or Northwestern Stations at pressures up to 300 psi, regulates these incoming volumes to lower pressures and sends to distribution via eight principal outgoing Transfer mains, see Figure 6.

2. Odorizes incoming Panhandle gas to a prescribed level. Odorant is stored in a 5,000 gallon, horizontal, cylindrical pressure vessel which contained 1,800 gallons at time of the attack.

3. Maintains and operates a 4-compressor, 800 MCFH each, 300 psi maximum pressure, gas engine driven plant. The plant is used to send Panhandle gas to Northwestern Station when in excess of distribution needs. A second, similar plant on the property of equal capacity is out of service.

4. Serves as the operating headquarters for the Distribution Station maintenance section of the Street Department. Operating materials kept on hand are minimal, consisting principally of tools and a few regulator parts.

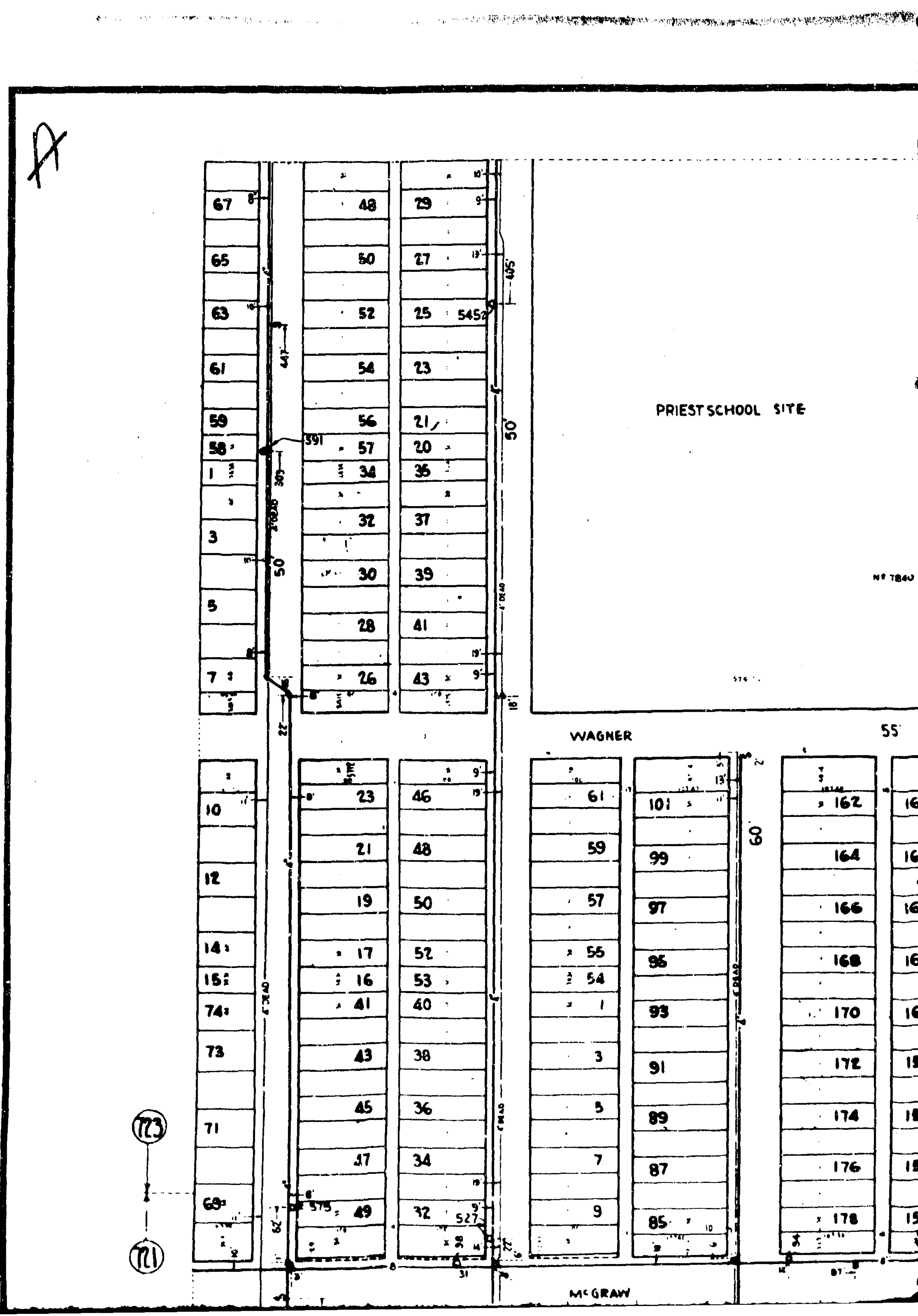
5. Serves as operating headquarters for the District Regulator maintenance section of the Street Department. Supplies on hand consist of a small quantity of parts for older regulators, Mueller Tapping equipment, stoppers and other special tools. A file of regulator installations is maintained at this location with a duplicate at One Woodward.

Station Buildings

There are nine major structures on the property plus nearby unmanned Panhandle Eastern Measurement building.*

Four structures—the two compressor buildings, a former boiler house and a storeroom are steel frame metal sheathed. All others have unreinforced, 12-inch thick, load bearing brick walls and

*The 43 x 50 foot U shaped Panhandle 12 inch wall, brick building is particularly sturdy by reason of 8 inch brick partitions subdividing it into five rooms. Equipment consists of six 12-inch outdoor orifice meter tubes and individual flow controllers located indoors. There are no regulators; regulation is performed at Pelham Station, 6 miles upstream, see Figure 6. Additional items of equipment in the building are a calorimeter, gravitometer and recording gauges.


A
McGRAW
PRIEST SCHOOL SITE
WAGNER
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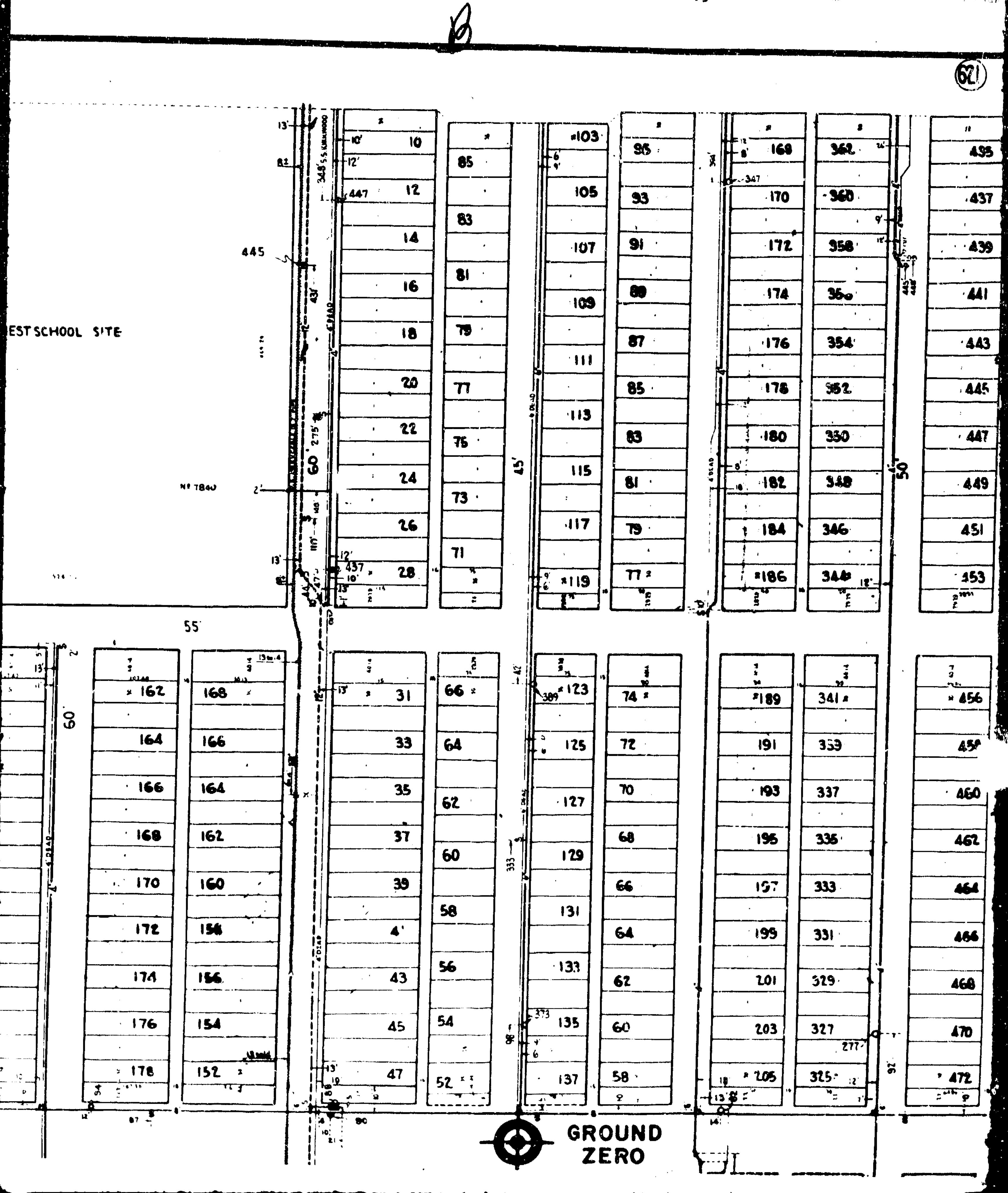
50'
60'
723
721
McGRAW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EST SCHOOL SITE
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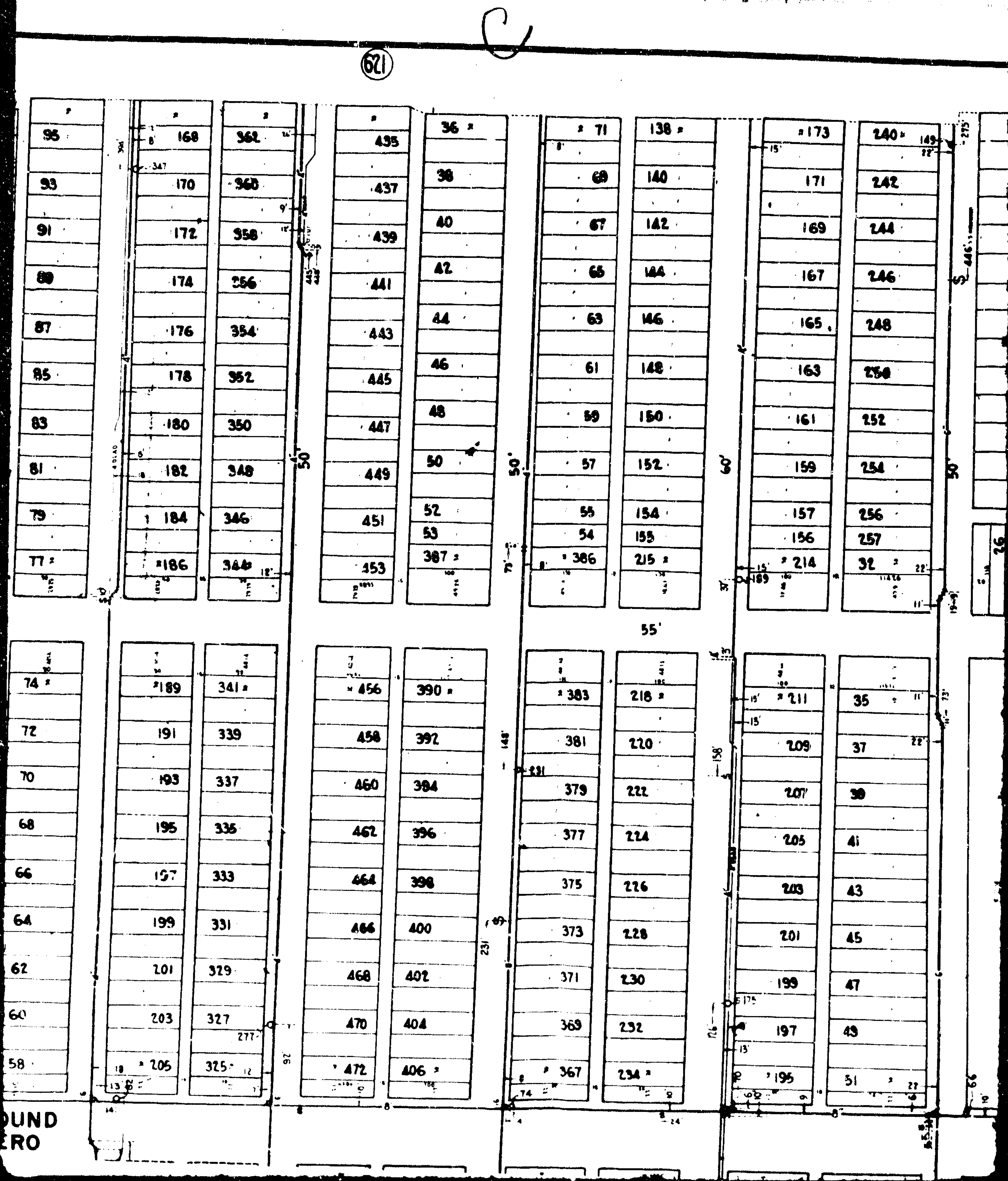
60'
45'
50'
GROUND
ZERO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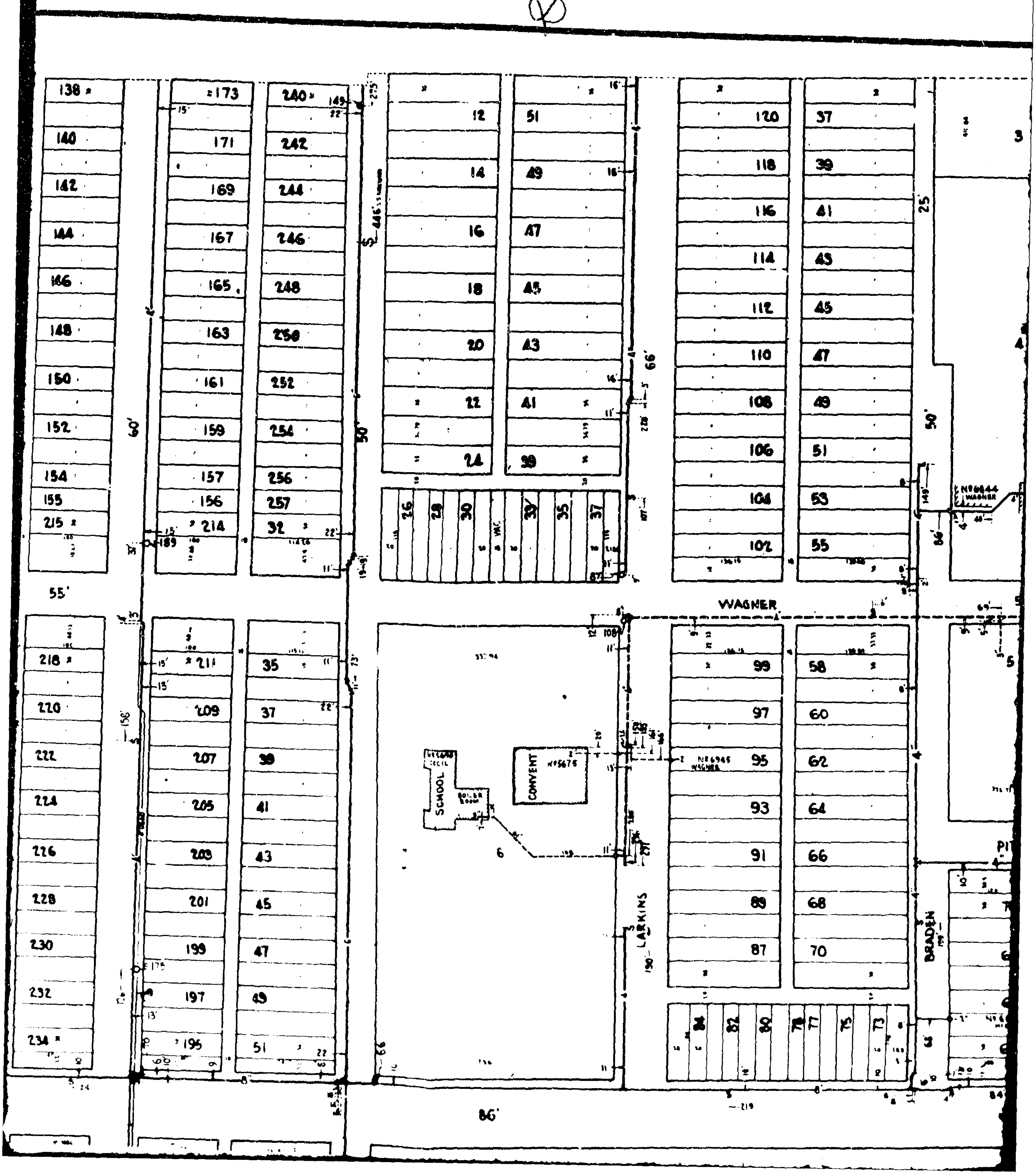
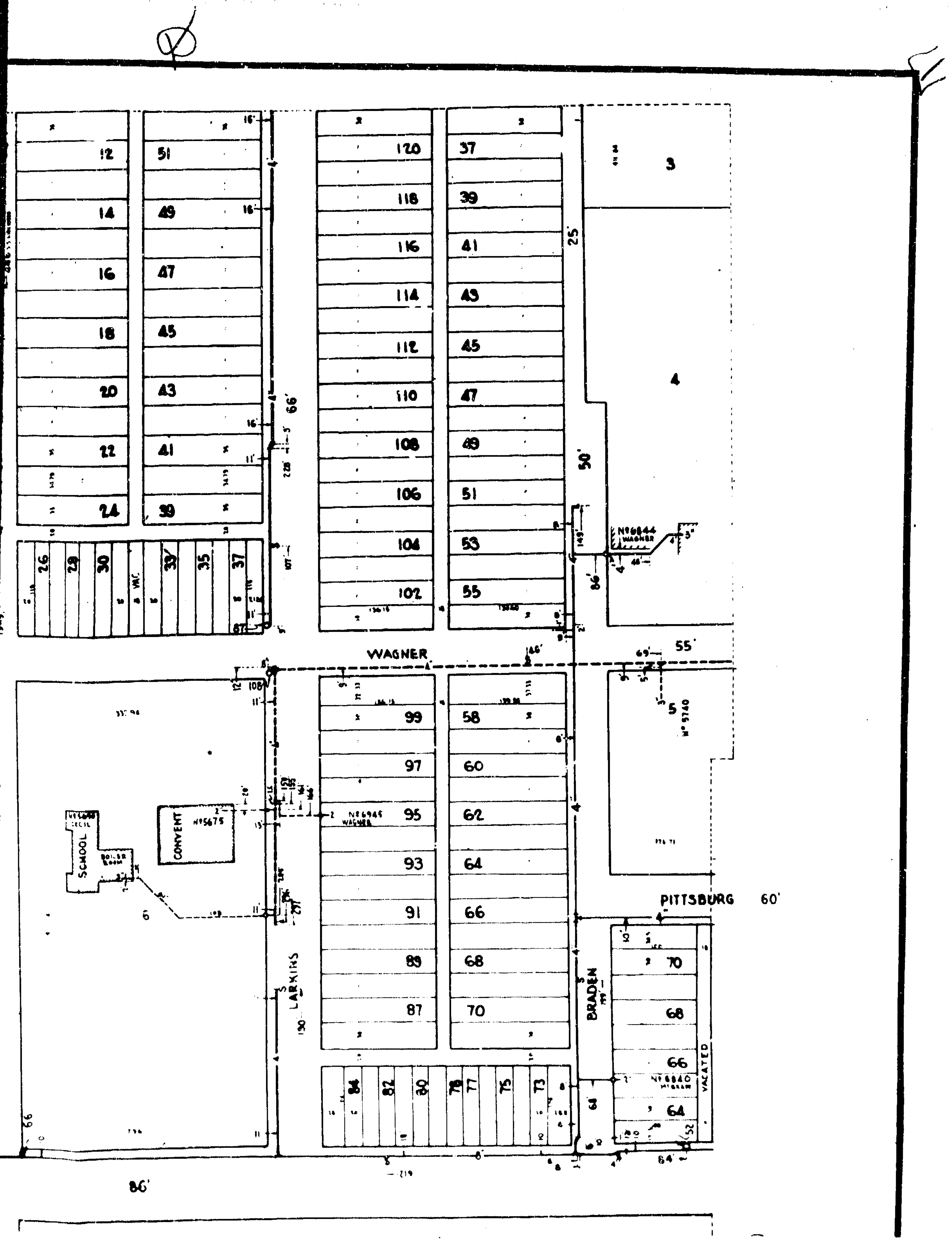


WAGNER
LARKINS
BRADEN
SCHOOL
BOILER ROOM
CONVENT
86'
66'
60'
55'
50'


WAGNER
PITTSBURG 60'
LARKINS
BRADEN
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CONVENT
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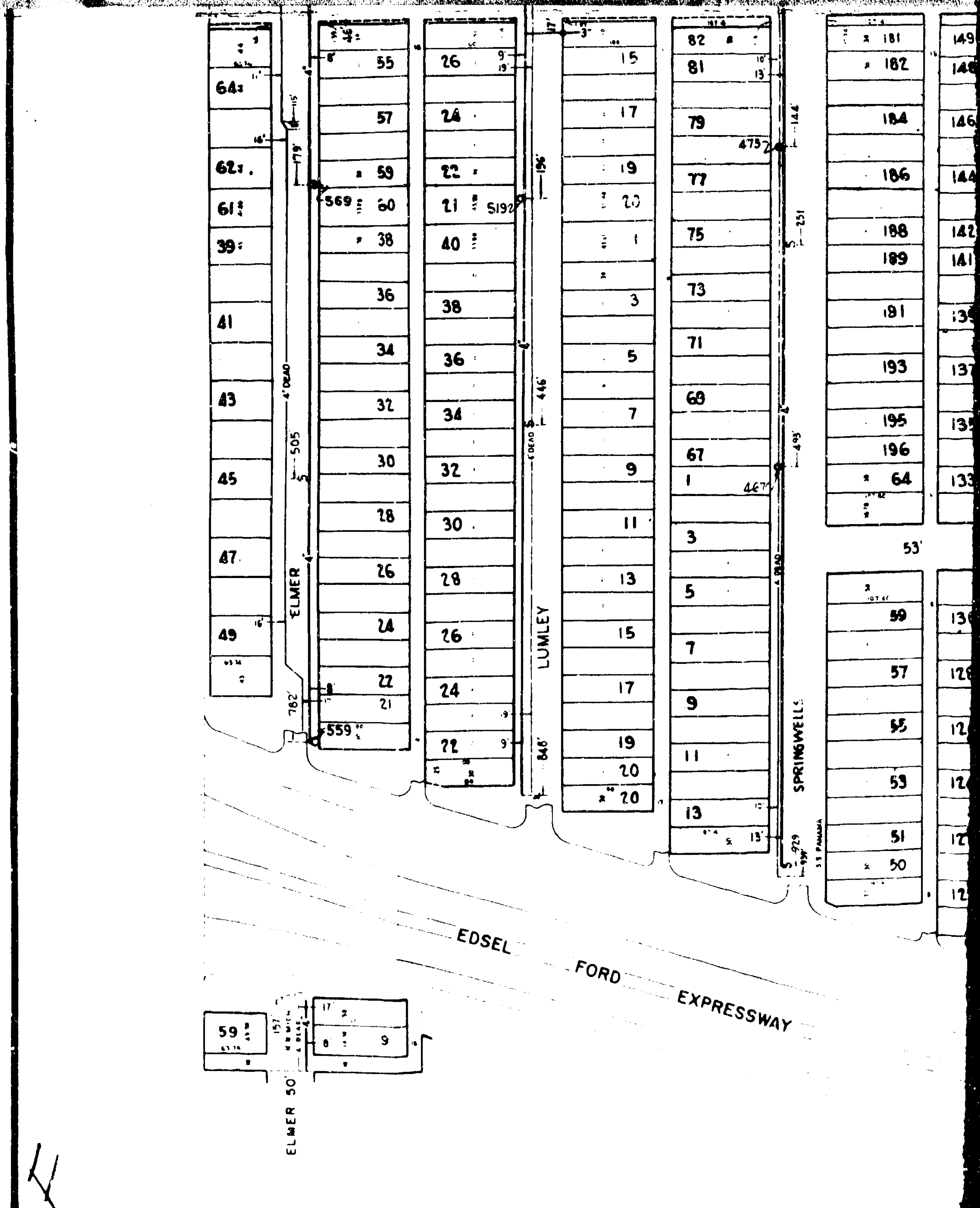
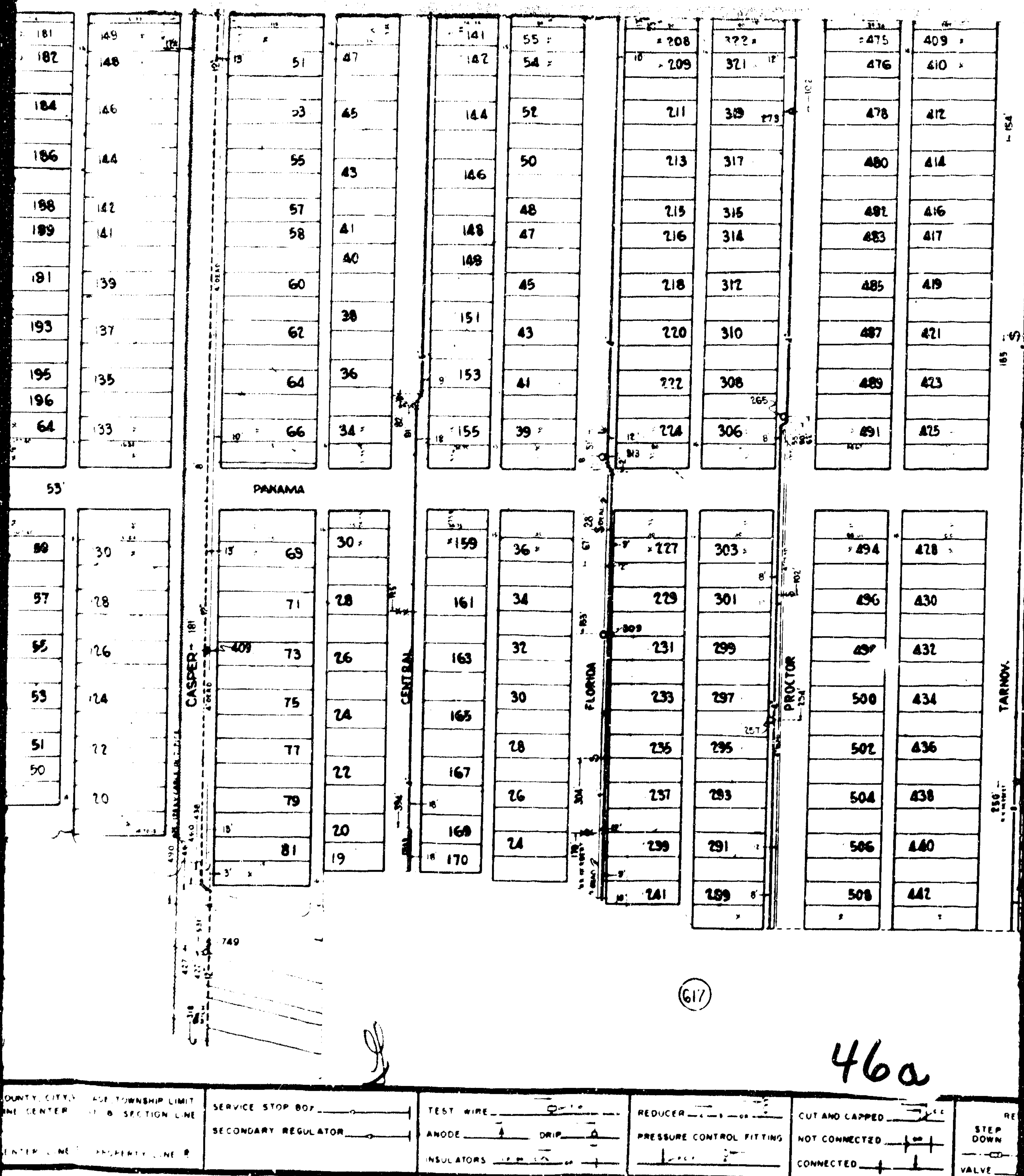


DATE PRINTED	SUMMIT	CABLE, CONDUIT	STREET OPENED	STREET CLOSED	COUNTY, CITY, VILL…
	LOW POINT	FOREIGN PIPELINE			LINE, CENTER LI…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FLORIDA
PROCTOR
TARNOV
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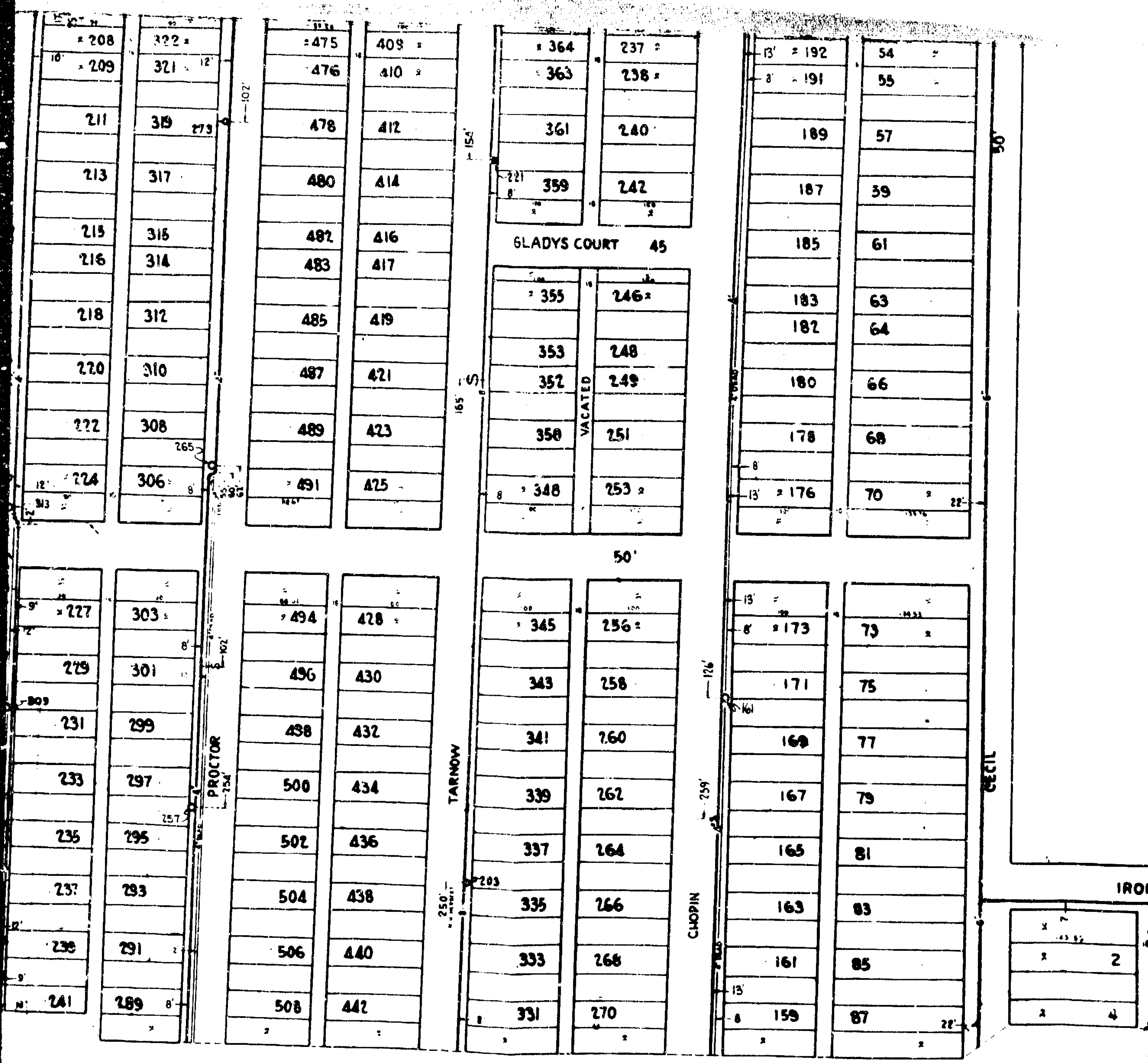
46a
SERVICE STOP BOX
SECONDARY REGULATOR
TEST WIRE
ANODE
DRIP
INSULATORS
REDUCER
PRESSURE CONTROL FITTING
CUT AND CAPPED
NOT CONNECTED
CONNECTED
STEP DOWN
VALVE



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REDUCER PRESSURE CONTROL FITTING	CUT AND CAPPED NOT CONNECTED CONNECTED	REGULATORS STEP DOWN — DISTRICT VALVE	0-10" WC ABOVE 10" WC-2 PSIG ABOVE 2 PSIG-10 PSIG ABOVE 10 PSIG-40 PSIG ABOVE 40 PSIG ABANDONED MAIN	DRAWN BY HAUT 10-17-28 COMLAN 1-21-1927 REPROD. 6-21-65 CHECKED BY BETTS 10-29-28 MILLARD 2-9-1927 APPROVED BY J.L. ROWBOTHAM 6-18-1927

MIC

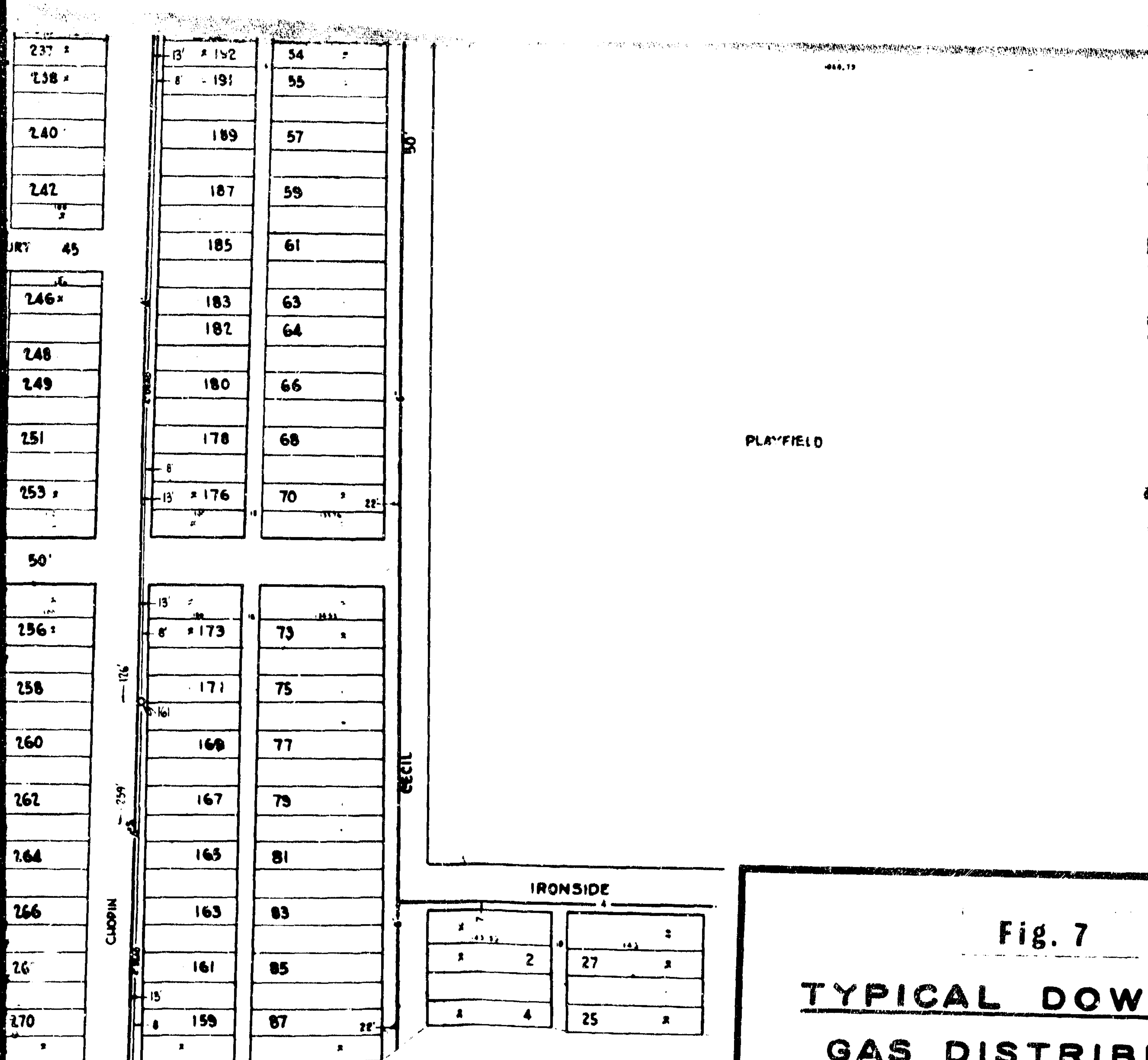


Fig. 7

TYPICAL DOW
GAS DISTRIB
FACILITIE
-DETROI

10" W.C. ABOVE 10" W.C. - 2 PSIG ABOVE 2 PSIG - 10 PSIG ABOVE 10 PSIG - 40 PSIG ABOVE 40 PSIG ABANDONED MAIN	DRAWN BY REPROD. CHECKED BY APPROVED BY	MICHIGAN CONSOLIDATED GAS COMPANY DETROIT DISTRICT SECTION OF DISTRIBUTION MAP	GM 1

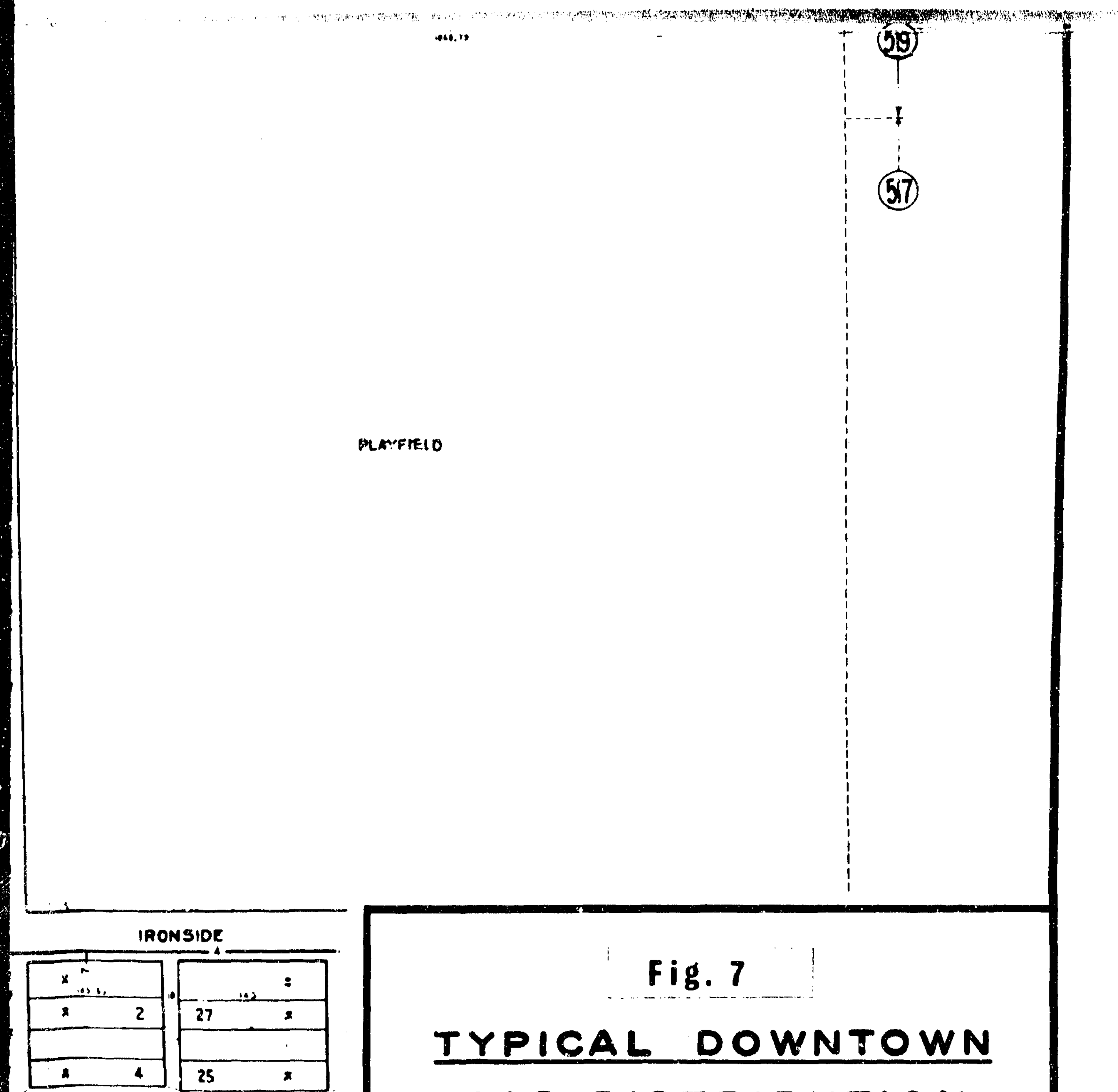


Fig. 7

TYPICAL DOWNTOWN GAS DISTRIBUTION FACILITIES

-DETROIT-

MICHIGAN CONSOLIDATED GAS COMPANY

DETROIT DISTRICT

SECTION OF DISTRIBUTION MAP

GM 1

MAP PLATE NO 619

tiled peak or gable roofs supported by steel trusses. One brick building—the Office—is two story; the balance are single story.

Figure 12. Interior of Regulator Room. River Rouge Station

Figure 13. Interior of Master Valve Building. River Rouge Station

Details of the buildings and equipment are:

1. *Regulator Building.* This is a 45 x 45 foot, 12-inch wall, one-story load bearing brick structure divided into two equally sized rooms by an 8-inch thick, brick fire wall partition.

One room contains pilot loaded Fisher and Emco regulators, valves and bypasses for handling incoming Panhandle and Willow and/or Northwestern supplies and for sending out regulated volumes in eight, 12 to 24 inch, Transfer mains. Each outgoing Transfer main contains an automatic, pressure limiting Hi-Low Operator. Piping runs, valve bodies and regulators, except loading heads, are encased in fibreglass blanket insulation. Centerline of piping is 6 feet below grade in a concrete lined pit. Regulators are 8, 10 and 12 inch sizes.

The second room contains the operating gauge board and two 40 HP steam boilers for station building heat. The boilers also supply a heat exchanger, installed outdoors, to preheat a portion of the 300 psi incoming gas supply in winter to offset temperature drop from pressure reduction.

An outdoor bank of 23 bottles of carbon dioxide actuated by a heat responsive element automatically floods the regulator room in event of fire.

Odorant proportioning pumps and the daily run tank are located in a separate room in the regulator room half of the building.

1. *Master Valve Building.* This is a 45 x 18 foot, one story, load bearing brick building containing outgoing Transfer mains, sectionalizing and bypass valves. Also located in this building are two regulators supplying the 24 inch 100 psi Fort Street main.

III. Personnel on Duty at Attack Warning Time:

Two Distribution Department employees are on duty. They leave the station after completing preattack emergency measures (see Section V—Preattack Emergency Measures) and seek shelter along with the general public.

IV. Extent of Damage:

All brick buildings are severely damaged by overpressure and missiles developed from four shattered brick and metal sheathed buildings located directly upstream towards ground zero. Building walls facing ground zero are in a state of incipient collapse. Roof tiles are badly cracked and partially removed; roof members are bent and shifted in their end supports.

The metal sheathed compressor buildings are destroyed. The steel frame of the compressor building in service and the adjoining aftercooler and attached piping are pulled from foundation bolts and are carried away.

The heavy compressors are not moved, but attached accessories are severely damaged from impact of window frames, sheathing and airborne parts of upwind shattered buildings.

In the regulator room, regulators and Hi-Low Operators* are severely damaged and rendered inoperative. Gas is leaking from small diameter broken tubing lines, sheared off pilot regulators and castings cracked by impact of nitrogen bottles, window frames and other missiles propelled into the room.

In the boiler room, the boilers are severely damaged by collapse of most of the fire wall. The operating gauge board is destroyed.

In the Master Valve building, valve damage is moderate, consisting of broken hand wheels, gears and key wrenches. The two Fort Street regulators, however, are severely damaged when an end of the building is crushed by the falling boiler stacks.

The radio mast is buckled by the 295 mph wind and falls.

The odorant tank, stripped of connections and gauges by missiles, is dislodged from its cradle. Contents drain out into a concrete sump.

The odorant pumps and operating tank are destroyed when the metal door and other missiles are hurled into the room.

Incoming and outgoing mains in the station, including a 40-foot length of 24 inch at ground level along the lee side of the Master Valve building, are undamaged. Those of cast iron are leak clamped and unaffected by the mild ground shock.

*See Regulators in Section 1 for function of Hi-Low Operators. They possess about the same degree of vulnerability as pilot loaded regulators because of small diameter tubing used in their control. Damage to the devices will not be evaluated; their control action in a nuclear damage situation has little significance. Rupture of the tubing inactivates the device and the valve remains open. In an undamaged state, Operator action is limited to preventing downstream pressure from exceeding maximum operating pressure by more than 10%. In such cases the Operator alternately opens and closes the valve to limit pressure. In either event, whether damaged or undamaged, the Operator will permit gas to continue to flow at its preattack rate.

There is no fire in the station. Pilot flames in the boilers are blown out by the blast entering the burner compartment through the breechings. There are no nearby sources of firebrands; closest wood buildings are more than 1,500 feet away.

V. **Results of Damage:**

The station, as an operating unit, is destroyed. Major repair and replacement will be required to return it to its preattack status.

The outgoing aggregate gas rate, immediately following the attack, depends on the nature of the damage sustained by each regulator. Some kinds of damage produce a full open regulator rate; others cause closure. The interplay of damage causing objects in the regulator room is not predictable and an appraisal involving the assignment of specific kinds of damages to individual regulators is not considered possible. It is certain, however, that some of the regulators will open wide; others will close. The net effect, it is felt, is that gas flow through the station will continue for a short time at about its preattack rate, then increase to try to satisfy mounting downstream system losses.

Loss of the headquarter buildings for regulator and station maintenance personnel is not critical, Mueller tapping equipment, special tools and regulator parts were removed when vehicles were dispersed prior to the attack. Other miscellaneous supplies, such as extra bags and stoppers, left behind in the cement basement are undamaged and available for postattack use.

An emergency type of gas service limited to 50 psi* could be reestablished in a matter of a few days in Transfer mains† outgoing from River Rouge without waiting for regulator repairs if needed in the immediate postattack period:

1. Valve off or otherwise strip the downstream mains to be repressured of damaged connected services and secondary branches not requiring repressuring.

*The maximum operating pressure for leak clamped cast iron mains.
†These mains are cast iron, leak clamped and undamaged by overpressure or ground shock.

2. Bring into River Rouge Station a 50 psi supply regulated at undamaged Willow Station.

3. Route the emergency supply to the selected outgoing Transfer mains by using bypasses around the damaged regulators.

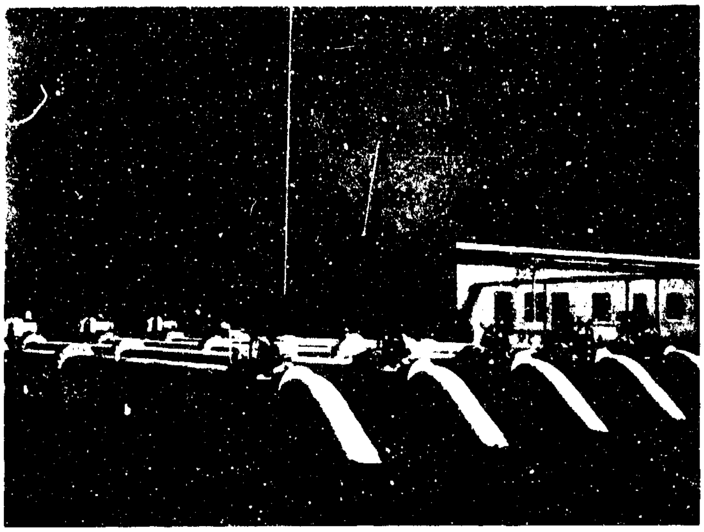


Figure 14. Station building and Meter Runs. Looking away from direction of ground zero.

DAMAGE APPRAISAL NO. 2–

NORTHEASTERN STATION

I. **Attack Data:**

Distance from G. Z. . . . . . . 19.6 km

Overpressure . . . . 1.1 psi

Dynamic pressure. < 0.1 psi

Wind speed . . . . . < 60 mph

Thermal radiation. 6 cal/cm^2

Residual nuclear radiation . . . 400 R/hr

II. **Description of Facility:**

Northeastern, an unmanned City Gate station, is the Detroit area terminus of the Belle River transmission system.

When gas is being taken from Belle River underground storage for Detroit distribution, Northeastern regulates incoming pressure to 300 psi and meters the hourly volumes delivered to the distribution system.

When gas is destined for storage at Belle River, Northeastern meters the hourly volumes delivered to the transmission system from Lynch Station compressors.

Regulators are remotely controlled from the Dispatcher's Office at One Woodward over a Michigan Bell wire line telephone circuit. Pressure and volumes at Northeastern are telemetered to the Dispatcher over the same facilities.

Two 8 inch regulators are aboveground in a room in the 30 x 60 foot, flat steel deck roof, load bearing brick building. Three 12 inch regulators are outdoors and buried, but gearing and control piping are aboveground.

The station is isolated with respect to neighborhood structures. The station building is near the rear of a 375 x 450 foot lawn covered lot. The front of the lot faces in the general direction of ground zero and adjoins the Detroit Edison outdoor switching yard. Its equipment is approximately 550 feet distant from the station building. There is, however, a large conical shaped, sheet metal enclosed incinerator of the sawmill type used for daytime burning of dry materials about 400 feet from the station building in the direction of ground zero.

III. Extend of Damage:

The station building is undamaged except for broken windows. The telemeter equipment in a windowless room is not damaged. The recording gauges, with their backs toward windows, suffer only cracked and broken glasses in the gauge doors.

The station is not endangered by fire. The nearest building is more than 600 feet distant, and the incinerator would be empty of burning material after midnight.

IV. Results of Damage:

Normal use of the station in August is to meter gas being sent to Belle River underground storage. It could continue in that capacity in the immediate postattack period as soon as regulators at Coolidge are repaired.

Normal use in winter is to deliver regulated gas from underground storage to Detroit distribution. It would be available for that use as soon as its regulators are manually readjusted.

DAMAGE APPRAISAL NO. 3—ALLEN ROAD STATION

I. **Attack Data:**

Distance from G. Z. . . . . 5.6 km

Overpressure . . . . 8.7 psi

Dynamic pressure . . . . 1.9 psi

Wind speed . . . . 290 mph

Thermal radiation . . . . 120 cal/cm^2

Residual nuclear radiation . . . 200 R/hr

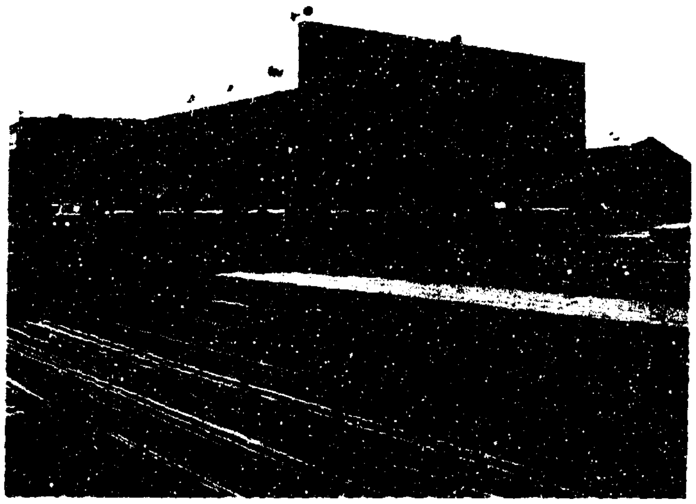
II. **Description of Facility:**

Allen Road is primarily a service and maintenance station, being the operating headquarters for a 145-man force performing customer service and Street Department distribution maintenance operations in the surrounding Allen Road service area.

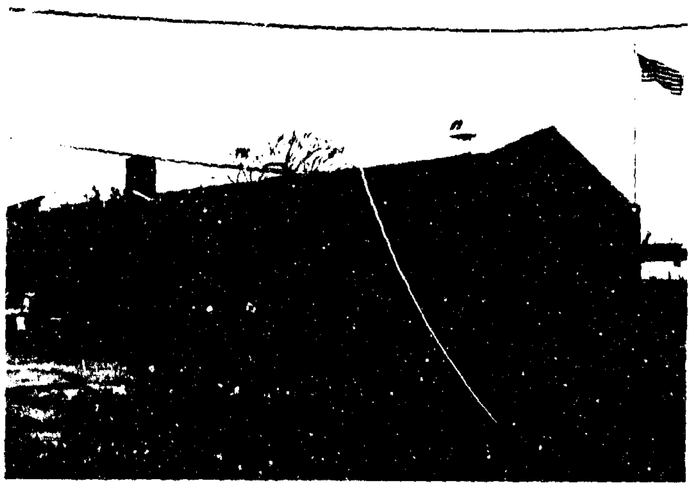
It is also one of the principal storehouses in Detroit District, being the central supply for large diameter steel pipe and fittings. In addition, its stocks of service and main supplies are substantial, amounting to 12 percent of the District total.

Allen Road is not a distribution system operating station. Distribution regulation in the Allen Road area is handled by River Rouge Station located approximately 1,000 feet directly upwind towards ground zero.

There are five buildings on the 18 acres of Station property: two main buildings—the storehouse and the combination Office and Garage--and three steel frame, transite covered buildings formerly employed in pipe wrapping operations, but now used for miscellaneous storage and new vehicle outfitting. These latter buildings are located upwind from the main buildings in the direct direction of gorund zero.



Allen Road Storehouse with Office-Garage at right. Blast strikes building front 9 degrees from head-on.



Office-Garage Building. Offices are in front section.

Figure 16. Storehouse and Garage at Allen Road Station

Details of the main building are:

1. *Storehouse.* This is a single story, concrete floor slab, 57 x 257 foot building with 12 inch unreinforced, load-bearing brick walls containing the Street Department local operating office in the front. An extension to the original building is identified by high level windows and a flat roof. Low level windows and saw tooth roof design are characteristics of the older portion of the building.

The roof of the newer part, constructed of interlocking, reinforced gypsum slabs and surfaced with roofing paper and tar, is supported by steel trusses whose ends are bolted to the top of the walls.

The roof of the older part, also of noncombustible slabs, is similarly surfaced and supported, except that the truss ends are anchored in the brick walls.

2. *Office and Garage Building.* This 50 x 110 foot, concrete floor, load-bearing, single story brick building contains the Customer Service and Street Department local operating offices in the front. A brick, partition wall separates the garage from the offices. Office partitions are wood studs, metal lathe and plaster. Interior doors are wood and glass; outdoor are metal.

The gypsum slab, pitch roof is supported by steel trusses whose ends are imbedded in the walls.

The gasoline tank is under pavement; pump is partially protected by a location in a niche in the loading platform on the lee side of the Storehouse with respect to the direction of the blast.

Windows in the front parts of both buildings are draped, but fuel arrays are absent. Office furniture is metal.

III. Personnel on Duty at H Hour:

Two garage mechanics are on duty. Three trucks are in the shop. Both employees leave the station and seek shelter along with the general public.

IV. **Extent of Damage:**

The blast strikes the building fronts at 9 degrees from head-on. Both buildings are severely damaged.

The front of the storehouse is smashed by the blast and heavy missiles from upstream stored pipe and demolished building parts. The high facade is pushed over, crushing a portion of the saw tooth roof. The rear wall is knocked down exposing stock contents. Side walls of the newer part are badly cracked and roof frames are bent and shifted.

There are no primary or secondary fires; drapes were removed prior to the attack. The station is isolated from sources of firebrands. The amount of cardboard and other combustible items remaining in the debris is insufficient to propagate fire.

The gasoline pump is torn out and carried away, but tank contents remain intact.

Stored pipe, stacked in tiers and generally parallel to the blast front, is rolled and scattered in the downwind open fields.

In the combination Office and Garage building, offices are completely demolished; partitions are down, furniture and counters are destroyed. Side walls are badly cracked and the roof is partially collapsed.

In the Garage, the roll-up doors are blown in, severely damaging three vehicles. The brick partition wall is partially down.

V. **Results of Damage:**

The station is destroyed and can no longer operate even on an emergency basis.

The storehouse supplies are both buried in the rubble and scattered over a large, downwind, open field. Recovery, exclusive of pipe, will be confined mostly to the larger heavy items.

Wrapped pipe, although recoverable will not be fully usable on account of dents, out of round conditions and damaged wrapping.

DAMAGE APPRAISAL NO. 4—COOLIDGE STATION

I Attack Data:

Distance from G. Z. . . . . 6.7 km	Wind speed . . . . 200 mph
Overpressure . . . . 6.2 psi	Thermal radiation . . . . 85 cal/cm^2
Dynamic pressure . . . . 1.0 psi	Residual nuclear radiation . 32 R/hr

II. Description of Facility:

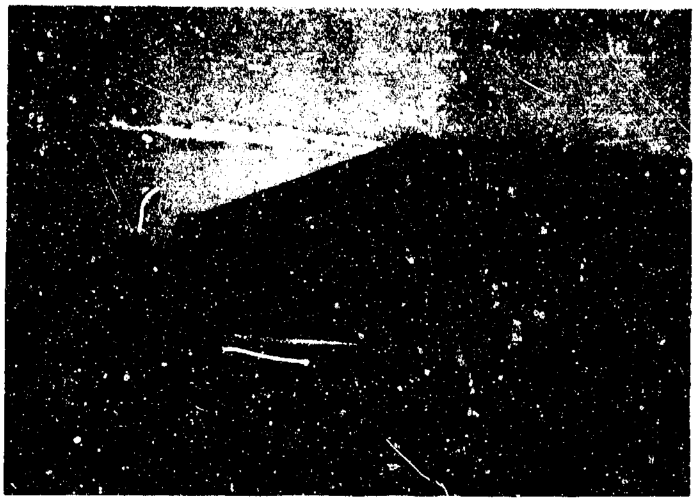
Located on 14 acres of property, this station contains four buildings, a 10 MMcf piston type, low pressure holder and a 210 foot reinforced concrete chimney. One building—the combination compressor and boiler house—an empty holder and a boiler chimney are out-of-service.

Coolidge is an important distribution regulating station, in addition to being the operating headquarters and supply point for a 165-man service and maintenance force.

Its distribution regulating equipment, unmanned and remotely controlled from One Woodward, supply four outgoing 22-24 inch Transfer mains which service a substantial part of Detroit. Coolidge is also the input point of gas destined for storage at Belle River via the 30 inch Crosstown main interconnecting at Lynch Station.

Coolidge also is a principal storehouse, ranking next to Tireman in the amount of heavy distribution materials with about 16 percent of the District's total.

1. *Storehouse and Office-Garage Buildings.* These two, single story, concrete floor, load bearing brick buildings are similar to those at Allen Road.



Storehouse. Looking away from direction of ground zero.

Interior view in Storehouse. Looking 45 degrees to the left of ground zero.

Figure 16. Storehouse at Coolidge Station.

Considerable quantities of combustible materials are intermixed with stock piled on shelves, consisting of cardboard cartons, wood pallets, rubber gaskets, cotton uniforms and plastic tubing. There are many instances of exposure to the thermal pulse.

2. *Regulator Building.* This 36 x 40 foot load-bearing brick building has a flat gypsum slab roof supported by 6 and 14 inch I beams.

The building is divided into two rooms—regulating and instrument control—by an 8 inch brick partition. The regulating room, 36 x 28 feet, contains the regulators, valves and Hi-Low Operators at ground level. Underground yard piping enters and leaves a full length concrete-lined pit below grade under steel grating.

The instrument control room contains a recording gauge board, telemeter instruments and control cabinet.

Emergency power is provided by an automatic start, gas engine driven 5 KW generator.

The 1/2 inch regulator control piping is brought into the regulator room at ceiling height, then drops vertically to the regulators with the final foot or so being 3/8 inch steel tubing. Overpressure operator tubing is also steel.

Heat needed in winter for gas pressure reduction is supplied by 6 foot diameter by 55 feet BS&B integral hot water boiler and submerged heat exchanger. Gas fuel is valved off in summer.

In the instrument room are a storage water heater and two balanced flue, enclosed firebox space heaters.

III. Regulator Station Operation:

Normally, gas is delivered to Coolidge from Northwestern by the 26-30 inch Schoolcraft main at pressures up to 300 psi. In the station, eight 8-12 inch Fisher and Emco regulators reduce

Regulator Building and Portion of Holder.
Looking normal to direction of blast.

Interior of Regulator Room. Looking towards ground zero.

Figure 17. Regulator Building and Interior--Coolidge Station.

incoming supply to 200 psi for the Crosstown main and 50 psi for four outg[illegible] 24 inch cast iron Transfer mains interconnected at a header (summer operation only).

Following the warning of attack, incoming pressure from Northwestern is lowered to 150 psi and outgoing pressure in the Crosstown main is cut to 100 psi by the Dispatcher at One Wo[illegible]

IV. Personnel on Duty at Attack Warning Time:

Personnel on duty at attack warning time are two garage mechanics. Both leave the station and seek shelter along with the general public.

V. Extent of Damage:

Storehouse and Supplies. The building sustains moderate to severe damage. The exterior wall of the high ceiling part facing the blast is bowed and badly cracked.

A primary fire, started by the thermal pulse, spreads and consumes the combustible stored materials. Cast iron system repair materials, including the stock set aside for emergencies, are rendered unusable by loss of rubber gaskets. Some of this damaged material could have been saved by storage on the dispersed vehicles.*

Garage and Office Building. The building sustains moderate damage.

The gasoline dispensing hose and piping (not a free standing cabinet type) are torn off by missiles. The underground storage tank and the pump and motor protected by the loading platform are undamaged.

Regulator Building. The building is moderately, but not extensively damaged, due largely to its squatness and absence of a nearby source of missiles.

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*Suggest that the thought be added that during time when emergency situation prior to nuclear blast became intense, extra emergency fittings were withdrawn from stock and were stored on vehicles which were dispersed as previously noted. This is normally done now during emergency situations such as times of deep frost penetration.

In the regulator room, equipment damage consists of small diameter tubing control lines, gauges and fittings leaking or broken by window fragments. Unhinged doors are not in locations to directly damage the regulators.

In the instrument control room, the gauge board, telemeter steel cabinet, electric generator set, water and space heaters are wrecked by a portion of the BS&B heater stack driven through an up-wind window.

Chimney and Holder. The chimney neither falls or is the foundation permanently tilted, see Appendix A.

The holder top and sides are crumpled. Columns and side plates are bent over, but the structure remains bolted to the foundation. The tar storage tank connections are ruptured releasing about 40,000 gallons of tar on the ground.

VI. Results of Damage:

Gas flow through the station immediately following the attack is expected to remain temporarily at about its preattack rate and then increase in attempting to satisfy downstream losses. The multiplicity of regulators assures increased flow through the station; two regulators feed the Cross-town main and five regulators in parallel deliver gas to a manifold supplying the four outgoing Transfer mains.

The Storehouse building is damaged beyond repair. All supplies, therein, with the exception of small steel and brass fittings in the far end of the building, not involved in the fire, are lost. This includes the emergency repair stock.

The station regulators are repairable with supplies on hand, but will have limited capacity until telemeter equipment is replaced or the regulators are converted back to direct pilot operation.

It is unlikely that the station would be needed in the immediate postattack period. An arrangement whereby the Transfer mains downstream from Coolidge would be supplied at [illegible] psi* directly from Northwestern and back fed from Lynch and Willow, whose regulators are undamaged, would suffice to supply the remaining load in the heavily damaged area of Detroit for an indefinite postattack period of time.

DAMAGE APPRAISAL NO. 5—EAST JEFFERSON STATION

I. **Attack Data:**

Distance from G. Z. . . . . 11.1 km

Overpressure . . . . 2.7 psi

Dynamic pressure. . . . . 0.22 psi

Wind speed . . . . [illegible]0 mph

Thermal radiation . . . . 26 cal/cm²

Residual nuclear radiation . 55 R/hr

II. **Description of Facility:**

Although this station contains distribution regulating equipment, two record† storage buildings and a storehouse, it is primarily an operating headquarters for a 115-man force performing Customer Service and Street Department maintenance activities in the East Jefferson service area.

The storehouse has a satellite status in that needed supplies are requisitioned at frequent intervals from other storehouses. Its stock, amounting to less than 0.1 percent of District total, consists mainly of appliance service parts.

Details of the building are:

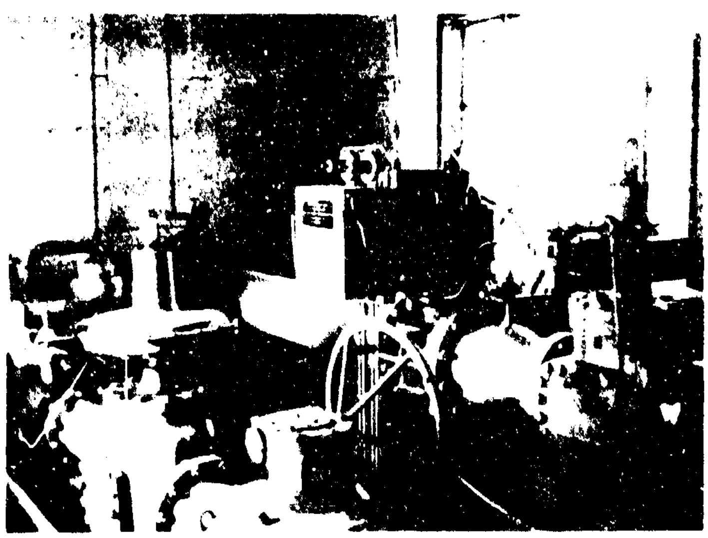
1. *Storehouse, garage and Office.* This is a 125 x 170 foot, concrete floor, brick building containing the storeroom, garage and operating offices. Sections are separated by concrete block partitions.

*Maximum operating pressure for clamped cast iron mains.

†Principally operating records of the kind that regulatory agencies require be retained for a stipulated number of years before being destroyed. Important documents and other records are microfilmed and stored in a fireproof vault at One Woodward.

The portion of the steel deck roofing over the storeroom is supported by light steel trusses and I beam columns. The roof decking over the balance of the floor space is supported by the walls and partitions.

Portion of front of Station Building. Regulator Building is in left rear, Uniroyal tire plant in background. Looking in direction away from ground zero.



Interior of Regulator Building showing Regulators and Hi-Low Operators. Looking towards ground zero.

Figure 18. Service and Regulator Buildings at East Jefferson Station.

There are no fuel arrays. Front window drapes are exposed to the thermal pulse, but surroundings are not readily ignitable. Cartons and tires in stock are not exposed.

The gasoline pump is free standing in the yard on the lee side of the building.

A gas-fired steam boiler, installed in a furnace room furnishes building heat.

2. *Regulator Building.* This is a 20 x 35 foot, load bearing brick building containing two pilot-loaded regulators (8 and 10 inch) and two Hi-Low Operators, all installed above grade. Piping loops and valves are below grade under steel grating in a full concrete-lined pit.

The regulators (unattended) supply the Beaufait and East Jefferson 10 psi mains taking supply from the 50 psi Larned main. The pilot regulators and tubing lines are above grade and exposed.

3. *Record Storage (main building).* This is 36 x 132 foot two-story reinforced concrete building with brick facing. Roof is a flat concrete slab. Records are stored in steel filing cabinets. There are no fuel arrays in the building.

4. *Record Storage (annex).* This is a 32 x 190 foot, wall-bearing brick building. Floors, stairs, partitions and roof are wood. Sales Department window displays also stored in the building contain numerous fuel arrays.

There are two adjacent, non-Company buildings endangering the station in event of an attack:

1. a two-story brick, light industrial building supporting a large advertising sign on its roof, upwind and offset from the garage section by 60 feet.

2. the seven-story Uniroyal tire plant located 275 feet downwind from the Storehouse, but only 60 feet from the main records building. The tire plant contains large quantities of rubber, carbon black and other combustible tire materials.

III. Personnel on Duty at Attack Warning Time:

Two mechanics are on duty in the garage at time of the attack warning. Both leave to seek shelter along with the general public.

IV. Extent of Damage:

Blast damages to the buildings are light consisting of broken windows, blown in doors and some cracks in wall and partitions.

The advertising sign on the adjacent building is blown down and falls on the garage roof, causing extensive damage.

In the regulator building, one pilot regulator and both pressure loading tubing lines are snapped off at fittings by window fragments and the metal door.

The gasoline pump is moderately damaged by missiles but usable as soon as power is available.

A primary fire develops in the Annex building.

V. Results of Damage:

The Storehouse supplies (small in amount) remain available for postattack use.

Both regulators shut off from loss of loading pressure. Neither are needed in the immediate postattack period, but can be returned to service by replacement of the tubing and pilot regulator, items normally carried in regulator maintenance trucks.

The Annex building and its records are destroyed by fire The records in the main records building will not survive if the Uniroyal plant burns. The records, however, are not vital.

DAMAGE APPRAISAL NO. 6–EVERGREEN STATION

I. Attack Data:

Distance from G. Z. . . . . 14.8 km	Wind speed . . . . < 60 mph
Overpressure . . . . 1.7 psi	Thermal radiation . . . . 13 cal/cm^2
Dynamic pressure. . . . . 0.1 psi	Residual nuclear radiation . < 5 R/hr

II. Description of Facility:

This is an unmanned, regulating station receiving gas from Northwestern at pressures up to 300 psi. Three regulators, remotely controlled by the Dispatcher at One Woodward (and associated Hi-Low Operators), supply the 26 inch and 16 inch Seven Mile and Beech-Daily road mains. These mains, in effect, loop the cast iron system on the north and west sides and provide one means for the Dispatcher to balance the system.

The 24 inch Southfield main, originating at Northwestern Station and terminating at River Rouge, bypasses station regulation at Evergreen Station and operates at incoming pressures up to 300 psi from Northwestern. Except for a sectionalizing valve in a steel platecovered pit in the station yard, the main is underground and unexposed. It does not enter the building.

The single structure on the 150 x 300 foot lawn-covered lot is a single story 50 x 115 foot load-bearing brick building. The 28 foot west end section of the building has an interlocking, concrete slab tile peak roof supported by light steel framing. The roof over the balance of the building, which contains a basement, is at a lower elevation and is a flat concrete slab supported by horizontal I beams.

The regulators and Hi-Low Operators are located in the concrete basement 4 feet below grade. Also located in the basement is a heat exchanger supplied by 3-1.3 million Btu, 25 psi steam boilers. The boilers are installed aboveground in the west section of the building.

Figure 19. Regulator Building, Evergreen Station. Looking away from ground zero and 45 degrees to the left.

Telephone wires for the telemeter circuit enter the building aboveground from an exchange in Pontiac.

There are no fuel arrays either within or adjacent to the building. Furniture, partitions and doors are steel.

Emergency power is supplied by an automatic start, gas engine driven 5 KW electric generator.

III. Extent of Damage:

Other than broken glass, unhinged doors and dislodged partitions, there is no significant damage in the station.

The back side of the gauge board faces ground zero and outside windows, thus protecting the vulnerable front sides of instruments from flying glass. Gauges sustain broken glasses in the doors and bent pens, but otherwise are operable. The telemeter steel control cabinet is undamaged.

The boilers (main burners are valved off in summer) are undamaged except for dislodged vents and a few broken tubi g control lines and water glasses. The operating storage water heater is undamaged.

Control lines (pipe and steel tubing) from the gauge board to the regulators are undamaged.

Although the station is in the fire spread area, fire does not develop in the station; there is neither escaping gas nor combustible material.

V. **Results of Damage:**

The station is unaffected by the minor damage and continues to be operable except for the remote control feature. Until telemeter facilities at One Woodward are repaired, or the regulators are converted back to pilot loading or hand controlled through bypasses, pressures and deliveries to the Seven Mile and Beech-Daly road mains are restricted to rates and pressure settings at attack time. These volumes and pressures, however, would be adequate for the immediate postattack remaining load.

Delivery of gas to River Rouge Station from Northwestern via the Southfield main is unaffected.

DAMAGE APPRAISAL NO. 7–GREEN AVENUE STATION

I. **Attack Data:**

Distance from G. Z. . . . . 4.6 km	Wind speed . . . . 375 mph
Overpressure . . . . 12.7 psi	Thermal radiation . . . . 200 cal/cm^2
Dynamic pressure . . . . 3.3 psi	Residual nuclear radiation . < 500 R/hr

II. **Description of Facility:**

Green Avenue is a small, unmanned regulating station. Two regulators, Hi-Low Operators, valves and piping are contained in a single story, 40 x 18 foot windowless, load-bearing brick building. Also contained in the building is a space heater, partitioned off from the regulators by a brick fire wall.

The flat, gypsum slab roof is supported by 4-6 inch I beams lengthwise and 2-10 beams crosswise.

A 40-foot side of the building facing ground zero fronts on a railroad right of way.

The 8 and 12 inch pilot loaded regulators reduce the 50 psi Green Avenue main gas to 25 and 10 psi for the Solvay and Lafayette Street mains. Two regulated taps from the Solvay main, downstream from the station, supply a small, isolated grid system with 1.5 psi gas.

II. Extent of Damage:

The building collapses into a pile of rubble partly carried downstream by the wind. The regulators are severely damaged from sheared off loading heads and crushed diaphragm chamber castings. The steel gas mains are dented but are not significantly damaged. Valve wheels and gears are broken. The overpressure operators are crushed.

III. Results of Damage:

The station is destroyed. Gas continues to flow through the regulator valves held partly open by bent stems.

Gas leaks into the rubble from broken tubing and cracked regulator bodies. It is not ignited. When fire spreads into the area later, gas pressure has declined to a low value and the flame is small.

The destruction of the station and loss of support for the Lafayette main is immaterial in the immediate postattack period. The Lafayette main is in the area purposely shut down by the utility, probably lasting until rebuilding again creates a need for gas service. In addition, Green Avenue is only one of numerous other feeds into the 10 psi system; its loss in summer, even in normal operation, would not be critical.

The Solvay main supplies industry in the area. Restoration of service to that main will require replacement of the regulator.

DAMAGE APPRAISAL NO. 8–LAWTON STATION

I. Attack Data:

Distance from G. Z. . . . . 7.0 km

Overpressure . . . . 5.8 psi

Dynamic pressure . . . . 0.9 psi

Wind speed . . . . 185 mph

Thermal radiation . . . . 77 cal/cm^2

Residual nuclear radiation . 50 R/hr

II. Description of Facility:

Lawton Station is primarily a headquarters for a 60-man force handling customer service activities in its service area and a 75-man inspection crew operating district wide.

Lawton storehouse supplies are limited to those associated with appliance servicing. It does not stock distribution system repair, maintenance or main extension supplies. It is, however, the buying storehouse for gas appliance service parts, small diameter galvanized pipe, brass and galvanized fittings, employee uniforms, plumbing and janitorial supplies. In addition, it contains the District's wood working shop and consequently stocks lumber and carpentry materials.

There is no distribution regulation equipment in the station, nor does it engage in distribution system maintenance.

The station consists of a single story, 460 x 80 foot, concrete floor, cement block building. The flat, metal deck roof is supported by light steel beams and columns.

The building is divided into three main areas: warehousing, the carpenter shop, and garage.

The amount of combustible material in the building is small. There are no identifiable fuel arrays involving lumber. Furniture, partitions and counters are steel. Windows in the storehouse section facing ground zero are opaque. Carpenter shop windows are in the lee side of the building. The front side of the building, however, faces a residential district towards ground zero separated by about 150 feet. The station also adjoins a bulk gasoline depot located downwind and offset from the direction of the blast. Gasoline and other fuels are reported to be stored underground, although there are aboveground tanks. The back side of the building faces a railroad right of way and open fields.

III. Personnel on Duty at Attack Warning Time:

Two mechanics are on duty in the garage. They leave the station and seek shelter along with the general public.

IV. Extent of Damage:

The concrete block walls are fractured and collapse. Bins and supply materials are scattered downwind in the open fields.

The exposed gasoline pump stand is sheared off and carried away.

The 2 inch gas pipe supplying building unit heaters is ruptured and gas escapes therefrom, but it is not ignited. It is ignited later from fire in the residential debris, but pressure in the system has declined to a low value and the flame is small.

V. Results of Damage:

The station is destroyed. Recoverable supplies are limited to the gasoline on hand and a small percentage of storehouse stock items.

DAMAGE APPRAISAL NO. 9–LYNCH ROAD STATION

I. Attack Data:

Distance from G. Z.	13.4 km	Wind speed	70 mph
Overpressure	2.0 psi	Thermal radiation	10 cal/cm^2
Dynamic pressure	0.1 psi	Residual nuclear radiation	90 R/hr

II. Description of Facility:

This station operates regulating equipment and a compressor plant in addition to providing operating supplies, vehicle repair and being a headquarters for a 155 man force handling Customer Service and Street Department maintenance activities in the Lynch service area.

The compressor plant consists of two gas engine driven units having a total capacity of two MMcf/hr, 175 psi inlet and 300 maximum outlet.* A standby gas engine driven cooling-water pump for the compressors and a 5 KW generator for electrical instruments enable the plant to operate without commercial power.

A 125 foot, unguyed radio mast with two antennae remotely operated by Dispatchers at One Woodward serves the area.

The station faces the runway areas of the Detroit City Airport. Nearest commercial building is more than 300 feet away.

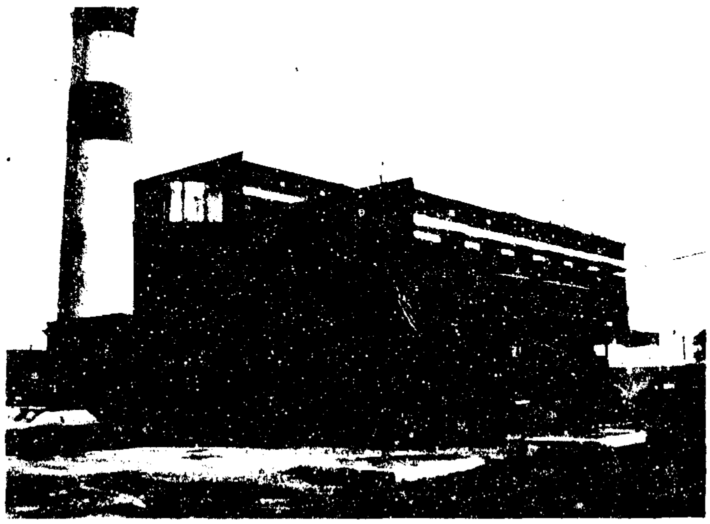
There are three buildings, active in operation, on the property. The unattended fourth building is used for miscellaneous storage.

Compressor, Regulator and Boiler Building. This combination building houses the compressors, station regulators and two out-of-service steam boilers. A low height, out-of-service, reinforced concrete stack adjoins the building.

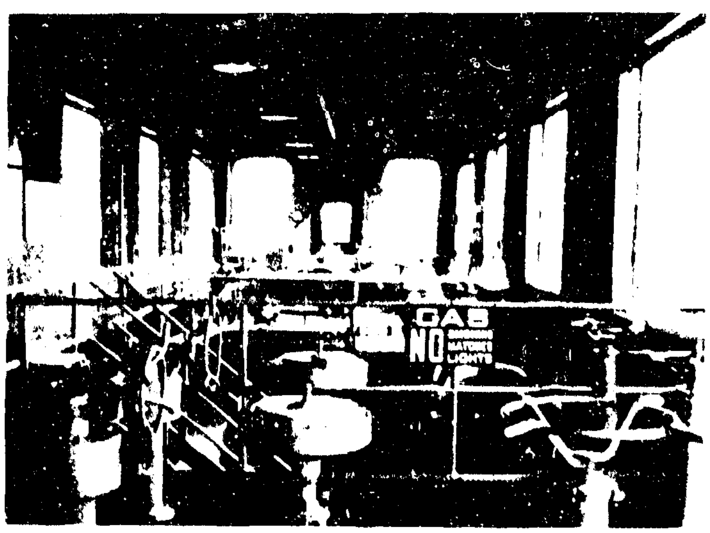
The compressor section of the building contains a built in steel frame for support of a 10 ton hoist. The frame also reinforces the brick walls and provides partial support for the roof trusses.

Roof is gypsum slab supported by moderately heavy trusses. About one-half of the truss ends are tied to the steel frame; remaining ones are anchored in the walls.

*A new 36 inch main, now under construction, which will directly connect Milford and Belle River transmission will eliminate need for the compressors after Winter 1969-70.



Compressor Building with Regulator Building in Foreground.
Looking in direction away from ground zero.



Interior of Regulator Building. Looking normal to direction of ground zero.

Figure 20. Views at Lynch Road Station.

The regulator room is a single story, steel grating floor, load bearing brick annex to the compressor building. Its flat, gypsum slab roof is supported by horizontal I beams.

The contained regulators and Hi-Low Operators are above grade. Mains enter and leave the building underground from a full-length, concrete lined pit.

In distribution operations, gas supply at 175-200 psi (or 300 when delivered by Northeastern from storage) is regulated in the station to 10, 50 and 100 psi for six outgoing Transfer mains.

Storehouse and Combination Garage and Office Buildings. These buildings are essentially the same as those at Allen Road.

Lynch storehouse is a satellite operation with appliance service and distribution maintenance stores being limited to minimal quantities. Supplies, not at hand, are requisitioned daily from Coolidge. Compressor plant repair parts, however, are adequate for normal needs.

There are no fuel arrays in the storehouse. Furniture, counters, shelves and bins are metal.

The gasoline pump is located in a niche in the concrete loading platform on the side of the storehouse radial to the blast and facing toward the airport.

III. Personnel on Duty at Attack Warning Time:

Two mechanics in the garage and two Distribution Operators in the compressor plant are on duty. The Operators after shutting down the compressor and the mechanics all leave the station and seek shelter along with the general public.

IV. Extent of Damage:

The buildings are not damaged except for broken windows and blown in doors.

A few gauge door glasses are broken in the compressor room and several small diameter repairable tubing control lines to regulators are leaking. Regulator operation is unaffected.

There is no fire, either primary or secondary.

The gasoline pump is undamaged.

The radio antennae is undamaged, but is out of service until telephone facilities at One Woodward are repaired.

V. **Results of Damage:**

The station is operable in the immediate postattack period as soon as there is need to distribute gas from the station.

Appliance service and distribution repair supplies, amounting to about 0.13 percent of District total, is available for postattack use.

DAMAGE APPRAISAL NO. 10—NOBLE STATION

I. **Attack Data:**

Distance from G. Z. . . . . 6.0 km

Overpressure . . . . 7.7 psi

Dynamic pressure. . . . . 1.5 psi

Wind speed . . . . 255 mph

Thermal radiation . . . . 105 cal/cm^2

Residual nuclear radiation . 300 R/hr

II. **Description of Facility:**

Noble Station serves primarily as headquarters for the General Office of the Street and Transportation departments, and as the operating center for a 55-man service force handling Customer Service activities in the Noble service area. All major vehicle repairs for the Detroit District are done at this station.

It is also the storehouse for Company stationery supplies and automotive parts and, in addition, is the District center for miscellaneous activities such as instrument repair, photographic equipment, film storage and others.

Noble Station neither contains distribution regulators or performs distribution system maintenance.

The Station consists of two principal buildings:

1. The Transportation building is a 3 floor, 135 x 200, reinforced concrete frame, brick wall structure. The entire building, including its flat roof, formerly was devoted to vehicle storage and repair. These activities are now confined to the first floor and a garage annex, the upper floors having been converted to office space.*

Except for wood-glass doors and composition floor tile on a plywood base over concrete, the upper stories of the main building contain little combustible material. Partitions are metal studs and non-flammable dry wall materials.

The Noble storehouse, reached from street level by ramps or building elevator, is in the basement.

The annex, wherein major repairs to Detroit District vehicles are made, is a single story 65 x 195 foot, concrete floor, concrete block, brick faced, load bearing structure. The flat roof is steel decking. The annex and Transportation building are interconnected by means of wide passageways.

Gasoline pumps are located in a parking lot across a street.

2. The Service building† is an 85 x 185 foot, concrete floor, load bearing brick building, largely used as office space.

*This change in building use largely took place in 1969. Damage evaluation is based on current status.

†This purchased building, a former supermarket, is structurally comparable in strength to "apartment house type."

III. Personnel on Duty at Attack Warning Time:

Five mechanics are on duty in the garage. They leave and seek shelter with the general public.

IV. Extent of Damage:

The reinforced concrete frame of the Transportation building is undamaged, but brick walls are bowed and cracked. Glass block windows are blown in. Partitions in the upper floors are down. Furniture and office equipment, including instruments and test benches, are extensively damaged and unusable.

The basement storehouse contents, largely stationery items, are slightly disarrayed but undamaged. Bins of automotive parts in a ground floor stockroom are blown over and scattered, but items are salvageable.

The annex is severely damaged. Walls are shattered, causing roof structure to collapse. Nine trucks being repaired are severely damaged.

The gasoline pumps are sheared off and destroyed, but tank and contents remain intact.

The Service building is destroyed. Walls and roof are collapsed.

V. Results of Damage:

In an operating sense, the station is destroyed. The reinforced concrete frame of the Transportation building is the only salvageable remaining aboveground structural item. Walls and interior will require complete replacement.

The loss of the station, however, has no immediate postattack effect; it contains no distribution gas supply facilities and, furthermore, is located in an area which will be shut down indefinitely.

DAMAGE APPRAISAL NO. 11—TIREMAN STATION

I. Attack Data:

Distance to G. Z.	2.0 km	Wind speed	> 1,000 mph
Overpressure	69 psi	Thermal radiation	
Dynamic pressure	96 psi	Residual nuclear radiation	300 R/hr

II. Description of Facility:

Tireman is an important station. It not only has the largest inventory of distribution materials in stock (about 46%), but performs district-wide centralized services as follows:

1. Meter test and repair
2. Laboratory testing
3. Employee training
4. Prefabrication of meter manifolds
5. Valve and fitting salvage
6. Tool repair

It is also the headquarters for 265 employees handling Customer Service and Street Department operations in the Tireman Service area.

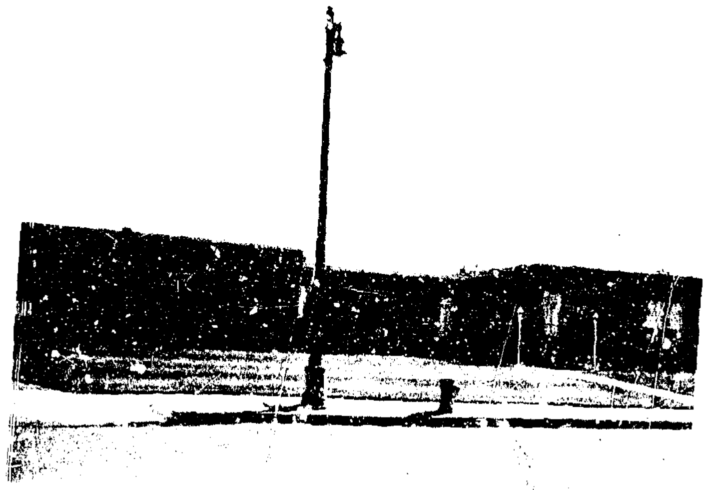
The station performs nc distribution regulation.*

Five buildings are located on the property, plus an annex which provides office space for Customer Service and Street Department operations.

Details of the building are:

1. *Combination Laboratory, Employee Training and Meter Shop.* This is a modern, single-story, concrete floor slab, load-bearing grick building providing 62,000 square feet of floor space for the foregoing activities 1. through 3.

*Regulating equipment in connection with Station J, a former gas manufacturing plant, has been removed.



Employee Training Headquarters. Looking 30 degrees to the left of ground zero.

Portion of Meter Shop. Looking away from direction of ground zero.

Figure 21. Views at Tireman Station

Contained in the building is an on-site gas engine driven generating plant. Two 300 KW generators (one is a spare) and a 125 KW unit provide power for the station.

2. *Storehouse and Garage.* This is a 196 x 108 single story, cement floor slab brick wall building. The flat roof is supported by wood beams on a steel frame and columns.

3. *Storehouse Storage Shed.* This is a 27 x 183 foot steel frame, metal sheathed building used for storing various bulk materials.

III. Personnel on Duty at Attack Warning Time:

Three mechanics are on duty in the garage. They leave and seek shelter with the general public.

IV. Extent of Damage:

All buildings are destroyed. Remnants are swept away and widely scattered.

Gas supply pipes to the gas engines and building heat boilers are torn out. Gas escapes to the atmosphere. It is not ignited.

V. Results of Damage:

Forty-six percent of the District's service and main supplies are destroyed along with the buildings.

In addition, a modern laboratory and its equipment and an automatic conveyor type meter repair shop with 16,200 meters being processed are destroyed. The loss of the station, however, has no immediate postattack effect; it contains no distribution gas supply facilities and furthermore, is located in an area which will be shut down indefinitely.

DAMAGE APPRAISAL NO. 12—EUCLID STATION

I. **Attack Data:**

Distance from G. Z. . . . . 5.3 km

Overpressure . . . . 9.7 psi

Dynamic pressure . . . . 2.2 psi

Wind speed . . . . 310 mph

Thermal radiation . . . . 14 cal/cm^2

Residual nuclear radiation . 135 R/hr

II. **Description of Facility:**

This is a small unmanned regulating station. It consists of a single story, 22 x 26 foot, load bearing, brick wall building containing a pilot loaded 12 inch regulator.

Gas is taken from the 50 psi Euclid main and reduced to 10 psi for the Twelfth Street main.

A four story brick veneer apartment house is located across a 20 foot alleyway from the station towards ground zero.

III. **Extent of Damage:**

The station building is crushed by the 9.7 psi overpressure and falling walls of the nearby apartment building. The regulator and bypass valves are snapped off from impact of the falling material. Gas, escaping to the atmosphere through the pile of rubble, is not expected to become ignited until fire spreads into the area.

IV. **Results of Damage:**

The station is destroyed. The regulator and station piping will require replacement to function again in a preattack capacity.

The loss of the station has no adverse effect in the immediate postattack period. It serves an area so heavily damaged that need no longer exists for either gas service or the station.

DAMAGE APPRAISAL NO. 13—STATIONS A AND E

I. Attack Data:

Distance from G. Z.	5.5 km	Wind speed	300 mph
Overpressure	9.0 psi	Thermal radiation	130 cal/cm^2
Dynamic pressure	2.0 psi	Residual nuclear radiation	> 500 R/hr

II. Description of Facilities:

These are two small unmanned regulating stations. The buildings containing the equipment remain from former gas manufacturing operations at the sites.

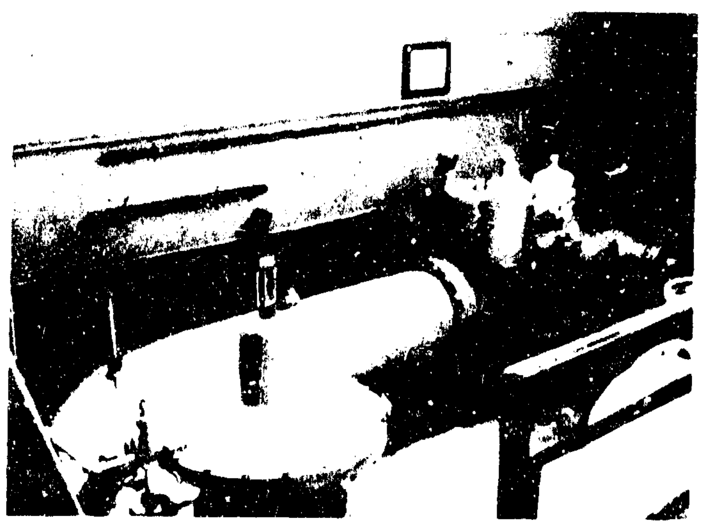
Station A is a 40 x 130 foot, single story, concrete floor slab, load-bearing brick building. The 40-foot front part of the building is the regulator room. Its roof is gypsum slab supported by steel framing and I beam columns. The back part, isolated by a concrete block fire wall, is used for storing advertising displays. It also contains a building heat, gas-fired hot water boiler in a pit. The displays are generally readily ignitable.

The single, 12 inch, pilot-loaded regulator reduces 100 psi pressure from the Fort Street main into a manifold supplying four outgoing 10 psi mains. The Gas Machinery valves in the manifold have cast iron bodies.

Station E is a 15 x 20 foot, windowless, single story, load-bearing brick structure having a flat, gypsum slab roof supported by horizontal I beams. The single 10 inch pilot-loaded regulator located in a full length concrete-lined pit reduces gas from the Fort Street main to 10 psi for the Lafayette main.

A two-story brick, commercial building butts against the station's side wall on the ground zero side.

Regulator and Hi-Low Operator Station A



Regulator and Hi-Low Operator Station E

Figure 22. Interior Views in Stations A and E

III. Extent of Damage:

The Station A building is severely damaged. Walls are badly cracked and partially collapsed. The steel frame is bent. The firewall is shattered and collapses.

Loose paper in a display next to an 8 x 8 foot window facing ground zero is ignited, but is extinguished when the lightweight articles are scattered in a downwind open field.

In the regulator room, the pilot regulator, Hi-Low Operator control and loading tubing lines and the diaphragm chamber are wrecked by the collapsed front wall and missiles generated therefrom. The valve stem is bent in the process, locking the regulator in the position existing at attack time.

Torsional stresses are expected to crack, but not shear welds of ells in the manifold. The castings and stems of the cast iron gate valves are cracked and bent.

The 2 inch gas pipe supplying the boiler is twisted off. Gas flows into the rubble but rapidly declines in volume as pressure drops from upstream losses. It does not ignite or endanger the nearby Ambassador Bridge because of station isolation from sources of firebrands.

The Station E building is also destroyed. The impact of the falling walls breaks off the pilot, the diaphragm chamber and cracks the regulator body. The escaping gas is ignited later as fire spreads, but the flame is confined to the pile of rubble.

The large diameter steel piping in the building is dented but otherwise undamaged.

IV. Results of Damage:

Both stations are rendered inoperative and will require rebuilding and extensive replacement of equipment.

Neither station is needed in the immediate postattack period; both are in the area purposely shut down by the utility.

Station A, when needed to serve a restored industry, can be made operable by piping repair and replacement of valve gearing and the pilot regulator. These latter items are salvageable for installation in the uptown shutdown area. Building replacement is not essential.

Station E probably would not be returned to operation in any event. It is merely one of many feed points into the 10 psi system.

DAMAGE APPRAISAL NO. 14–PARDEE HEATING STATION

I. Attack Data:

Distance from G. Z.	12.1 km	Wind speed	80 mph
Overpressure	2.4 psi	Thermal radiation	24 cal/cm^2
Dynamic pressure	0.16 psi	Residual nuclear radiation	5 R/hr

II. Description of Facility:

The function of this unmanned heating station is to maintain gas temperature in the 24 inch Beech-Daly Road main above 32°F in winter following a 150 psi reduction in pressure from the Van Born main.

The equipment which consists of a one million Btu, 15 psi steam boiler separated from a heat exchanger by an 8 inch brick firewall, heats a bypassed portion of the Pardee volume.

The equipment is housed in a 20 x 22 foot, unreinforced, 8 inch thick wall, load bearing, masonry building (4 inch concrete blocks faced with 4 inch brick). Building location is in the center of an 80 x 130 foot lot. The composition shingle, peak roof is supported by 2 x 6 inch rafters on 16 inch centers.

The surrounding area is not built up. Closest building is a concrete block service station about 60 feet distant towards ground zero. Other structures in the area are single story, concrete block commercial buildings more than 200 feet distant.

There are no fuel arrays within or adjacent to the building. Yard surface is [illegible] surrounded on two sides by shrubbery and open space on others, except for the service station.

III. Extent of Damage:

Windows are broken, the metal doors are blown in and the roof is moderately damaged from cracked rafters and torn off shingles.

Equipment sustains minor damage, consisting of broken gauges and glasses.

Because of its isolated location, fire is not expected from either primary or secondary causes even though the building is within the fire spread area.

IV. Result of Damage:

Normally, the station is needed only during winter months. It would be fully operable in the postattack period after minor repair.

DAMAGE APPRAISAL NO. 15–GAS MAIN CROSSING
EDSEL FORD FREEWAY–LIVERNOIS AVENUE

I. Attack Data:

Distance from G. Z. . . . . 1.3 km

Angle of incidence . . . . 17 deg*

Overpressure . . . . 215 psi

Dynamic pressure . . . . 290 psi

Wind speed . . . . > 1500 mph

Thermal radiation . . . . > 1000 cal/cm^2

Residual nuclear radiation . 500 R/hr

*The angle between the blast front and the longitudinal axis of the bridge.

II. Description of Facility:

Two hundred and six feet of 8 inch steel main cross the freeway on hangers under the bridge. Main is anchored in bridge headwalls. An expansion joint intervenes. It is one of several connections between cast iron header mains in that area operating at 2 psi on both sides of the freeway. See Table XII for other locations of overcrossings.

Figure 23. Edsel Ford-Livernois Avenue Crossing. Looking in direction away from G. Z.

III. Extent of Damage:

Both bridge and attached gas main are torn out by the wind. The gas main pulls apart on each side of freeway where transition is made from steel to cast iron. Gas blows to the atmosphere from the broken ends until gas pressure in the area dissipates.

IV. Result of Damage:

The loss of this tie across the freeway has no significance in the postattack period. It is in the area purposely shut down by the utility because of destruction of buildings therein and disappearance of need for gas service until the area is rebuilt.

Need for this interconnection, in normal operation, occurs in winter; its loss in summer would not be critical.

DAMAGE APPRAISAL NO. 16—GAS MAIN CROSSING
WYOMING AND SOUTHERN STREETS

I. Attack Data:

Distance from G. Z. . . . . 2.4 km	Dynamic pressure . . . . 47 psi
Angle of incidence . . . . 47 deg.	Wind speed . . . . > 800 mph
Overpressure . . . . 46 psi	Thermal radiation . . . . 750 cal/cm^2

II. **Description of Facility**

This installation consists of ... feet ... 12 inch wrapped steel pipe operating at 10 psi crossing Wyoming on the sidewalk behind ... 12 inch th..., 4 foot high concrete side wall facing in the direction of ground zero. The exposed pipe ... a ...sser coupling near its midpoint.

III. **Extent of Damage:**

The overcrossing is destroyed. Pipe ... at each end where transition is made to cast iron.

IV. **Results of Damage:**

The effects of the rupture of this main has no significance in the postattack period. It is in the area purposely shutdown indefinitely by the utility. Its replacement where needed would be a minor job.

DAMAGE APPRAISAL NO. 17—PIPELINE BRIDGE

RIVER ROUGE—ZUG ISLAND

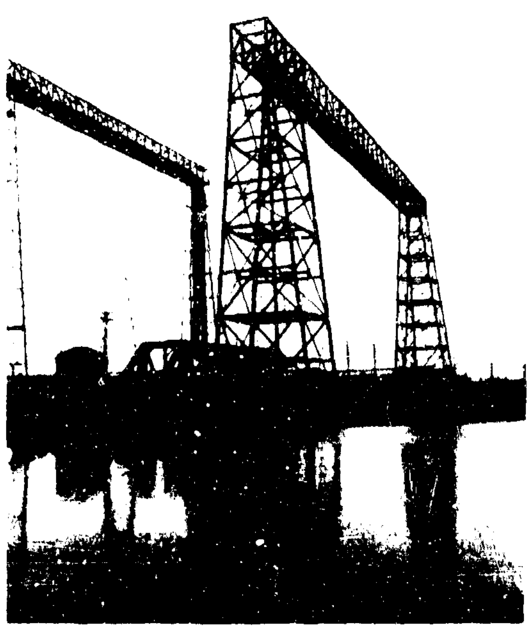


Figure 24. Pipeline Bridge Direction is away from G. Z.

I. **Attack Data:**

Distance from G. Z.	6.6 km
Angle of incidence	39 deg.
Overpressure	6.6 psi
Dynamic pressure	1.1 psi
Wind speed	215 mph
Thermal radiation	88 cal/cm^2
Residual nuclear radiation	420 R/hr

II. **Description of Facility:**

The 11 foot high by 12 foot deep, box-truss center portion of the structure and the two 115 foot high towers support a 240 foot span of 16 inch—300 psi maximum pressure gas pipeline over the River Rouge to supply natural gas to the Great Lakes Steel Company. The structure is designed to resist 100 mph wind (0.24 psi). Structure is bolted to 40 x 40 foot concrete piers supported by piles.

III. Extent of Damage:

The structure fails* from a wind load 4.6 times greater than design specification. The gas pipe is ruptured at one or more places by torsional stresses at ells.

IV. Results of Damage:

Natural gas service to Great Lakes Steel is interrupted until the span is replaced.†

Gas pressure at attack time is about 80 psi, lowered from the normal 150 at River Rouge Station as a preattack emergency measure.

Gas rate loss to the atmosphere is estimated at 3.5 MMcf/per hour based on a stabilized 40 psi at River Rouge.

A nearby similar structure, owned by Great Lakes Steel and supporting coke oven gas mains over the river, is assumed to be destroyed also cutting off all gas fuel to the steel plant.

*Conclusion of Michigan Consolidated Distribution Design Department and L. E. Daiglo & Associates, Detroit, designer of the structure.

†Construction of piers and erection of structure and piping required nearly three months. In general, work on all parts of the structure proceeded concurrently.

SECTION III

GAS SYSTEM SUPPORT FACILITIES AND DAMAGE APPRAISALS

GENERAL

Gas system supporting facilities and services covered in this study comprise the following: (1) electric power, (2) trucks and major portable tools, (3) storehouse maintenance and operating supplies, and (4) communication facilities.

Description of the facilities, locations where employed, attack environmental data, expected damage and effects on gas system operation follow:

ELECTRIC POWER

Electric power is not an essential requirement in the transmission or distribution operations of either Michigan Consolidated or its suppliers--the Michigan Wisconsin and Panhandle Eastern Pipeline systems. Station compressors of the three companies for transmission and underground gas storage operations are gas engine driven.

Gas is not a factor in the generation of commercial power by Detroit Edison, the electric utility in the Detroit area. Coal* is the primary boiler fuel in its steam electric plants.

Normal electrical needs of Michigan Consolidated in the Detroit area for lighting, office equipment, power tools and other miscellaneous equipment are purchased from Detroit Edison except for (1) Willow Station and its gas processing facilities and (2) Tireman Station. On-site natural gas engine-generator sets and reserve spares supply all electrical requirements at these locations without commercial power standby.

*In 1969, Detroit Edison began using gas as supplementary fuel in Detroit area generating plants at an annual rate of 27.8 billion cu. ft.

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At One Woodward, a roof mounted natural gas engine driven generator is maintained for emergency operation of one elevator, electronic data processing, standby radio transmitter, telemeter instruments and essential lighting.

For regulator control in the unmanned regulating stations of Coolidge, Evergreen and Northeastern, automatic 5 KW gas engine driven generators provide emergency power. At Lynch Road and River Rouge, gas engine driven units supply compressor plant auxiliary equipment and necessary lighting.

Electric power, while a convenience, is not essential for control of the gas transmission and distribution systems in the Detroit area. However, in conjunction with telephone circuits, it enables the Gas Dispatcher to precisely regulate the system with the aid of 53 telemetered pressures and volumes and by remote operation of major regulators at seventeen strategic points.

Prolonged inactivation of telemeter facilities, while a handicap to the Michigan Consolidated Dispatcher, would not impair gas system capacity. The situation would be offset by stationing personnel at critical locations to manually control in conjunction with mobile radio for communication.

Damage Appraisal

Damages sustained by Michigan Consolidated electric generating equipment from this attack are listed in Table IV.

TRUCKS AND MAJOR PORTABLE EQUIPMENT

In normal operation, Detroit District trucks and portable equipment are parked in the open in the yards of the eight Service and Maintenance Stations listed in Table V.

Acting on advice that conflict seems inevitable because of increasing international tensions, Michigan Consolidated in August 1965 relocated its trucks and mobile equipment in accordance with

TABLE IV—ELECTRIC GENERATING UNITS AND DAMAGE APPRAISAL

Michigan Consolidated Gas Company

LOCATION	Rating KW	No. of Units		Degree of Damage
Coolidge	5	1	(standby emergency use for instrumentation; telemetering & minimal lighting.)	severe
Evergreen	12.5	1		undamaged
Lynch Road	5	1		undamaged
Northeastern	5	1	same	undamaged
Northwestern	12.5	1	same	undamaged
River Rouge	12.5	1	same	severe
Willow Station	12.5	1	same	undamaged
One Woodward	250	1	as above plus computer and elevator.	light
Tireman	300	2	(continuous operation, total energy needs.)	destroyed
Tireman	125	1	same	destroyed
Willow Processing Plant	300	2	same	undamaged

its attack emergency plan by reassigning east of Woodward equipment to Northeastern Station and west of Woodward equally between Willow and Northwestern Stations. The redistribution is shown in Table VI.

Table XIII in Appendix B lists Michigan Consolidated equipment potentially available from locations outside of Detroit District.

TABLE V—NORMAL DISTRIBUTION OF TRUCKS AND MOBILE EQUIPMENT

Michigan Consolidated Gas Company
Detroit District

AUTOMOTIVE	STATIONS							
	Noble	Allen	Coolidge	E. Jefferson	Eureka	Lawton	Lynch	Tireman
Trucks, delivery and service: vans, station wagons, panels	60	58	54	48	41	66	50	67
Trucks: pickup, compact 1/2, 3/4 & 1 ton	9	19	10	7	10	1	7	20
Trucks: platform 1-5 tons	—	2	3	1	2	—	1	8
Trucks: utility 1/2, 3/4, 1 & 1-1/2 ton	4	39	24	20	21	34	22	27
MAJOR PORTABLE EQUIPMENT								
Arc welding machines	—	—	1	—	1	—	—	7
Auger	1	—	—	—	—	—	—	—
Back fill	—	—	1	—	—	—	1	10
Back hoe	—	—	1	—	3	—	1	—
Compressors	1	2	6	2	2	—	8	17
Crane	—	1	—	—	—	—	—	2
Dozer	—	1	1	—	—	—	2	—
Dump	—	2	3	1	2	—	1	8
Loaders	—	—	—	1	2	—	—	1
Roller, asphalt	—	—	—	—	—	—	—	1
Tractors	—	5	2	—	—	—	1	6
Trailers and semi-trailers 1-10 tons	—	6	—	—	1	1	—	2
Transit-mix	—	—	—	—	—	—	—	4

TABLE VI—EMERGENCY DISTRIBUTION OF TRUCKS AND MOBILE EQUIPMENT

Michigan Consolidated Gas Company
Detroit District

AUTOMOTIVE	STATIONS		
	Northeastern	Northwestern	Willow
Trucks, delivery and service: vans, station wagons, panels	98	173	173
Trucks: pickup, compact, 1/2, 3/4, & 1 ton	14	35	34
Trucks: platform 1-5 tons	2	8	7
Trucks: utility 1/2, 3/4, 1 & 1-1/2 ton	44	75	74
MAJOR PORTABLE EQUIPMENT			
Arc welding machines	–	5	4
Auger	–	1	–
Back fill	1	6	5
Back hoe	1	2	2
Compressors	10	14	14
Crane	–	2	1
Dozer	2	1	1
Dump	2	7	8
Loaders	1	2	1
Roller, asphalt	–	1	–
Tractors	1	7	6
Trailers and semi-trailers 1-10 tons	–	5	5
Transit-mix	–	2	2

Damage Appraisal

No significant damage is sustained by the trucks and equipment at the three relocation stations.

The damage potential of the blast wave at the locations is of a low order:

Station	Overpressure	Wind Speed
Northeastern	1.2 psi	< 60 mph
Northwestern	0.7	< 60
Willow	0.4	< 60

There are, however, 38 one-half ton service vans and six 1-1/2 ton compressor equipped distribution trucks on duty in the District in addition to 26 vans and 4 trucks in the station garages for repairs at attack warning time.

Assuming that the on-duty vehicles are left parked in the streets in the general locations of the job sites by the drivers seeking shelter, the vehicle locations at H hour and damages sustained are given in Table VII.

TABLE VII—TRUCK LOCATIONS AT H HOUR AND DAMAGE APPRAISAL

OVER-PRESS. psi	OUTDOORS				INDOORS			
	Streets		Stations(1)		Company Garages			
	Service Vans	1-1/2 T. Trucks	All Types	Damage	Service Vans	1-1/2 T. Trucks	Other Types	Damage(2)
0-2	14	2	640	none	5	—	1	none
2-5	15	3	-	light	1	1	1	light-mod.
5-10	4	—	—	moderate	12	2	5	severe
over 10	5	1	—	severe	1	—	1	severe

(1)Emergency relocations stations of Northeastern, Northwestern and Willow.
(2)Damage to indoor vehicles is based on damage to garage building.
(3)Passenger vehicles.
(4)Except cracked window glass.

Nine service vans and two 1-1/2 ton trucks of the above tabulation, all undamaged by blast, are in streets outside of the fire area. Thirteen service vans and two 1-1/2 ton trucks are in garages experiencing severe damage. Assuming that vehicles in the streets in the fire area are disabled by fire, a total of forty-two vans and six trucks sustain severe damage. These numbers represent 9.5 percent of service vans, 5.5 percent of 1-1/2 ton distribution trucks and 6.7 percent of total vehicles in the Company's Detroit area truck fleet.

The number of remaining operable trucks is ample for postattack needs.

Note: H hour is time of bomb burst.

MICHIGAN CONSOLIDATED WAREHOUSES AND SUPPLIES

In Detroit District, maintenance and operating materials are stored in the supply sections of the eight Service and Maintenance stations shown in Figure 6.* In areas outside of Detroit, stocks are maintained at Ann Arbor, Muskegon, Grand Rapids, Six Lakes and twenty other locations so supply the Company's five additional operating Districts and the Department of Production, Transmission and Storage.

In Detroit District, three stations—Allen, Coolidge and Tireman—contain the bulk of steel pipe, plastic tubing, fittings, valves, repair items and associated materials employed in new construction (main extensions and new services) and for the maintenance of the existing distribution system. These stations also have substantial stocks of supplies used in customer service work, such as meter set components, appliance adjustment and repair parts.

Large diameter steel pipe, 8 inch and over, is stored only at Allen Station. Cast iron pipe is not stocked; steel is used for cast iron replacement.

Eureka, East Jefferson and Lynch, three of the smaller stations, carry moderate stocks of steel pipe (4 inch or under), gas main repair materials, service regulators and other items associated with system repair and maintenance, running and renewing services and performing appliance service work on customers' premises.

Lawton Station operations are limited to customer service work and leak inspections, hence its supplies consist principally of parts for appliance installation and servicing. It does not stock materials for gas distribution system repair or maintenance.

*Figure 6 locates seven stations; the eighth—Eureka—is located in Southgate at Eureka and Allen Roads, see Figure 27.

Noble, the eighth operating station, functions primarily as an automotive center, storing vehicle repair parts and performing major automotive repairs. It is also the central distribution point for Company stationery, forms and allied materials. It does not store gas system repair or maintenance materials.

All stations, except Eureka, Noble and Lawton, have case iron fittings and cast iron pipe repair materials on hand.

The Company's supply operations are not dependent on a central storehouse to order and dispense supplies therefrom to satellite substores. Instead, one or more of the storehouses are designated as the "buying" storehouses for one or more stock items. Each is responsible for keeping its stock of the particular item within prescribed limits. Other storehouses requisition from the buying storehouse. For example, Tireman is the primary storehouse for black iron fittings, valves, meters and other specific materials; Lawton handles galvanized fittings, uniforms, electrical supplies, appliance service items; Noble handles Company stationery and automotive repair parts.

Supply materials listed in the Company catalog for gas system operation, maintenance and new construction number about 3,500 exclusive of stationery, office supplies, first aid and other items not directly used in operating and maintaining the system. An inventory count August 1969 totaled nearly 1.1 million individual items and 1.3 million feet of steel and plastic pipe of assorted sizes and grades.

Damage Appraisal

Storehouse supply totals for construction, maintenance and repair of the gas system and for gas appliance servicing are divided into two categories in Table VIII:

1. pipe and tubing
2. materials for gas main construction, maintenance and repair and supplies used for servicing gas appliances on customers' premises.

TABLE VIII—STOREHOUSE SUPPLIES
GAS SYSTEM AND CUSTOMER SERVICE
DETROIT DISTRICT

STOREHOUSE	DISTRIBUTION AND SERVICE SUPPLIES				STOREHOUSE DAMAGE
	Pipe and Tubing—Metal and Plastic		Main and Service Materials		
	Feet	Percent	Number of Items	Percent	
Pre-Fab Meter Sets[1]			210,959	18.8	Destroyed
Pipeyard Coolsaet[2]	36,327	2.8	—	—	—
Allen Road	854,709[3]	65.0	139,886	12.4	Severe
Coolidge	287,173[4]	21.8	182,818	16.3	Destroyed By Fire
Lynch Road	28,611	2.2	1,486	0.1	Light
East Jefferson	15,396	1.2	726	0.1	Light
Noble	4,748	0.4	92,803	8.3	Moderate
Tireman	27,011	2.0	305,919	27.2	Destroyed
Lawton	21,758[5]	1.7	187,773	16.7	Severe
Eureka	38,576	2.9	304	0.1	Undamaged
TOTALS	1,314,309	100.0	1,122,674	100.0	

[1] Tireman Station
[2] Private Contractor
[3] 36% Plastic
[4] 61% Plastic
[5] 90% Metal Tubing

Given in the table are the percentage of total supplies in Detroit District for each storehouse building.

Gas main operating and maintenance supplies contained in Tireman and Coolidge storehouses make up more than 62 percent of the District stock. Although these two stocks are likely to be either unrecoverable or unusable because of fire damage at Coolidge, no shortage of repair items develops in the immediate postattack period. Work in that period consists of cutting off and isolating the part of the gas system in the heavily damaged area, repressuring the remaining operable part and restoring service on customers' premises. Supplies needed are moderate in quantity.

When valves are not available in the isolating process, cutting and plugging or capping of mains are required. Steel mains present no problem; cutting and capping by welding offers many alternatives without requiring stock fittings. Cast iron mains, however, require conventional cast iron caps or, if not available, impose use of more difficult means such as wood or cement plugs, bags or other substitutes. Fortunately, only 13 cast iron caps are needed in the isolating operations, see Section V. Except for the 12 inch size, which are dug out of the debris of Allen Station, the other smaller sizes are available from truck stocks.

Neither is there any shortage of supplies to reestablish service on customers' premises. Appliance service and repair parts normally carried in service vans will suffice for an indefinite time in the postattack period because of the reduced number of appliances.

Gasoline

It is expected that gasoline tanks and stocks will survive and that commercial power will be available for gasoline pumping at Eureka Station (postattack operating headquarters) as soon as needed for Company vehicles.

Capacities of gasoline storage tanks and stocks on hand at H hour are:

STATION	UNDERGROUND STORAGE		PUMP DAMAGE
	Capacity-Gallons	On Hand-Gallons	
Allen	8,000	4,096	Severe
Coolidge	8,000	6,544	Moderate
Eureka	8,000	6,337	Undamaged
E. Jefferson	10,000	5,049	Light
Lawton	8,000	5,264	Severe
Lynch	8,000	3,526	Undamaged
Noble	16,000	9,951	Severe
Tireman	8,000	2,343	Severe
TOTALS	74,000	43,110	

Although supply on hand at Eureka is limited and inadequate to complete gas restoration operations, it is expected that additional supply will be available to the Company for its high priority public service from a nearby undamaged refinery in Trenton.

MICHIGAN CONSOLIDATED COMMUNICATION FACILITIES

The Michigan Consolidated General Office at One Woodward is the hub of Company communication activities in Detroit District.

TELEPHONE FACILITIES

Communication by telephone between the Company's departments, offices and field operating centers is by means of wire line telephone circuits and associated equipment leased from the Michigan Bell Telephone Company.

Also leased from Michigan Bell are the wire line circuits required for the telemetering of volumes and pressures to the Gas Dispatcher at One Woodward and for remote control by him of certain distribution regulators in the field.

Except in the central downtown area, telephone circuits enter operating station properties (Allen Road, River Rouge, Lynch, etc.) from overhead wires or cables.

The PBX telephone board at One Woodward is located in a two door, windowless, interior room on the 7th floor. Low strength partitions enclose the room. The switching equipment, located on the 6th floor, is likewise enclosed in an interior room formed by light partitions.

Damage Appraisal

The PBX board and switching equipment are extensively damaged when doors and partitions are blown in by the 4.5 psi overpressure. This situation, in conjunction with similar damage at the Cass Street Michigan Bell exchange, renders Michigan Consolidated's telephone facilities emanating from One Woodward totally inoperative in the immediate postattack period.

RADIO FACILITIES

Communication between the Dispatchers of the Customer Service, Distriubtion, Street and Production, Transmission and Storage Departments at One Woodward and their Detroit District departmental personnel in the field is mainly by means of four base radio stations and 537 mobile, two-way radios in trucks and cars of supervisors. A fifth base station with antenna on the Guardian Building, located across the street from One Woodward, is maintained in a standby status. All radio equipment is owned and operated by Michigan Consolidated.

The distribution of radio equipped vehicles by departments is:

DEPARTMENT	VEHICLES		
	CARS	TRUCKS	VANS
Street	50	80	–
Service	63*	–	235
P.T.&S.	12	11	–
Other	28	8	–
Totals	153	99	285

*To reduce air congestion, 252 Customer Service trucks and cars receive and transmit on different frequencies, see Figure 25. They cannot communicate directly with each other.

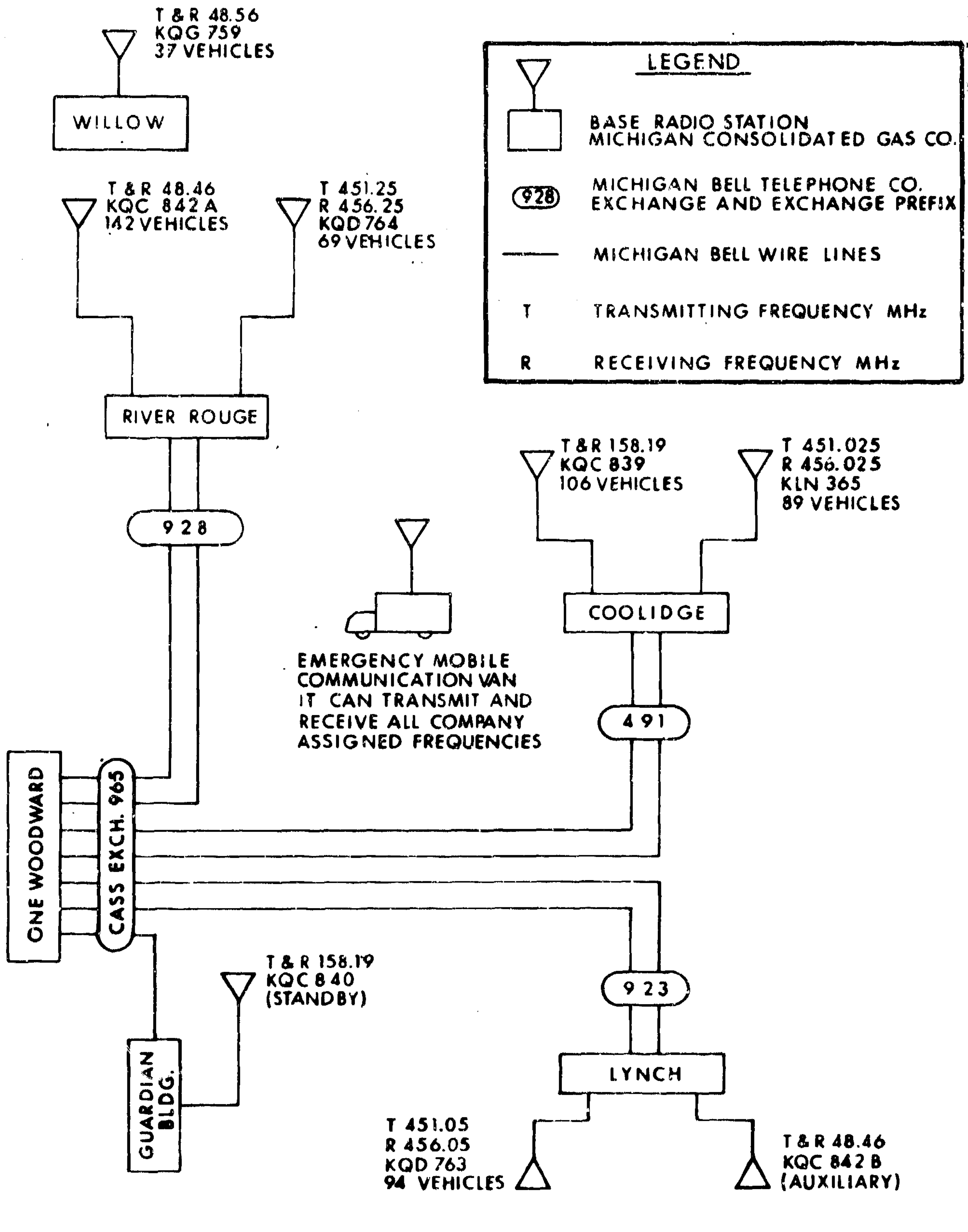
The interconnections between the base stations and One Woodward are shown diagrammatically in Figure 25.

The Company also maintains an auxiliary powered, mobile base station. It can transmit and receive on all frequencies assigned to Detroit District. The equipment is contained in a van type truck normally garaged at Noble Station. In accordance with the Company's Emergency Plan, the truck with an added assortment of radio replacement parts is moved to Northwestern Station prior to the attack.

Damage Appraisal

Normal use of radio facilities from One Woodward is completely disrupted as a result of damage to the telephone equipment interconnecting One Woodward with the base stations. In addition, radio masts, antennae and equipment are destroyed at the Guardian Building, Coolidge and River Rouge Stations. One Woodward ceases to be a center for postattack communication.

Willow and Lynch Stations are undamaged. Willow, having its own power supply, remains operable; Lynch requires a portable generator (available) for power. Neither station, though, is suitable as a postattack communication center. Both are too far from the first area of recovery



RADIO COMMUNICATION FACILITIES
MICHIGAN CONSOLIDATED GAS COMPANY
DETROIT DISTRICT
FIG. 25

operations west of Detroit, see Figure 27. In addition, less than 25 percent of the vehicles employ the frequencies of these stations.

There is no problem, however, in establishing a postattack communications center for coordinating the first phase of recovery operations. This is done by deploying at Eureka Station the mobile base station with its multi-frequency equipment. Eureka is the logical choice, not only for its undamaged building, gasoline supply and other facilities, but because its adjacent area probably will have early reinstatement of telephone service.

When east side recovery work is started, Lynch base station is returned to operation by bringing in a portable generator. Both frequencies of the station are used in order to employ more vehicles and personnel for the work of restoring gas service in the area.

SECTION IV
ORGANIZATION AND PERSONNEL

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MICHIGAN CONSOLIDATED ORGANIZATION

The Company's operating area is divided into five districts. All are within Lower Michigan. Detroit District is the largest in terms of customers receiving gas service. The four other districts are listed in the outline of the Company's organizational structure shown by Figure 26. The 26 floor, main office building of the Company is located at One Woodward Avenue, Detroit. It functions as the Main Office of the Company and as the commercial and operating headquarters for Detroit District.

The activities employed in conducting the Company's business are grouped into the eight categories shown in Figure 26. In Detroit District, each activity is administered by a Vice President and his staff. In other districts, the General Office groups provide staff assistance to local district Managers, who are responsible for all functions within their areas except operations of the Department of Production, Transmission and Storage in Lower Michigan. Operations of this department in the areas outside of Detroit are directed from three headquarters of Belle River Mills, Six Lakes and Big Rapids.

Personnel employed in Detroit District numbered 3,520 in 1969, of which 2,050 are located at One Woodward and rented space in the nearby Guardian Building.

PERSONNEL CASUALTIES

GENERAL

A casualty analysis is made to determine the number of uninjured, operating department personnel who have the skills and experience to repair and restore to operation the salvagable part of the physical gas system. The dashed enclosures of Figure 26 identify the operating departments involved in the analysis. The postattack functions of the employees analyzed are limited to restoring and maintaining gas service and to provide a few supporting services in the field, for example

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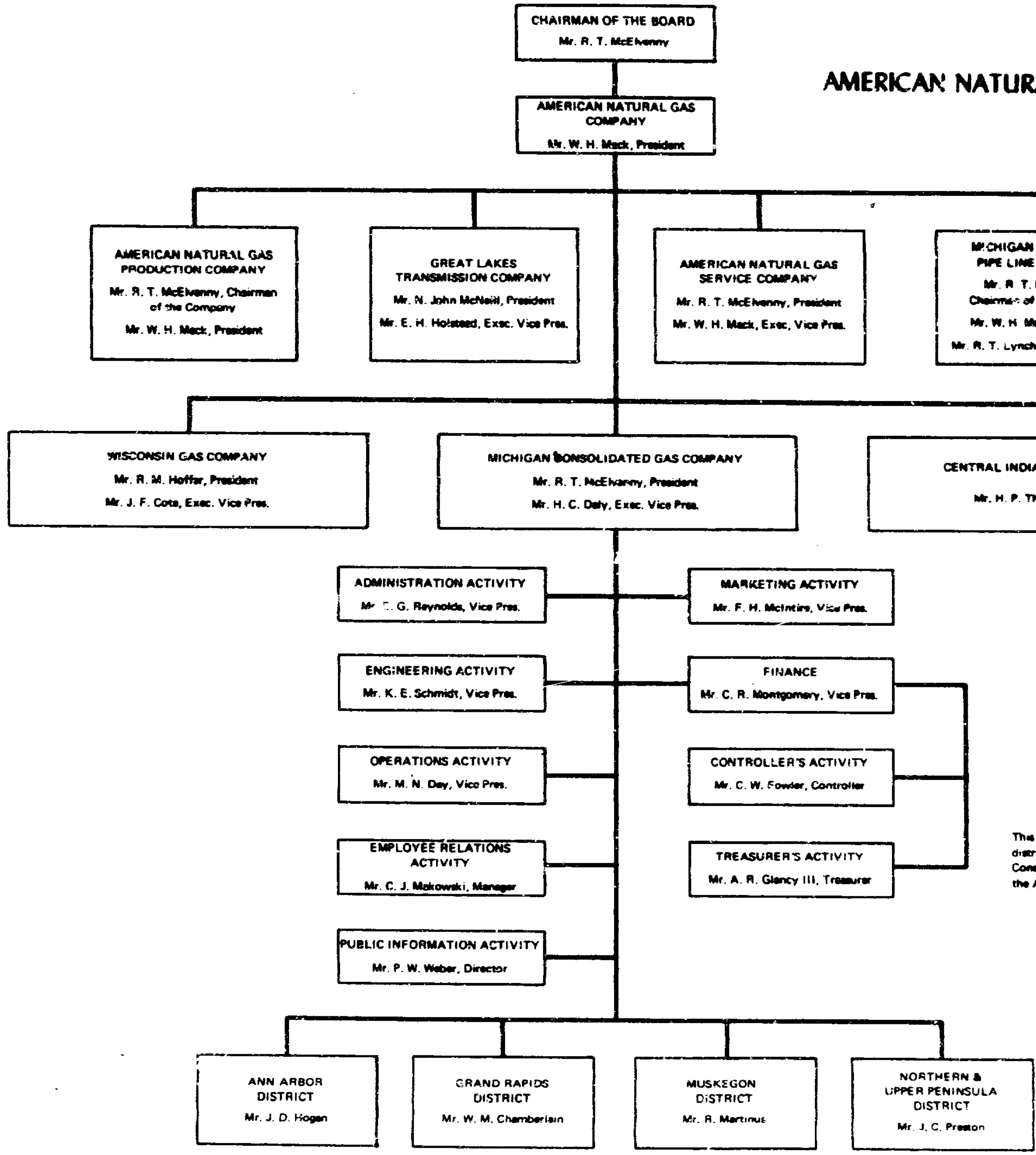
AMERICAN NATURAL GAS SYSTEM



This chart reflects the general and district management of the Michigan Consolidated Gas Company within the American Natural Gas System

Revised September 1, 1970
Employee Relations Activity
Wage and Salary Administration Division

transportation and radio communication. The skills of the selected personnel do not extend to other major activities of the Company. It is felt, however, that the developed survival rate is applicable to other groups of employees and departments and enable conclusions to be made as to the degree that other activities can be resumed.

Occupational Grouping of Operating Personnel for Analysis

A listing of 1,975 operating employees by departments, occupational titles and residence addresses was supplied by the Company. Included were on-duty employees of these departments by work shifts and location of operating headquarters. From these lists, 1,412 employees whose occupational skills are considered essential in postattack restoration work, but not necessarily in preattack numbers, are grouped into Company organizational units and subdivided into occupational categories shown in Table IX. The "Management" item of each operating unit in the table starts with second line supervisors and extends to and includes middle management assistant managers and superintendents of departments.

Basis of Analysis

At present, in the Detroit area, directly applicable blast and fallout basic casualty data is limited to the 434 Standard Location Areas (SLA) within the City (Reference 6). These data estimate Detroit City population overall casualties at 26.7 percent killed and 40.7 percent injured.

Inspection of residence addresses in the Company listing disclosed that 57 percent of Michigan Consolidated operating personnel live outside of Detroit city limits. Being more remote from ground zero, it is reasonable to conclude that this group of employees is subject to less casualty loss. On that basis, it appears that sufficient personnel will remain uninjured to handle emergency repairs and to operate the postattack system in its reduced size.

A casualty determination, however, to be usable for estimating time to complete minimum repairs to the system should survey all selected qualified operating manpower irrespective of

Table IX—Postattack Gas System Restoration Personnel by Occupational Categories
Michigan Consolidated Gas Company

Company Organizational Unit and Postattack Function	Occupational Category	Category Identification Number
1. Operation Activity		
(a) Street Dept. distribution repair and maintenance	Management	1
	Supervisors	2
	Street Leaders, Dispatchers & Helpers	3
	Pressure Operators	4
	Equipment Operators & Welders	5
(b) Service and Metering restoration of gas service on customer premises	Management	6
	Supervisors	7
	Servicemen, Service Dispatchers, Carpenters and Plumbers	8
(c) Gas Distribution station operation and pressure control	Management	9
	Supervisors	10
	Plant Operators	11
	Gas Dispatchers	12
(d) Transportation vehicle maintenance	Management	13
	Supervisors	14
	Mechanics	15
2. Engineering Activity		
Distribution Design and Technical Services system capacity, radio, telephone and instrument repair, gas main purging	Management	16
	Supervisors	17
	Engineers	18
	Communication & Electronic Technicians	19
	Instrument Technicians	20
	Laboratory Technicians	21

Management consists of Assistant Managers, Superintendents, Assistant Superintendents, Supervisors of sub-departments and General Foremen.
Supervisors consist of Foremen, Section Foremen and Supervisors of field operating groups.

residence locations. To do this, the Dikewood data is used in modified form to predict casualties among employees located outside of Detroit city limits.

The analysis, which includes all selected operating employees located both within and outside of Detroit city limits, adheres to the following assumptions:

1. All off-duty employees, except those voluntarily evacuating the area, are at home at the attack warning time. They are considered to follow the general population shelter plans established in the areas. These plans, also, are assumed to be essentially the same throughout the Detroit area. On-duty employees, except as provided for in the Company's Attack Emergency Plan, will proceed on warning to the nearest NFSS shelter in the area.

2. Ten (10) percent of the Company's personnel in the Detroit District voluntarily evacuate the area (Reference 2). A further assumption is that all evacuees are unharmed. Individual evacuees are chosen by taking every tenth qualified employee from the list, regardless of his occupational category.

3. An employee injured by both blast and fallout is counted as a single casualty.

Map Plot of Operating Personnel

Residence locations of off-duty employees and places of employment of on-duty employees are plotted by occupational categories in Figure 29, a general outline of the Detroit area.

Gas Operations Personnel Casualties

Estimated casualties incurred by gas operating personnel, both in and outside of the City of Detroit, (except fallout casualties for employees outside of the City which will be estimated separately) are given in Table X. Evacuees are included in the uninjured. Further details are supplied in Table XV in Appendix C.

Table X—Casualties Among Gas System Restoration Personnel by Occupational Categories
Detroit District—Michigan Consolidated Gas Company

Category Number	Number of Employees	Casualties		Uninjured	
		Deaths	Injured	Number	Percent
1	15	–	5	10	67
2	38	3	10	25	66
3	375	56	97	222	59
4	35	4	11	20	57
5	57	7	18	32	56
6	16	1	4	11	69
7	52	4	14	34	67
8	633	67	166	400	63
9	4	–	1	3	75
10	10	1	3	6	60
11	49	11	12	26	53
12	8	1	5	2	25
13	4	–	1	3	75
14	5	–	2	3	60
15	67	15	20	32	48
16	5	–	2	3	60
17	5	–	1	4	80
18	8	–	1	7	87
19	8	–	5	3	37
20	13	–	3	10	77
21	5	–	2	3	60
Total or Average	1,412	170	383	859	61

NOTES:
Includes on and off-duty operating personnel and evacuees.
Includes casualties from blast effects irrespective of employee location in the Detroit Area.
Includes casualties from fallout for personnel within Detroit city limits.
Fallout casualties among personnel located outside of Detroit not included, see text.

Within City limits, personnel casualties from blast and fallout are derived from the Dikewood reports (Reference 6). The determinations are made by computing the percentages of killed and injured for the general population in each SLA of employee residence, followed by use of random numbers to identify whether the employee is killed, injured or uninjured.

Outside of City Limits, blast casualty percentages are obtained from curves similar to the graphs illustrated in "Development of Typical Urban Areas and Associated Casualty Curves" (Reference 8). The curves developed for the Detroit area are reproduced in Appendix C. They are smooth curves constructed from Dikewood's blast effect fatality and injury percentages in SLA's plotted against the average distance of each SLA from ground zero. After extrapolation to zero percent casualties, the curves are applicable to employees located outside of Detroit because of the close similarity of land use and type of building structures in the concentric areas surrounding ground zero.

Fallout casualties among employees located outside of Detroit cannot be determined on an individual basis from available data. No consistent relationship exists between fallout casualties and residual radiation intensity values in the SLA's. There are, however, similarities between the intensity contour patterns of the areas (inside and outside of Detroit, see Figure 29). Each has a zone of high intensity radiation with approximately equal areas of lesser values. On this basis, it is reasonable to assign to the group of employees located outside of Detroit the same number of fallout casualties incurred by employees within Detroit. This number is one death and sixty injured.

A casualty summary, which includes the foregoing fallout casualties (one death and sixty injured) is given in Table XI.

Table XI—Casualty Distribution—Gas System Restoration Personnel
Detroit District—Michigan Consolidated Gas Company

Location	Number of Personnel	Casualties—Killed and Injured				Uninjured	
		Blast		Fallout			
		No.	%	No.	%	No.	%
In Detroit	602	324	54	61	10	217	36
Outside Detroit	810	168	21	61	7	581	72
Both Groups	1,412	492	35	122	9	798	57

SECTION V
EMERGENCY MEASURES, POSTATTACK REPAIRS AND RESTORATION OF SERVICE IN THE DETROIT AREA

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GENERAL

The time interval beginning with official warning that an attack on the United States has started and ending with restoration of gas service in the postattack habitable part of the Detroit area is divided into periods identified as:

1. *Preattack Emergency Measures*—This period extends from the moment of warning of the attack until detonation of the bomb. Following the warning, the Company's emergency plan, designed to prepare the system for the attack, is activated.

2. *Postattack Emergency Measures*—This period extends from the detonation of the bomb until the measures decided necessary by the Detroit Emergency Operating Center to control the gas system are completed.

3. *Postattack Repairs and Restoration of Gas Service*—This period extends from the start of emergency repairs until gas service is restored in the remaining habitable part of the area.

PREATTACK EMERGENCY MEASURES

Michigan Consolidated's nuclear attack emergency plan, issued in 1962, provided for dispersal of mobile equipment, the designation of postattack operating centers and the assignment of duties by location to supervisory personnel.

Specifically, the plan stipulated that Willow, Northeastern and Northwestern Stations would be the postattack operating headquarters and that Detroit District mobile equipment (trucks, compressors, arc machines, etc.) would be relocated at these three stations.

It was recognized, at the time, that defensive measures to prepare the gas system for an attack and for its control, if damaged, also are needed. It was felt, however, that formulation of such measures could be deferred until the need was more urgent and thus be based on the current status of the system.

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The Company believes that under the circumstances of this hypothetical attack (Reference 2) defensive action with respect to the distribution system would have taken the form of:

1. reducing operating pressures consistent with an estimated lower load on the system following the warning.

2. providing means at a location outside of Detroit for complete shut down of the distribution system, if necessary.

To secure single point control, the plan requires that gas supply into Detroit District would be cut back to a single station—Northwestern—by shutting down and valving off the remaining City Gate Stations. Northwestern is located in a non-industrial area nearly 20 miles from downtown Detroit. It is easily capable of supplying at reduced pressure the "pilot light" load of about 4.5 MMCFH remaining on the system after industry shuts down and other users turn off appliances. To protect employees remaining on duty at Northwestern, a stocked, underground shelter is built on the property. It is equipped with gas pressure and volume recorders for operating guidance, radiation monitoring instruments and radio for communicating with the Detroit Emergency Operating Center. In addition, control piping employing gas pressure for remote closure of block valves of incoming transmission mains is extended into the shelter from a front gate location. These valves and apparatus for remote operation antedate nuclear attack planning, having been installed in 1960 as a station safety feature.

Activation of Emergency Plan

When notified that an attack has started, Gas Dispatch instructs station operators to complete the following predetermined elements of the plan before leaving for public shelter:

1. *River Rouge Station*—Shut off Panhandle Eastern gas at C 50 valve and place in operation #1A and Glenwood regulators at 80 psig outlet pressure. Notification of Panhandle Eastern is not required; it is aware of the action that will be taken by Michigan Consolidated.

2. *Willow Station*—Shut off the 30 and 36 inch Van Born & Van Born Parallel mains. Continue to let incoming Michigan-Wisconsin gas flow to storage via the Milford-Austin Detroit transmission mains. By-pass the Willow gas processing plant and shut it down.

3. *Northwestern Station*—Shut off the 24 inch—"A" Line incoming to the station and drop outlet pressure in the 24 inch, 26 inch and 30 inch mains supplying Detroit to 150 psig. This station has its own underground shelter and also controls the unmanned Northeastern Station.

4. *Milford-Detroit-Austin Transmission System*—No specific precautions are considered necessary for this transmission system. Its mains contain automatic valves capable of isolating any section experiencing catastrophic damage.

5. *Coolidge Station*—Reduce pressure in the Crosstown main from 200 to approximately 100 psig. (Accomplished by remote operation from the Dispatcher's office.*)

6. *Evergreen Station*—Reduce outgoing pressures to 100 psig. (Accomplished by remote operation from the Dispatcher's office.*)

7. *Lynch Station*—Shut down the operating compressor and isolate it and the East Outer Drive main (Northeastern Station and Belle River transmission main) from the distribution system.

8. *Belle River Mills*—Stop injection into the storage and isolate the station from the Belle River transmission main.

9. *Other Remotely Controlled Regulators*—Reduce to permissible minimum pressures.

*Located at One Woodward Avenue, Detroit.

POSTATTACK EMERGENCY MEASURES

The effects of the blast (0.7 psi overpressure and less than 70 mph wind) neighter damages Northwestern Station facilities or harms the operators. About thirty minutes later the station reports to E.O.C. that the gas pressure and flow meters indicate no change in the Detroit-Austin pipeline system, but show a rising rate into Detroit.

In the meantime at the Emergency Operating Center, also unaffected by the blast,* advantage is taken of the low radiation intensity to make a visual survey from the shelter's entrance. Nearby structural damage to apartments along Whitmore Avenue and reflection of fires are noted.

A second report from Northwestern Station a little later predicts that the flow rate into Detroit, now at about 13 MMCFH, will level out at about 16 MMCFH. Additional reports, beginning to be received from Civil Defense shelters in other parts of the area, report widespread structural damage and high radiation values indicating a surface burst.

Based on these observations and the following considerations, decision is made to shut down the gas distribution system:

1. The 16 MMCFH rate in the 300 psi Transfer system downstream from Northwestern Station indicates that these facilities are operating at maximum capacity in response to extensive damage to the distribution system and gas loss therefrom. See Appendices D and F.

2. In view of reports of substantial amounts of residual radiation, there is a feeling that the delay and elapsed time before emergency repairs can be completed will be too long to permit that volume of gas loss to continue.

*Overpressure is 3.3 psi; station is designed for 100 psi.

3. The alternative to a complete shutdown, namely to throttle at Northwestern to reduce gas loss to an acceptable amount, would not maintain minimum operating pressures in the undamaged areas. The reduced volume would preferentially channel to the points of major damage.

Northwestern is instructed to shut down the supply into Detroit. It is accomplished from the shelter by remote operation of the block valves. The shutdown operation is complete about one hour after detonation of the bomb and cuts off gas supply to the entire Detroit District distribution system with its preattack 685,200 customers.

Time for System to Depressure

Pressure in the Detroit District distribution system declines to zero gauge in 85 minutes after shutdown at Northwestern, see Appendix D.

POSTATTACK REPAIRS AND RESTORATION OF GAS SERVICE IN DETROIT DISTRICT

The low intensity of 0.1 R/hr of residual radiation after 28 hours* along the western border of the fire area permitted inspection as soon as fire spread had stopped. Based on the findings, Michigan Consolidated decided to isolate and not to return to immediate service that part of the distribution system coinciding, in general, with the area devastated by blast and fire.

The high level of 22 R/hr of residual radiation after 28 hours along the eastern boundary of the fire zone delayed exploration and selection of a separation boundary in that area for a week.

The two parts of the system, west and east of Detroit, wherein gas service is fully restored in the immediate postattack period, together with the shutdown area, are shown in Figure 27. The restored areas include all sub-areas in units of one square mile where surviving buildings are 5 percent or more of the original number, Reference 7.

*Intensities after decay from values shown in Figure 30.

The west side area is resupplied from Northwestern and Willow Stations via connecting Beech-Daly, Van Born and Pardee mains. East side supply is brought in from Northeastern Station via the portion of the 7 Mile main east of its intersection with the Outer Drive main.

The not restored area covers nearly all of the City of Detroit together with parts of adjoining communities.* The grid and Transfer systems therein will remain inoperative for an indefinite period in the future as an integrated system. Although the underground gas facilities sustain damage, especially as ground zero is approached, continued shutdown is mainly because buildings and need for gas service are wiped out by the blast and fire except for the small minority of surviving buildings.

Table XII gives statistics of the areas wherein both the grid and Transfer systems are restored to service and the required isolating operations:

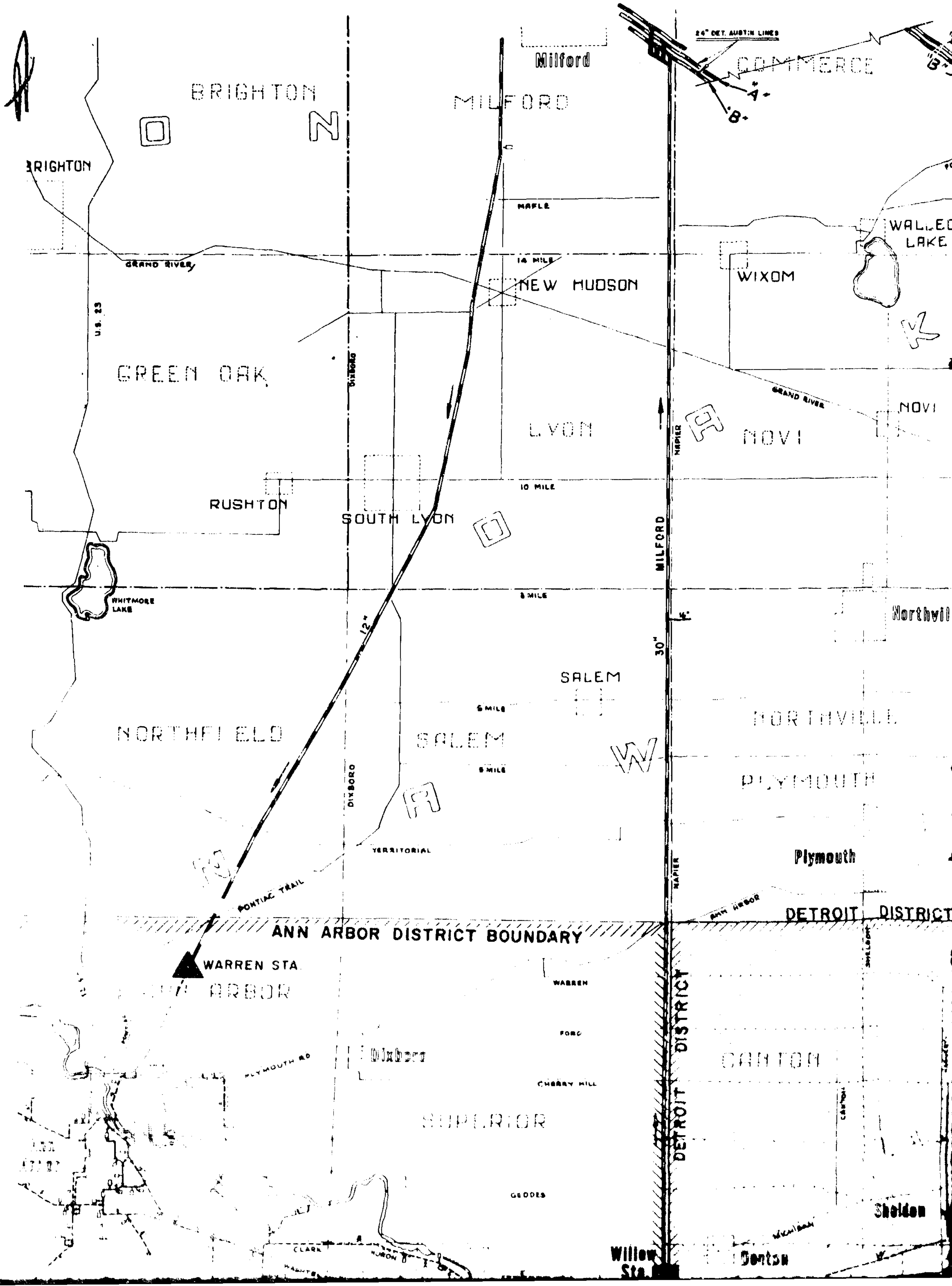
Table XII—Postattack Areas and Numbers of Customers Restored to Gas Service

Area	West of Detroit	East of Detroit
Square miles	328	4
Number of customers	87,135	5,188
Number of services	75,116	4,472
Mains cut and capped:		
cast iron	7	6
steel	54	–
Services cut and capped	2,253	223
Valves and regulators shut off	196	24

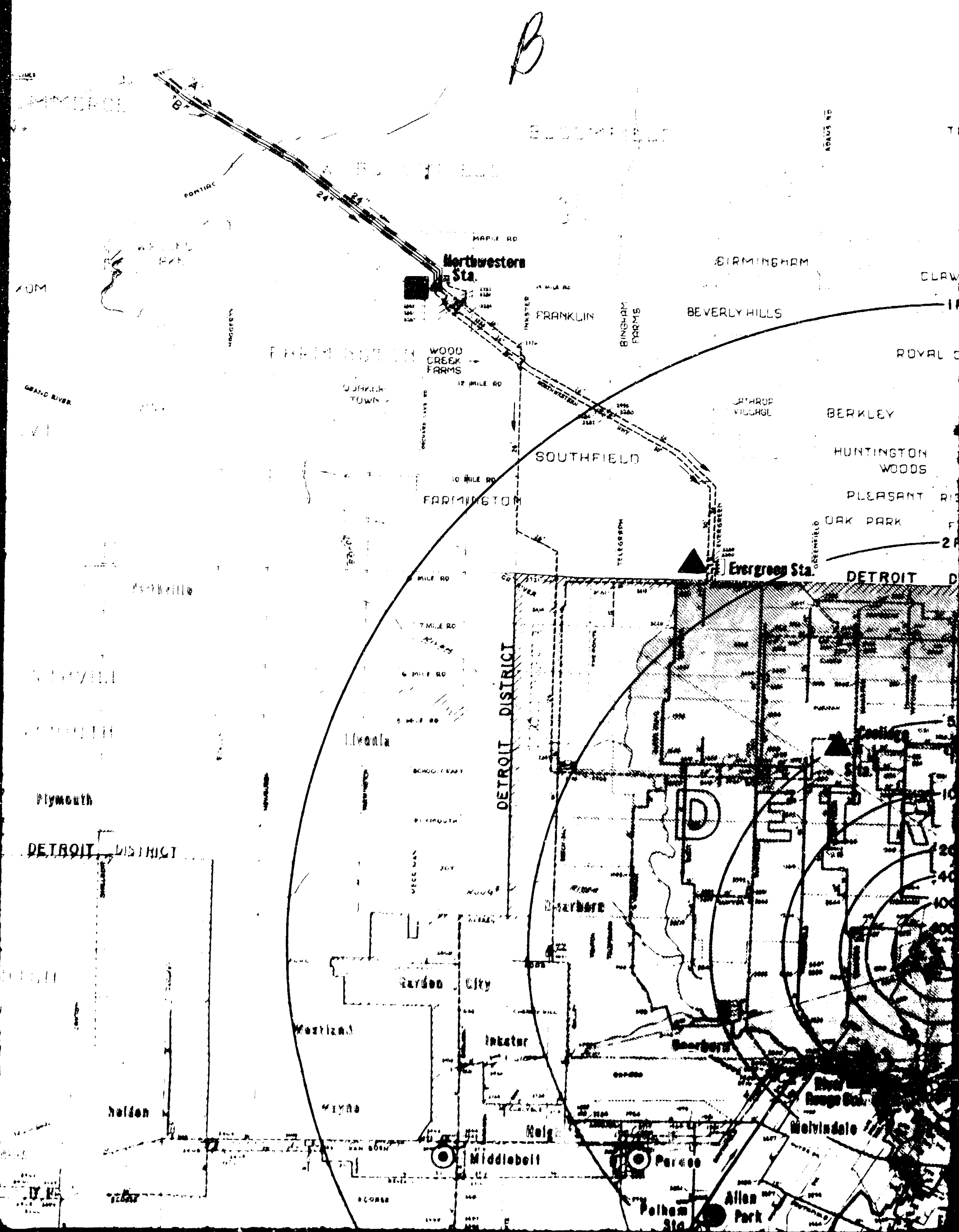
Time Required to Restore Gas Service in the Postattack Areas

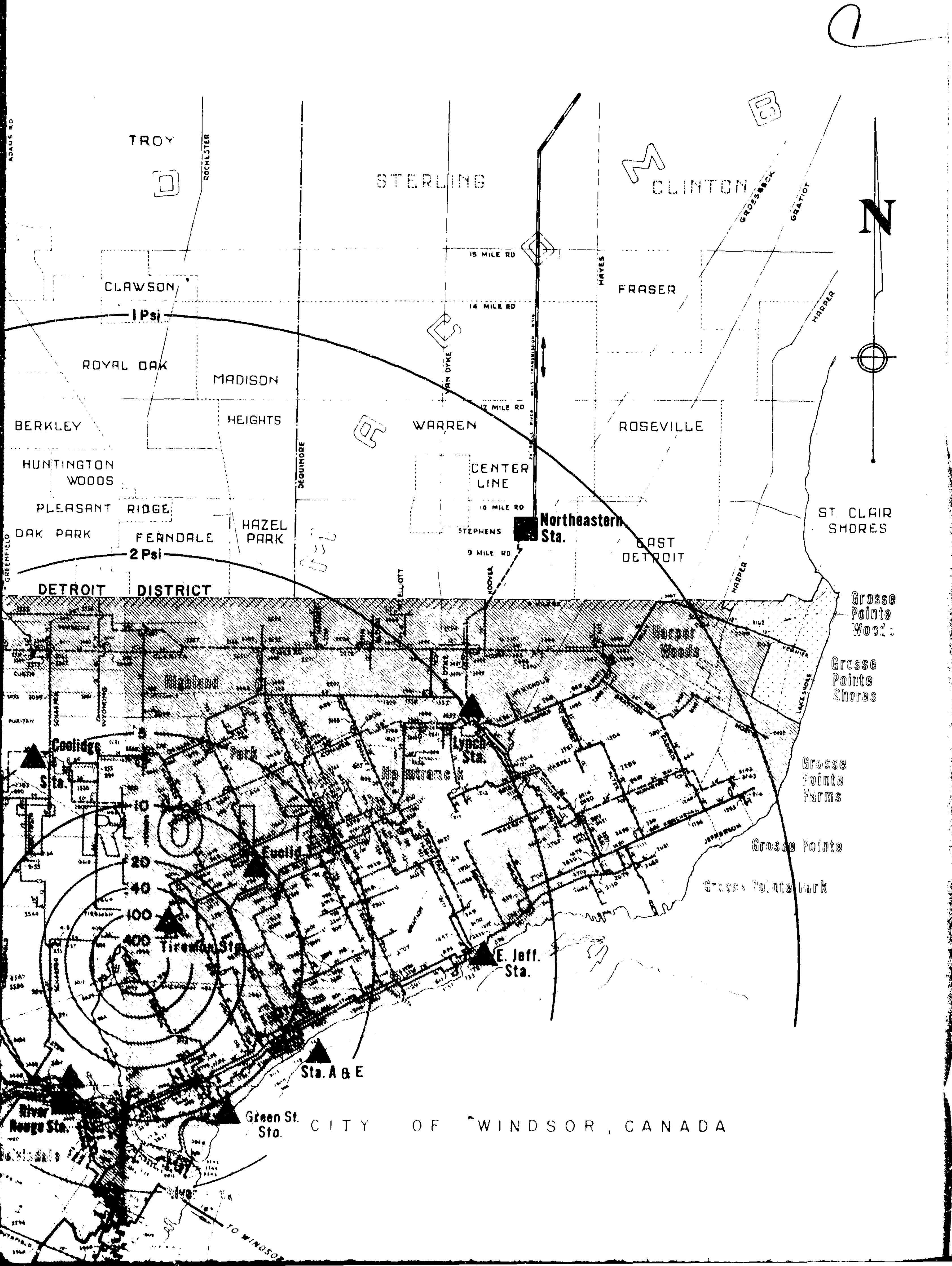
The overall time required to isolate, purge and repressure the distribution system serving the west side area and for Company servicemen to relight gas appliances in customers' premises is

*The area of fire spread extends about 3 1/2 miles north of Eight Mile Road by 17 miles laterally in Consumers Power gas franchise area. There are 131,200 gas customers in the affected area. Destroyed premises are estimated at 80,500, Reference 7. Damage to Company gas facilities on the premises will be burned out regulators, meters and melted or warped service valve cores. Leakage could reach 96 MMCFH if the system can maintain normal service pressure. The action taken by Consumers Power to handle the situation is not determined in this study.

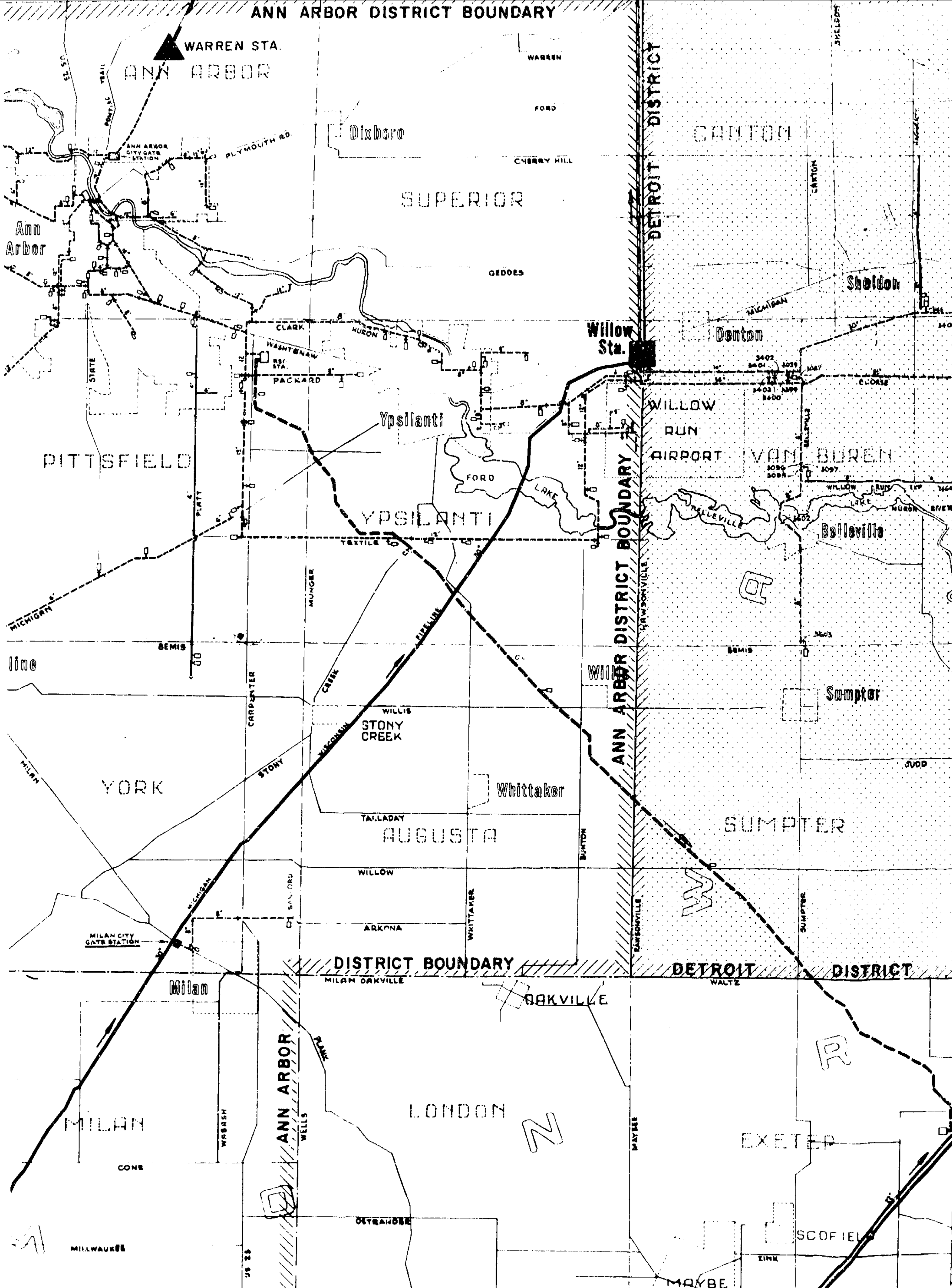


24" DET. AUSTIN LINES
Milford
BRIGHTON
MILFORD
COMMERCE
"A"
"B"
BRIGHTON
MAPLE
WALLED LAKE
14 MILE
GRAND RIVER
NEW HUDSON
WIXOM
U.S. 23
GREEN OAK
DIXBORO
GRAND RIVER
NOVI
LYON
NAPIER
NOVI
10 MILE
RUSHTON
SOUTH LYON
MILFORD
WHITMORE LAKE
8 MILE
Northville
12"
30"
SALEM
6 MILE
NORTHFIELD
SALEM
5 MILE
NORTHVILLE
PLYMOUTH
DIXBORO
TERRITORIAL
Plymouth
PONTIAC TRAIL
NAPIER
ANN ARBOR
DETROIT DISTRICT
ANN ARBOR DISTRICT BOUNDARY
WARREN STA.
ARBOR
WARREN
SHELDON
DETROIT DISTRICT
FORD
Dixboro
PLYMOUTH RD
CANTON
CHERRY HILL
SUPERIOR
GEDDES
Sheldon
CLARK
Willow Sta.
Denton

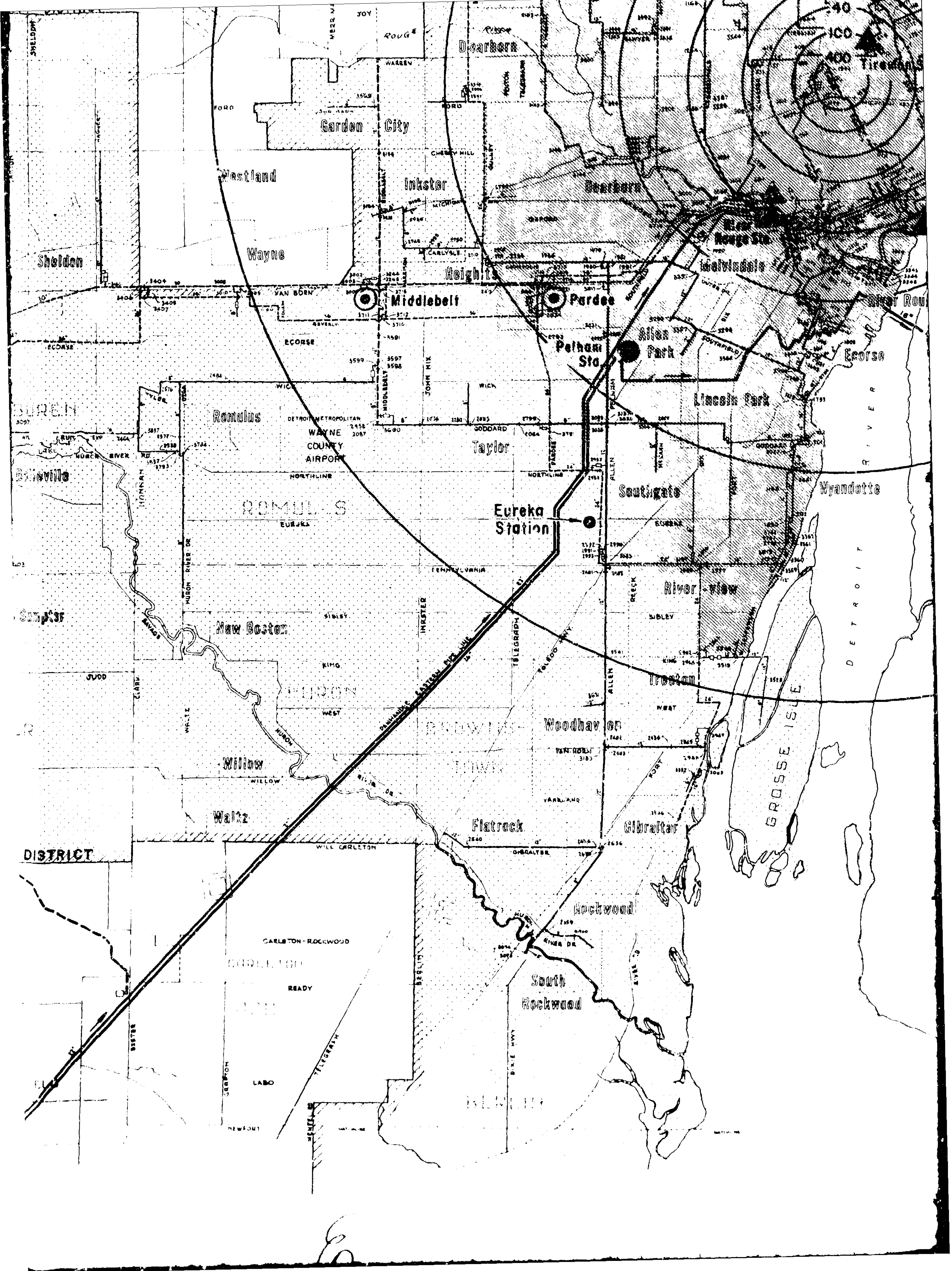

B
Northwestern Sta.
MAPLE RD
BIRMINGHAM
FRANKLIN
BINGHAM FARMS
BEVERLY HILLS
ROYAL O
WOOD CREEK FARMS
12 MILE RD
LATHROP VILLAGE
BERKLEY
SOUTHFIELD
HUNTINGTON WOODS
PLEASANT RI
10 MILE RD
FARMINGTON
OAK PARK
TELEGRAPH
GREENFIELD
EVERGREEN
Evergreen Sta.
DETROIT
7 MILE RD
6 MILE RD
DETROIT DISTRICT
Livonia
Plymouth
DETROIT DISTRICT
Dearborn
Garden City
Westland
Inkster
Wayne
Melvindale
Middlebelt
Pardee
Allen Park
Pelham Sta.
GRAND RIVER
PONTIAC
ADAMS RD



TROY
STERLING
CLINTON
N
CLAWSON
FRASER
15 MILE RD
14 MILE RD
1 Psi
ROYAL OAK
MADISON
HEIGHTS
BERKLEY
WARREN
ROSEVILLE
HUNTINGTON
WOODS
CENTER
LINE
PLEASANT RIDGE
10 MILE RD
Northeastern
Sta.
OAK PARK
FERNDALE
HAZEL
PARK
STEPHENS
9 MILE RD
EAST
DETROIT
ST. CLAIR
SHORES
2 Psi
DETROIT
DISTRICT
Grosse
Pointe
Woods
Harper
Woods
Grosse
Pointe
Shores
Highland
Coolidge
Sta.
Lynch
Sta.
Grosse
Pointe
Farms
Grosse Pointe
Euclid
Tireman Sta.
E. Jeff.
Sta.
Sta. A & E
River
Rouge Sta.
Green St.
Sta.
CITY OF WINDSOR, CANADA
TO WINDSOR
ADAMS RD
ROCHESTER
GROESBECK
GRATIOT
HARPER
HAYES
VAN DYKE
DEQUINDRE
HOOVER
ELLIOTT
GREENFIELD
5
10
20
40
100
400



ANN ARBOR DISTRICT BOUNDARY
WARREN STA.
ANN ARBOR
Ann Arbor
ANN ARBOR CITY GATE STATION
PLYMOUTH RD.
Dixboro
WARREN
FORD
CHERRY HILL
SUPERIOR
GEDDES
DETROIT DISTRICT
CANTON
Sheldon
Willow Sta.
Denton
MICHIGAN
CLARK
HURON
WASHTENAW
PACKARD
STATE
PLATT
Ypsilanti
PITTSFIELD
YPSILANTI
FORD LAKE
TEXTILE
WILLOW RUN AIRPORT
VAN BUREN
BELLEVILLE
Belleville
ANN ARBOR DISTRICT BOUNDARY
BEMIS
line
MICHIGAN
CARPENTER
MUNGER
PIPELINE
CREEK
WILLIS
STONY CREEK
YORK
STONY
MILAN
Whittaker
TALLADAY
AUGUSTA
WILLOW
ARKONA
WHITTAKER
BUNTON
Sumpter
JUDD
SUMPTER
RAWSONVILLE
MILAN CITY GATE STATION
DISTRICT BOUNDARY
DETROIT DISTRICT
MILAN OAKVILLE
WALTZ
Milan
OAKVILLE
ANN ARBOR
PLANK
WABASH
WELLS
LONDON
MAYBEE
EXETER
MILAN
CONE
OSTRANDER
MILLWAUKEE
US 23
SCOFIELD
MAYBE
DRY
HEISS



Dearborn
Garden City
Westland
Inkster
Wayne
Sheldon
Heights
Middlebelt
Pardee
Dearborn
New Rouge Sta.
Melvindale
River Rouge
Allen Park
Pelham Sta.
Ecorse
Lincoln Park
Romulus
DETROIT METROPOLITAN
WAYNE COUNTY AIRPORT
Taylor
Belleville
Southgate
Eureka Station
Wyandotte
Riverview
Sumpter
New Boston
Trenton
DETROIT RIVER
GROSSE ISLE
Woodhaven
Willow
Waltz
Flatrock
Gibraltar
DISTRICT
Rockwood
South Rockwood
CARLETON - ROCKWOOD
VAN BORN
ECORSE
WICK
GODDARD
NORTHLINE
EUREKA
PENNSYLVANIA
SIBLEY
KING
WEST
WILLOW
WILL CARLETON
GIBRALTER
TELEGRAPH
INKSTER
ALLEN
FORT
READY
LABO
NEWPORT

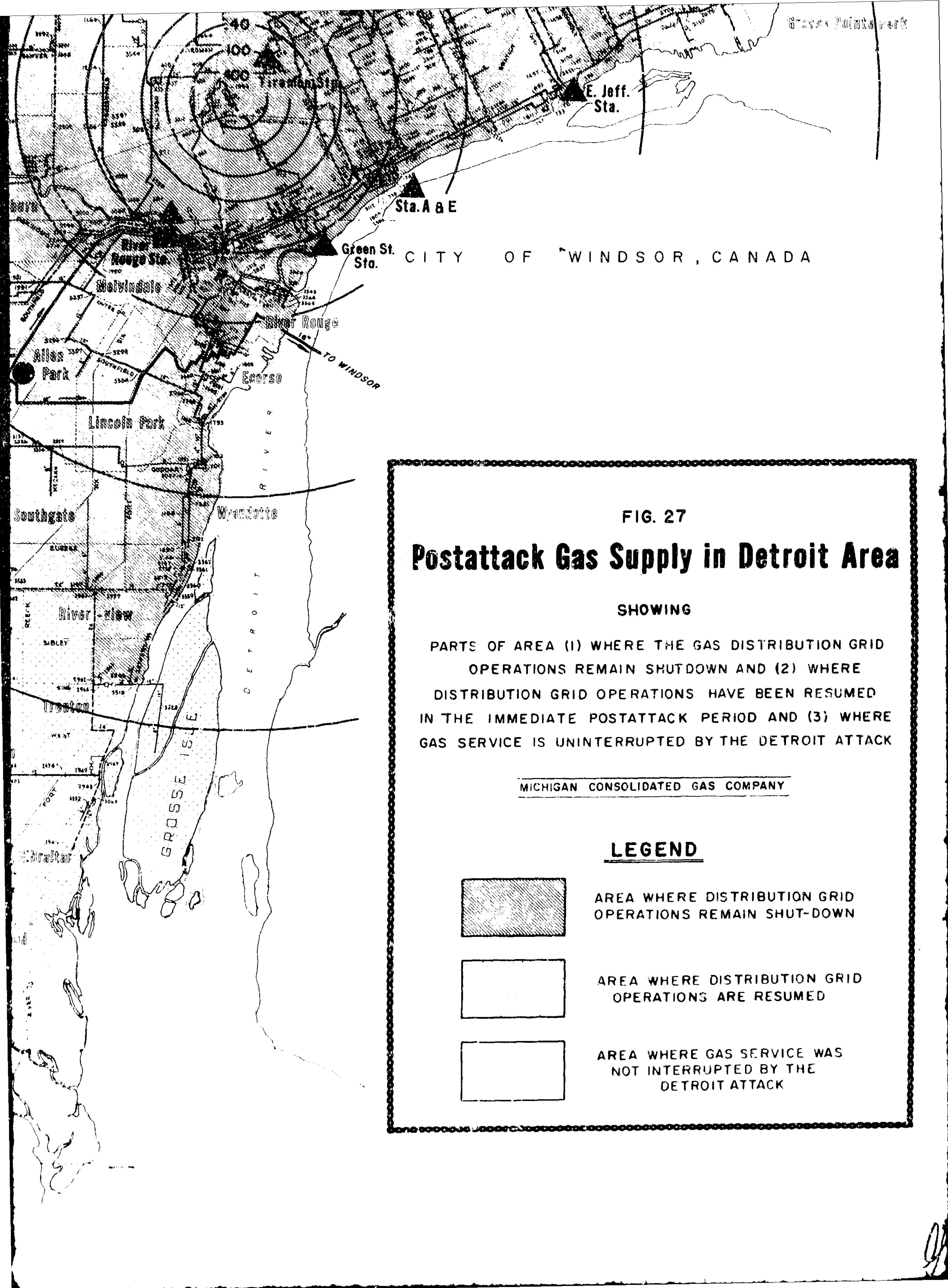


FIG. 27

Postattack Gas Supply in Detroit Area

SHOWING

PARTS OF AREA (1) WHERE THE GAS DISTRIBUTION GRID OPERATIONS REMAIN SHUTDOWN AND (2) WHERE DISTRIBUTION GRID OPERATIONS HAVE BEEN RESUMED IN THE IMMEDIATE POSTATTACK PERIOD AND (3) WHERE GAS SERVICE IS UNINTERRUPTED BY THE DETROIT ATTACK

MICHIGAN CONSOLIDATED GAS COMPANY

LEGEND

AREA WHERE DISTRIBUTION GRID OPERATIONS REMAIN SHUT-DOWN

AREA WHERE DISTRIBUTION GRID OPERATIONS ARE RESUMED

AREA WHERE GAS SERVICE WAS NOT INTERRUPTED BY THE DETROIT ATTACK estimated by Michigan Consolidated to require a span of 39 ten to twelve hour working days after start of the work and with all work being done in accordance with its standard practices.

Operable appliances progressively become available to householders beginning about nine days after start of the work. Work in the east side area, delayed for two weeks by residual radiation, is carried on concurrently and completed 25 days after start in the west side.

The unit field operations necessary to restore gas service and the amounts of time to complete each one, using restoration personnel to best advantage, are shown graphically in Figure 31 in Appendix E.

RESTORATION OF SERVICE TO INDIVIDUAL ESTABLISHMENTS IN THE POSTATTACK AREA SHUT DOWN INDEFINITELY

The numerous high and intermediate pressure mains comprising the Transfer system network in the isolated area shut down indefinitely, particularly the portion outside of the 20 psi overpressure radius where cast iron as well as steel facilities are not likely to be damaged significantly, will enable early reinstatement of gas service to be made to surviving important establishments located therein. This is possible because most substantial users of gas are supplied from intermediate pressure mains rather than from the grid. Generally, valving and purging with only a minimum of cutting and capping are necessary to reach the locations even though the surviving buildings may be located deep within the shutdown area.

Examples of the use of Transfer mains and the resupply of eight hospitals are shown in Table XVI in Appendix E. These hospitals, subjected to less than 5 psi overpressure, may have use for gas as soon as it can be made available.

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MICHIGAN CONSOLIDATED DISTRIBUTION FACILITIES IN DETROIT AREA NOT SHUT DOWN

The Company's adjoining and undamaged Ann Arbor District with its 43,775 customers is unaffected by the attack and continues to receive an uninterrupted gas supply.

It is assumed in this study that a proposed program instructing householders to turn off gas supply to their premises at the service valve before taking shelter is not in effect. Thus, householders returning to their premises have immediate, full use of their appliances. See Appendix F for a general discussion of the proposed turn off proposal.

COUNTERMEASURES

The Michigan Consolidated gas supply system in the Detroit Area possesses nuclear attack defensive properties to a high degree. This favorable posture exists by virtue of (1) most distribution operating facilities are underground, (2) the Emergency Plan for dispersal of trucks, mobile tools and radio communication facilities minimizes potential damage to these categories of equipment, (3) important operating buildings are reasonably strong structurally; they are practically fireproof and generally separated by several hundred feet or more of lawn, gravel or black top from the nearest combustible buildings, and (4) there are no fire arrays, either indoors or adjacent to operating buildings, except the conventional use of combustible packaging materials and containers in storehouses.

The four City Gate and eight aboveground distribution regulating stations and one major gas main overcrossing are the few elements of the system that are plainly vulnerable. From an operating viewpoint, however, none of these facilities is truly critical in a postattack situation when considered individually:

1. *City Gate Stations.* Their multiplicity in number and miles of separation from each other virtually guarantees a supply of pressure regulated gas for postattack operation.

2. *Distribution Stations (distribution, regulation and maintenance and storehouse supplies).* The study shows that all stations, except two, experience disabling damage, yet postattack operation in the habitable areas is not significantly affected. The redundancy of pressure regulation, characteristic of gas systems, permits bypassing of the stations and reassigning regulation to upstream regulating facilities.

Damaged or destroyed supplies leading to scarcity in the postattack period, while not especially critical, would not be readily replaceable and, thus, warrant safeguarding by all practical means.

Comments and recommendations for further hardening of specific elements of the system against nuclear attack are:

1. *Cast Iron Piping.* It is plain that the underground system would be less vulnerable if replaced with steel (or plastic where practicable) and by further expansion of the policy of leak clamping bell and spigot joints. The Company is fully aware of the more resistant properties of these other pipe materials and procedures; and, in fact, has been using steel in cast iron pipe replacements for years.

A program to replace cast iron in order to harden the system against nuclear attack cannot be justified. The study indicates that the cast iron system in its present state, possesses far more resistance to damage than the aboveground facilities which it serves. To substitute steel would merely enlarge the postattack operable part of the underground system deeper into the area (towards ground zero) in which surface structures are totally destroyed and need for gas service no longer exists. Since years probably would be required to rebuild surface structures and recreate a demand for gas, there is little reason to incur expense to strengthen a system and then stand idle.

2. *Regulating Equipment in Stations.* Distribution regulators and associated control equipment are located, as a rule, in brick buildings and thus are subject to damage from building disintegration or collapse. In a few instances, major regulators are located outdoors in steel grating or plate covered concrete pits when indoor floor space was unavailable.

Regulators would be less vulnerable if located in pits, preferably grating covered, where noise is not a factor. But again, the study shows that this equipment is not indispensable in the postattack period and outdoor relocation, simply for nuclear attack hardening, is not justified. Neither is strengthening of the already strong buildings.

Accordingly, it is recommended that consideration be given to below grade location in pits for future relocations or new installations of station regulators. This location does not apply to gauge boards, telemeter or other accessory control equipment not suited for pit conditions.

3. *Storehouses and Supplies.* It is recommended that defensive measures with respect to storehouses be directed towards fire prevention. The buildings are reasonably strong (8–10 psi required for severe damage). The value to be derived from the cost of further structural strengthening is questionable, since the storehouse stock would still be salvageable even though the building is severely damaged, providing fire is not involved.

Storehouse construction is practically fireproof even with use of roofing paper and tar to waterproof the gypsum roof slabs. Storehouse supplies, however, contain appreciable quantities of cardboard, cotton uniforms, rubber, plastic, wood and other combustible materials.

Fire liability arises mainly from potential primary ignitions by fireball thermal radiation penetrating storage areas through large, clear glass window areas. Ignition from firebrands is less

...ly because of wide distances separating most storehouse buildings from the nearest combustible structures.

Fire prevention recommendations proposed for storehouses and similar buildings are pre-attack measures. They consist of the opaquing of clear glass windows or, as an alternative, the elimination of indoor materials such as window coverings, drapes, exposed paper in office sections and packaging materials, paper, cotton uniforms and other readily flammable items in warehouse sections.

4. *Overcrossings.* Sections of gas mains crossing freeways, rivers, etc., are steel and, generally, are hung in protected locations from the undersides of the steel-concrete bridging structures.

Although vulnerable to a degree, their change to underground location is not justified. The bridges are strong with respect to dynamic pressure and, in addition, the crossings, with one outstanding exception, are alternate supply routes and not the sole support for the area.

The exception is the River Rouge—Zug Island single crossing to Great Lakes Steel. Months would be required to rebuild the overcrossing structure. A submarine crossing is not feasible. Originally planned as an underwater crossing, instability of the soil of the river banks required change to overhead construction.

5. *System Shutdown.* The purpose of system shutdown, in whole or in part, following an attack is to eliminate leaking gas as a potential participant in the initiation or spread of secondary fire. Rapid release of gas stored in the system at a safe disposal point will shorten the time duration of gas leakage. It is recommended that a Company suggestion to use blow down valves at the shut-off point be added to its Emergency Plan as a potential action.

6. *Service Valve Turn-off by Householders.* It has been proposed as a countermeasure that householders turn off gas supplies to their premises at service valves in the event of an imminent

nuclear attack. The intention is to materially reduce postattack fire spread by eliminating gas leakage from damaged, gas household equipment as a potential ingredient for fire initiation.

Based on an examination of available data, it is concluded that service valve turn-off would not have been effective in lessening fire spread in the Detroit area, see Appendix F.

SECTION VI
SUMMARY

SUMMARY

The effects of a hypothetical, 5 MT surface burst, nuclear attack on the supply and distribution of natural gas by the Michigan Consolidated Gas Company to 685,200 customers in its Detroit District are investigated and evaluated.

Following the warning of an impending attack, the Company activates its Emergency Plan. Principal provisions of the Plan to prepare the system for a nuclear attack are:

1. Valve off, shut down and leave unmanned three of the four City Gate Stations normally supplying the Detroit District distribution system. The purpose is to delegate further control of gas entry into the distribution systems to a single, manned station.

2. Reduce normal operating pressures in specified high pressure distribution mains. The purpose is to minimize gas volume inventory in the distribution system.

3. Relocate trucks and major mobile equipment to be designated, less vulnerable points outside of Detroit. This element of the Plan is completed several weeks prior to the attack.

One hour after the detonation, supply to Detroit District distribution is shut off by the Company at the City Gate Station. The shutdown is made to stop gas leaking at a 16 MMCFH rate from damaged gas facilities in the distribution area. After shutdown, distribution pressure declines to zero pounds gauge in about 85 minutes.

In the immediate postattack period, a part of the Detroit District distribution system surrounding and extending out from ground zero and formerly serving 592,900 customers is not restored to service. It is isolated from the balance of the system and left shut down indefinitely, because most buildings and residences therein and need for gas fuel are wiped out by the blast and fire. The area covers 227 square miles, comprising the City of Detroit and all or substantial portions of adjoining communities.

Gas distribution operations are fully restored in two separate areas, east and west of Detroit, containing a total of 92,323 customers or 13.5% of the preattack number. Gas appliances therein are progressively returned to use by Company personnel beginning nine days after start of emergency repairs; completion is thirty-nine days later.

The separation boundaries between the distribution system parts restored and not restored to gas service follow, in general, the outer limits of severe, secondary fire damage.

Principal damage to Michigan Consolidated aboveground facilities is to buildings of regulating stations and storehouses. Losses in supplies and incapacitation of operating stations is not critical in the postattack period because the amount of system remaining to be operated is small.

The underground distribution "grid" mains in the vulnerable area are cast iron employing cement packed joints. High pressure "feeder" mains interlacing the area are either steel or leak clamped cast iron.

It is expected that the grid mains (unclamped and most vulnerable) will remain operational to at least the 20 psi overpressure radius. Distribution regulator vaults begin to experience damage at 16 psi. As an area operational limit, neither value has significance in the immediate postattack period. Both represent distances deep within the shutdown area, where need for gas service no longer exists.

Natural gas supply available for the Detroit area in the postattack period will be more than adequate. Three of the four incoming transmission systems are undamaged and capable of resuming normal deliveries. In addition, by late August, the amount of gas placed in underground storage by Michigan Consolidated will supply the reduced system for months if, for some reason, transmission deliveries cannot be resumed immediately.

The number of Detroit District uninjured personnel is ample to handle the system in the postattack period, except for a temporary shortage of certain skills during the emergency repair and repressuring operations. It is likely, although not pursued in the study, that help from other districts would offset the deficiency.

The number of undamaged vehicles is adequate at all times in the postattack period. Less than 7 percent of the truck fleet is damaged. Gasoline is not a problem in view of a nearby undamaged refinery.

Mobile radio is the sole means of communication for directing and coordinating recovery operations. Telephone facilities emanating from the General Office are damaged beyond short term repair. The two surviving base radio stations of the Company and 485 mobile, two-way radios in vehicles provide adequate coverage of the area. Adding to the flexibility is a Company-owned base station, mounted in a van type vehicle, which enables the station to be moved to any location in the area.

Gas supply to the Company's adjoining Ann Arbor District and its 43,775 customers is unaffected and uninterrupted by the Detroit attack.

Although not a study assignment, a proposed countermeasure that service valves be turned off by householders when an attack is imminent was examined. The purpose of the measure, whose effectiveness on a national basis is not yet resolved, is reduction of fire spread.

Available data indicate that the measure would not have curtailed fire spread in the Detroit area, since expected primary fires, initiated by fireball radiation, possessed capability to spread without participation of gas. The absence of gas, at the best, would be to delay fire spread in some degree, but not to limit its expansion. This suggests that, following an attack warning, a householder's limited time would be better spent in clearing rooms of articles ignitable by fireball radiation.

APPENDIX A

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ANALYSIS OF GAS REGULATOR VAULT DAMAGE BY OVERPRESSURE

Michigan Consolidated regulator vaults are shallow buried, concrete structures, their roofs being close to ground level, see Figure 28. There is, therefore, no attenuation in the attack environmental overpressure exerted on the vault roof (Reference 3, Chart #5).

The lateral pressures developed on vertical surfaces of a buried structure may be as low as 15 percent of surface overpressure in dry, well compacted silty soils, but generally are greater for most soils and may approach 100 percent for porous saturated soil (Reference 1, page 163). The percentage used in this analysis is 25, being based on the assumption that near surface, Detroit soil is compact and moderately dry. This force is in addition to passive soil pressure.

The unreinforced four inch thick, floor slab has the least flexural strength. Damage to it, however, will not nullify the vault's postattack serviceability if the walls and roof remain intact. Although the floor by itself is not necessarily a limiting factor as to the amount of overpressure that the vault will sustain, it is a controlling element in side wall resistance to lateral force.

If the floor remains intact, the side walls are treated as a slab supported on four edges:

1. **Load distribution for slab supported on four edges**

$$W_s = \frac{L}{S} - 0.5$$

where W_s = fraction of load carried by short span
L = length, long span
S = length, short span

For Vault 318E (see figure 28, page 145), W_s = 1.5 indicating computation is based on short span carrying all load.

2. **Bending moment at failure**

$$= fc \times S$$

where fc = 550 psi, tensile strength concrete
S = section modulus 228 in^3 (12" X 12" beam)

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3. **Bending moment in beam**

$$= \frac{wl^2}{8} \text{ or } \frac{p \times l^2 \times 12}{4 \times 8} \qquad \text{where } w = \frac{p}{4}$$

p = overpressure, lbs/ft^2
l = length beam, feet

4. **Overpressure at failure**

$$p = \frac{550 \times 288}{4 \times 8 \times 144} = 11{,}000^*$$

$$= 76 \text{ psi}$$

5. **Overpressure for light damage†**

$$= 0.8 \times 76$$
$$= 61 \text{ psi}$$

If the floor fails, the load on the bottom strip is transferred to the long span which is treated as a beam with two end supports:

1. **Bending moment**

$$= \frac{wl^2}{8} \times 12 = \qquad \text{where } w = \frac{p}{4} \text{ lb/ft}^2$$

l = beam length feet

2. **Overpressure at failure**

$$p = \frac{fc \times S \times 4 \times 8}{144 \times 12 \times 144} = 20.4 \text{ psi}$$

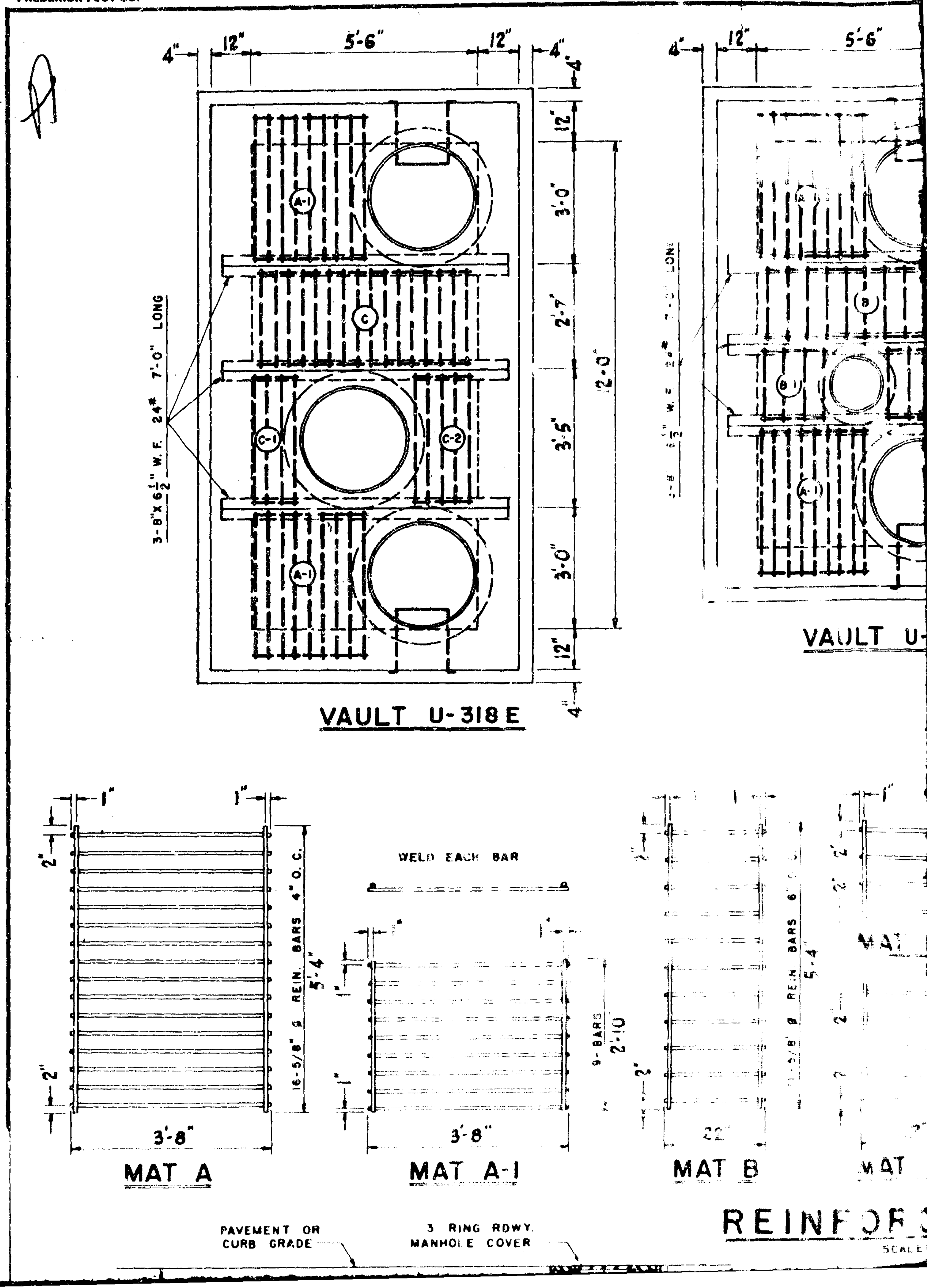
3. **Overpressure for light damage**

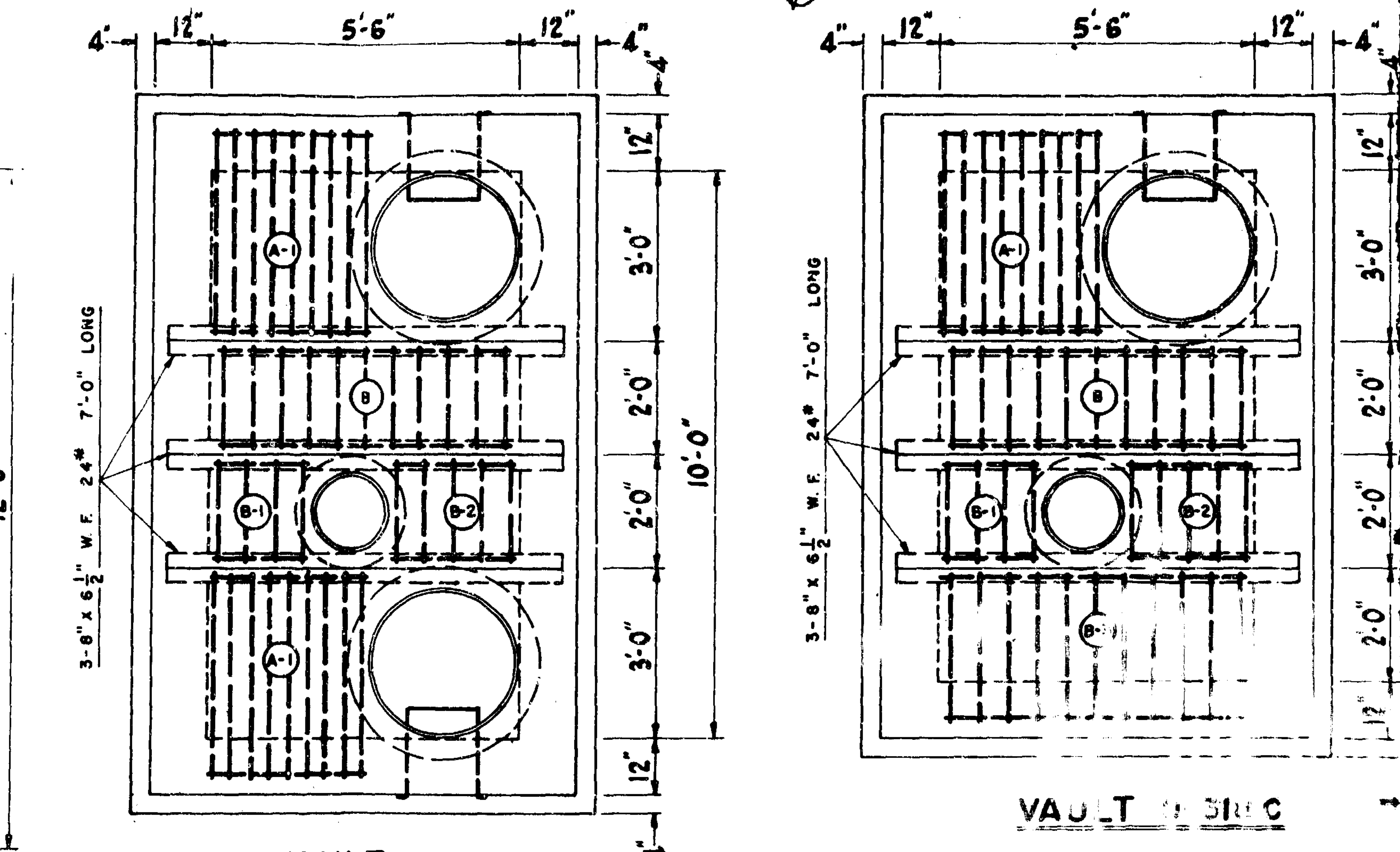
Vault 318E $= 0.8 \times 20.4$
$= 16$ psi

If both floor and side walls remain intact, the roof may be the controlling element. Roof damage from loading is directly related to the strength of the I beams.

*Passive soil pressure for Vault 318E where bottom slab 18 8 feet below grade is 11,000 in-lbs.
†Overpressure for light damage is taken as 80% of failure.

FREDERICK POST CO. 179H 500 12-60



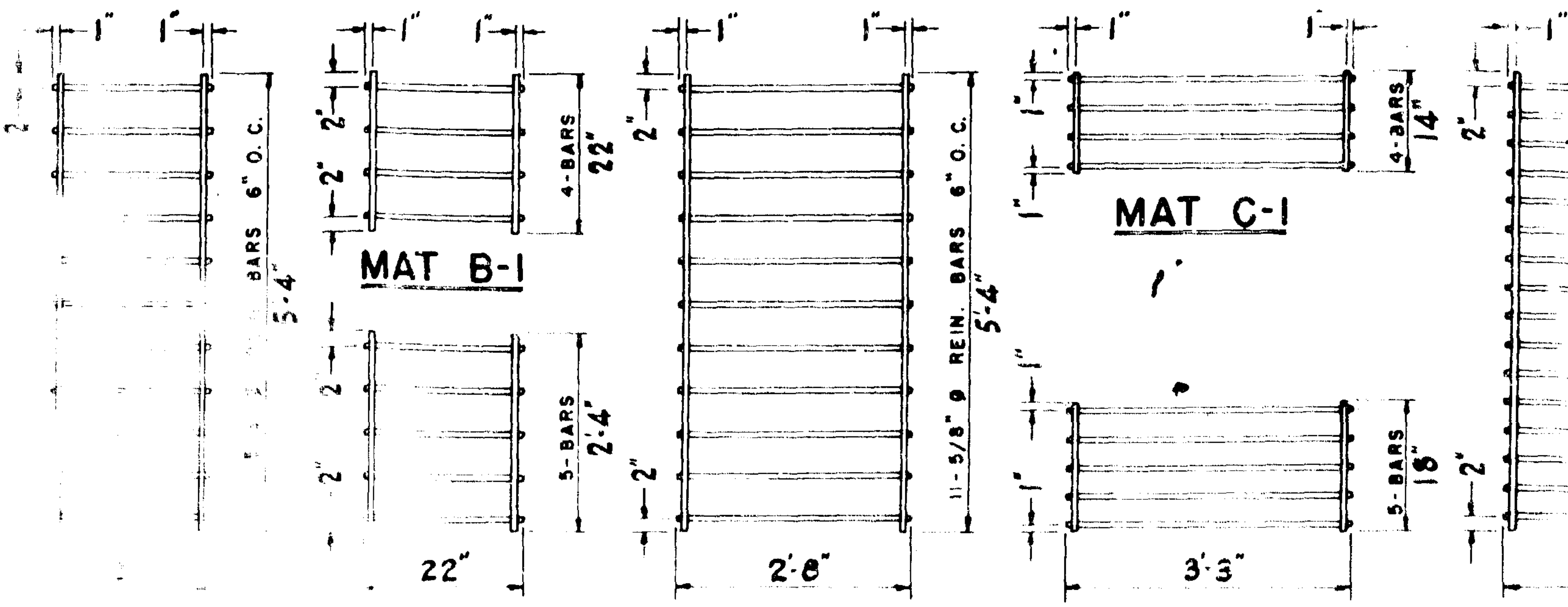


VAULT U-318D

VAULT ... C

VAULT ROOF PLAN

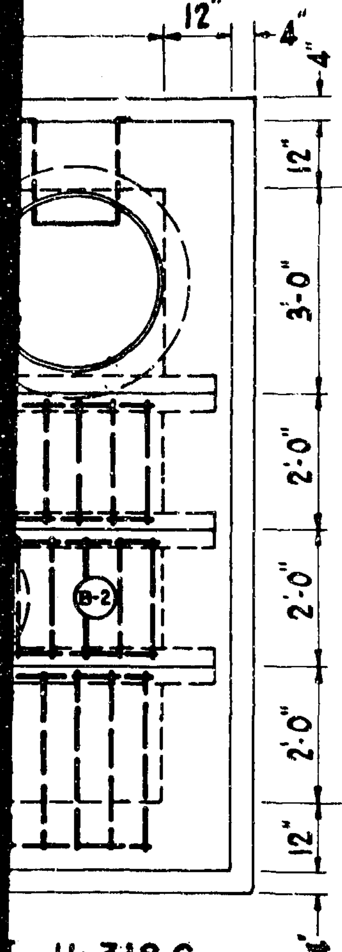
SCALE: 3/8" = 12"



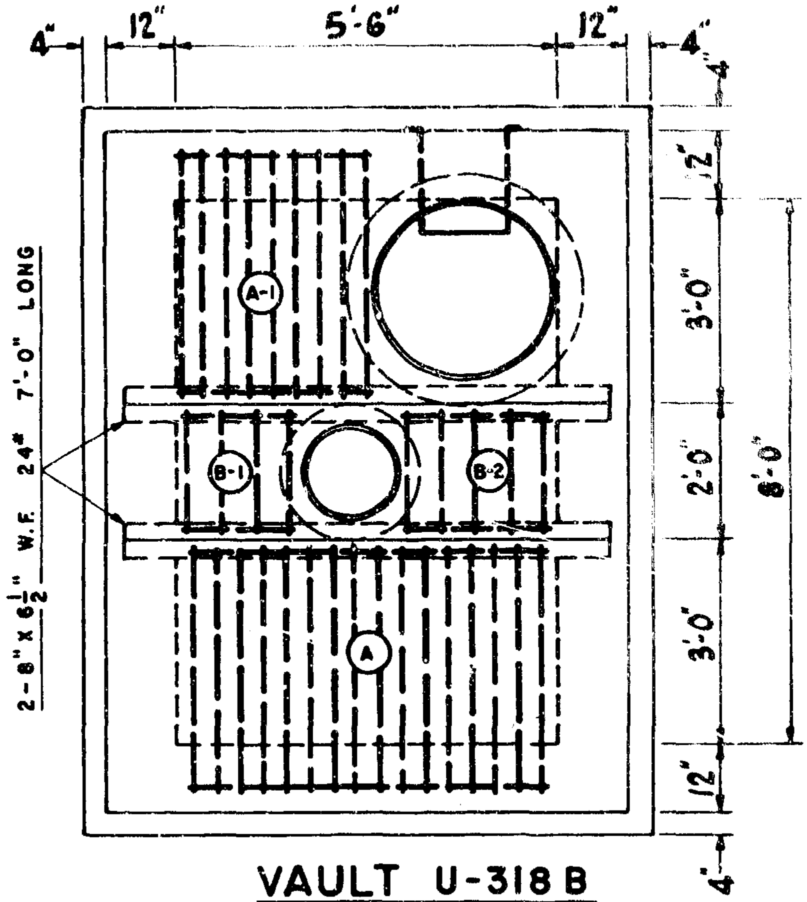
MAT B-2 MAT B-3 MAT C-2

... CING MATS

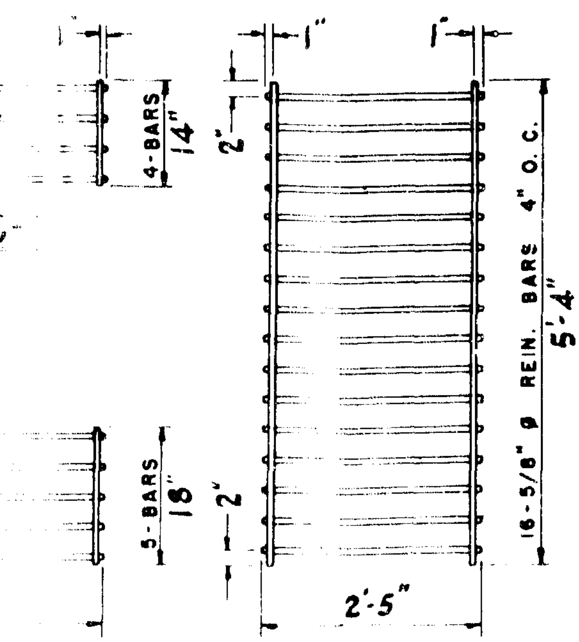
SCALE 1/2" = 12"



U-318 C



VAULT U-318 B



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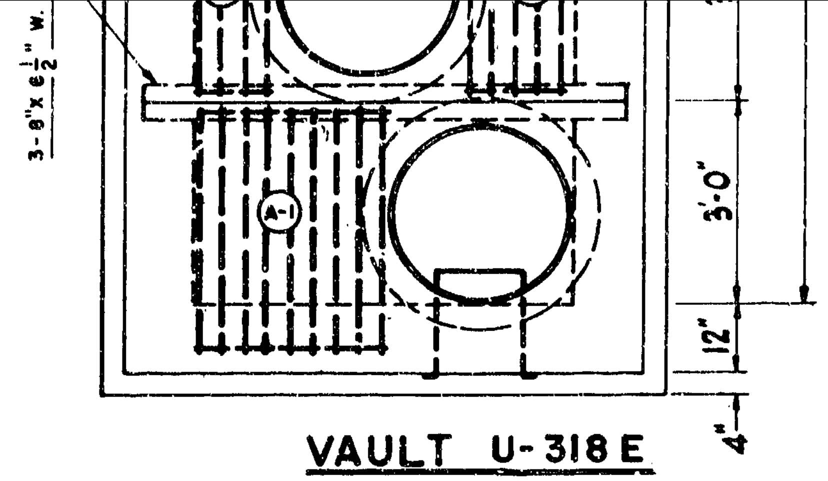
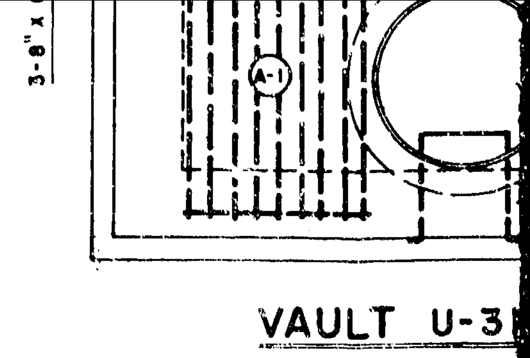
MAT C

STANDARD ITEMS FOR ALL VAULTS		
1	VAULT LADDER 6'-0" LONG	STL.
1	3 RING ROADWAY MANHOLE COVER	C. I.
1	12" SEWER CROCK (1 LENGTH)	VIT.
1	16" VALVE BOX COVER (OMIT ON VAULT	C. I.
VAULT U-318 B		
2	8" x 6 1/2" W.F. 24# 7'-0" LONG	STL.
1	REIN. MAT (A) 69'-4"	STL.
1	REIN. MAT (A-1) 38'-8"	STL.
1 EACH	REIN. MATS (B-1) 11'-0" (B-2) 13'-10"	STL.
10 1/2 CU. YDS.	CONCRETE	
28	1/2" x 12" DOWELS	STL.
	WIRE MESH 9'-0" x 6'-0" (6x6 - 6 GAUGE	STL.
VAULT U-318 C		
3	8" x 6 1/2" W.F. 24# 7'-0" LONG	STL.
1	REIN. MAT (A-1) 38'-8"	STL.
1 EACH	REIN. MATS (B) 30'-10" (B-3) 40'-0"	STL.
1 EACH	REIN. MATS (B-1) 11'-0" (B-2) 13'-10"	STL.
11 1/2 CU. YDS.	CONCRETE	
30	1/2" x 12" DOWELS	STL.
	WIRE MESH 10'-0" x 6'-0" (6 x 6 - 6 GAUGE)	STL.
VAULT U-318 D		
3	8" x 6 1/2" W.F. 24# 7'-0" LONG	STL.
2	REIN. MATS (A-1) 38'-8"	STL.
1	REIN. MAT (B) 30'-10"	STL.
1 EACH	REIN. MATS (B-1) 11'-0" (B-2) 13'-10"	STL.
12 1/2 CU. YDS.	CONCRETE	
32	1/2" x 12" DOWELS	STL.
	WIRE MESH 11'-0" x 6'-0" (6 x 6 - 6 GAUGE	STL.
1	3 RING ROADWAY MANHOLE COVER	C. I.
1	VAULT LADDER 6'-0" LONG	STL.
VAULTS U-318 E		
[illegible]	[illegible]	STL.

WORKED IN AROUND BEAMS AND REINFORCING

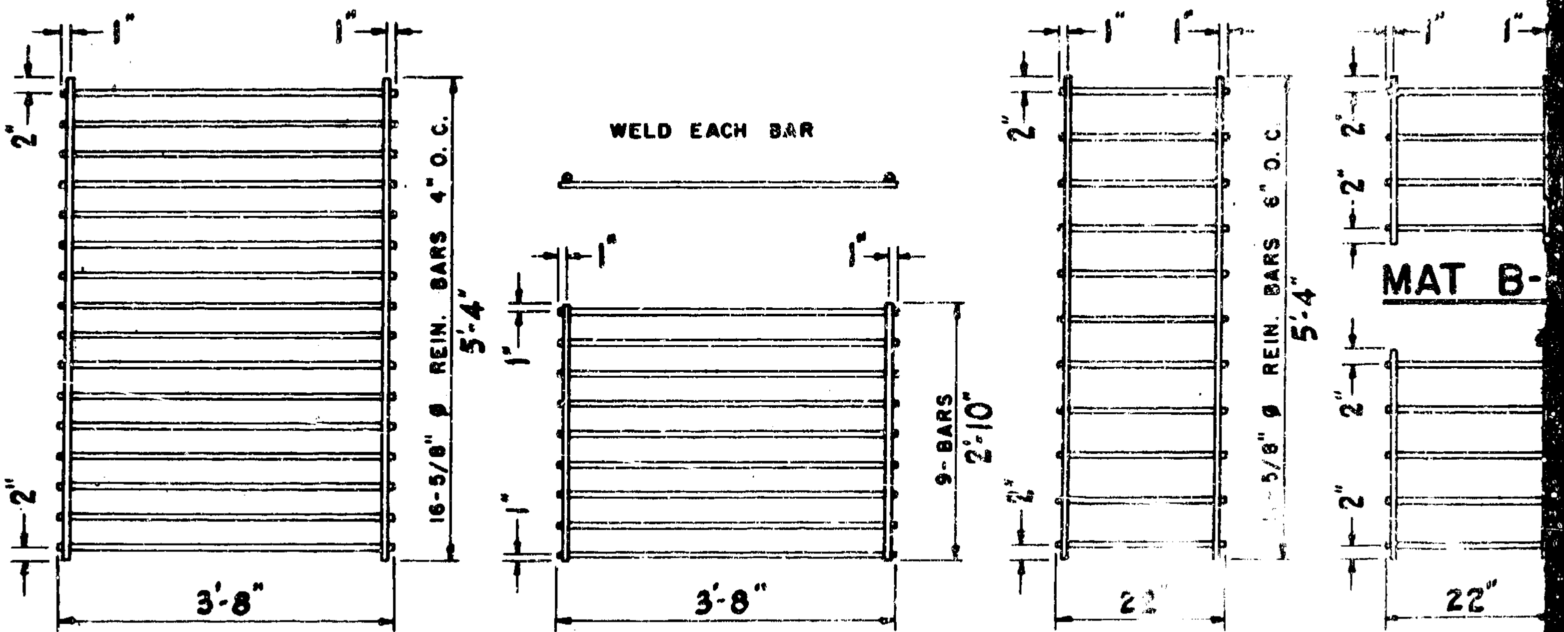


VAULT U-318 E



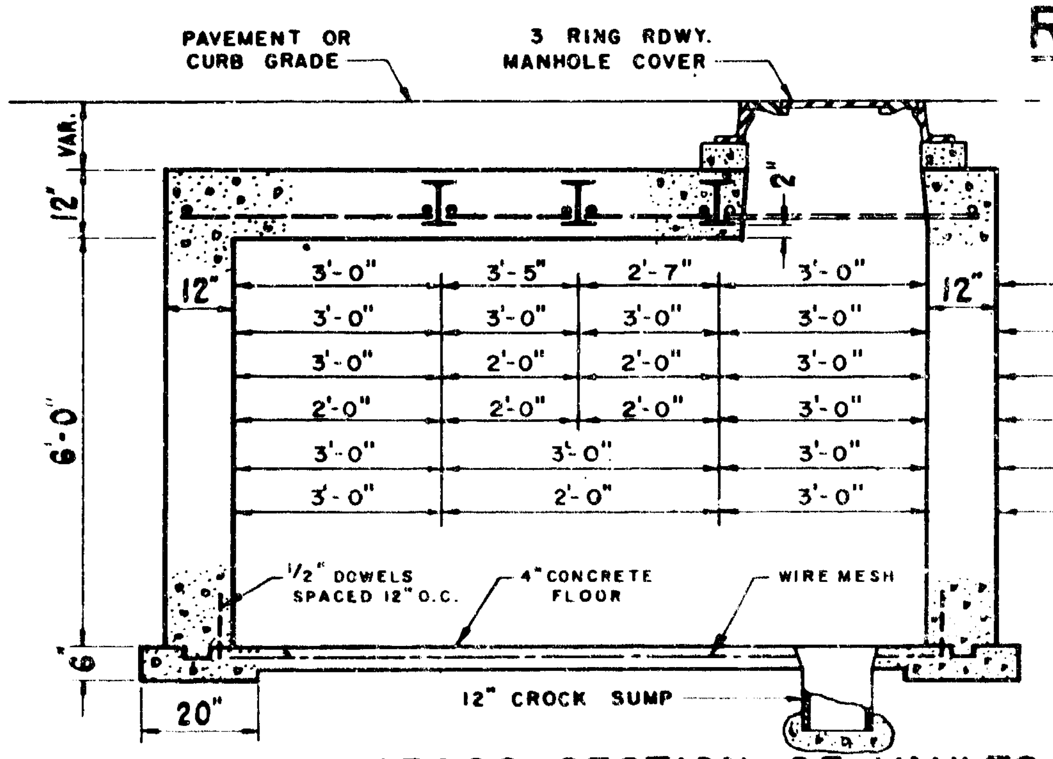
VAULT U-3

V



REINFORCI

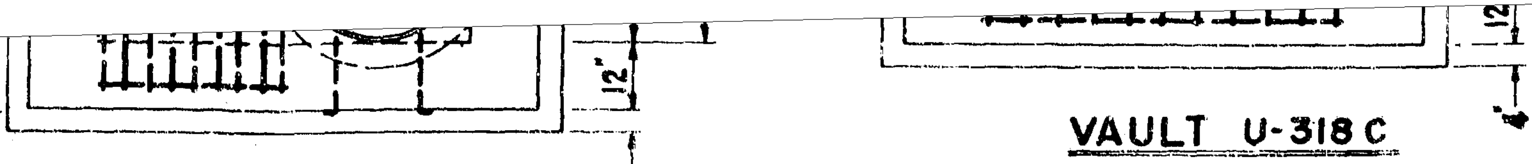
SCALE: 1/2



TYPICAL CROSS SECTION OF VAULTS

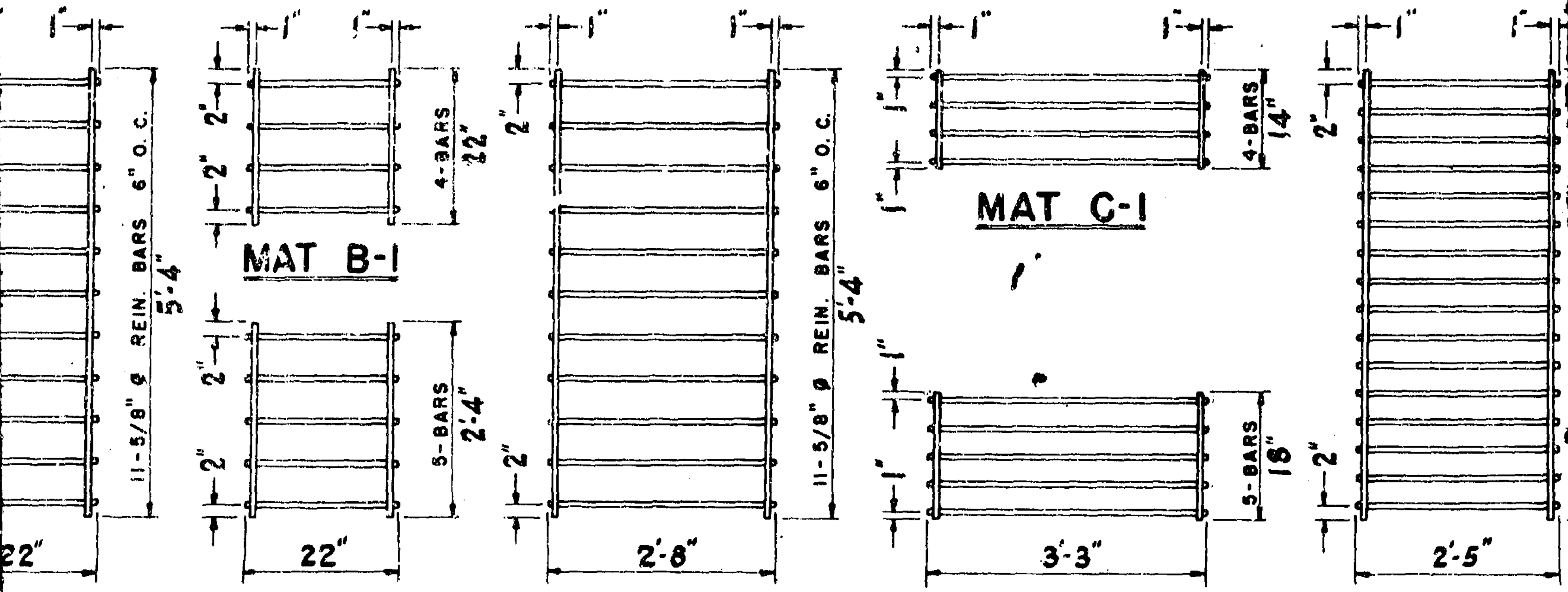
SCALE: NONE

VAULT SIZE	REGU
U - 318 E	FIS
U - 318 E	EM
U - 318 D	FIS
U - 318 C	FIS
U - 318 C	EM
U - 318 B	FIS



VAULT ROOF PLAN

SCALE: 3/8" = 12"



AT B MAT B-2 MAT B-3 MAT C-2 MAT C

REINFORCING MATS

SCALE: 1/2" = 12"

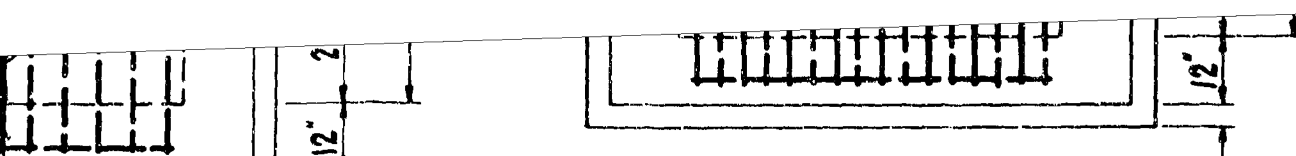
VAULT SIZE	REGULATORS
U - 318 E	FISHER
U - 318 E	EMCO
U - 318 D	FISHER / EMCO
U - 318 C	FISHER
U - 318 C	EMCO
U - 318 B	FISHER / EMCO

NOTES:

1. CONCRETE TO BE THOROUGHLY WORKED IN AROUND BEAMS AND RE MATS.
2. 3000 TEST CONCRETE TO BE USED.
3. REGULATOR MANHOLES OR BOXES ON VAULTS 1, 2 AND 3 MAY PLACED IN EITHER CENTER PANEL BY SHIFTING MATS.
4. ALL (A) AND (C) MATS 4" ON CENTER. ALL (B) MATS 6" ON CENT
5. ALL REINFORCING MATS 5/8" ø BARS.
6. USE ROADWAY TYPE MANHOLE COVERS OVER THE FOLLOWING REGU FISHER 298K (8" TO 12") FISHER 880 CLASS.
7. IF VOIDS EXIST AFTER VAULT CONSTRUCTION, GROUT PIPE INTO TH

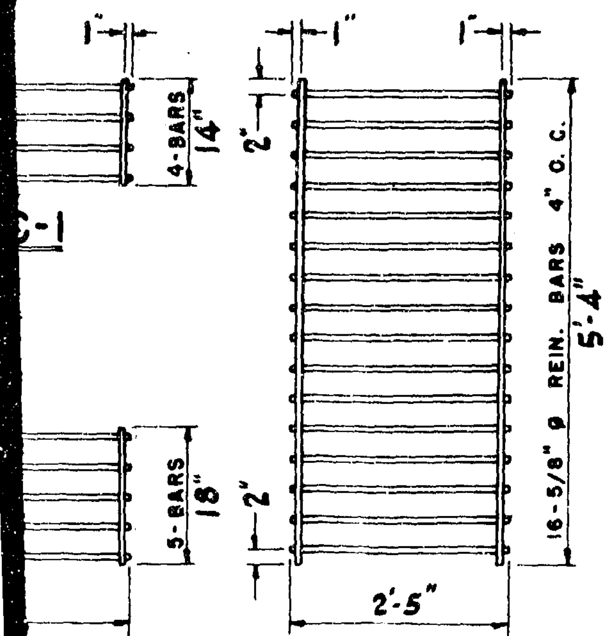
REVISIONS			REFERENCE DRAWINGS	
A				DRAWN
DATE	BY	O. K.		TRACED
B				CHECKED
DATE	BY	O. K.		O. K.
C			JOB NO.	O. K.
DATE	BY	O. K.		APPROVED
				USE DIMENSIONS ON

145



VAULT U-318 B

T U-318 C



MAT C

STANDARD ITEMS FOR ALL VAULTS		
1	VAULT LADDER 6'-0" LONG	STL.
1	3 RING ROADWAY MANHOLE COVER	C. I.
1	12" SEWER CROCK (1 LENGTH)	VIT.
1	16" VALVE BOX COVER (OMIT ON VAULT	C. I.
VAULT U-318 B		
2	8"x 6½" W.F. 24# 7'-0" LONG	STL.
1	REIN. MAT (A) 69'-4"	STL.
1	REIN. MAT (A-1) 38'-8"	STL.
1 EACH	REIN. MATS (B-1) 11'-0" (B-2) 13'-10"	STL.
10½ CU. YDS.	CONCRETE	
28	1/2" x 12" DOWELS	STL.
	WIRE MESH 9'-0" x 6'-0" (6x6 - 6 GAUGE	STL.
VAULT U-318 C		
3	8"x 6½" W.F. 24# 7'-0" LONG	STL.
1	REIN. MAT (A-1) 38'-8"	STL.
1 EACH	REIN. MATS (B) 30'-10" (B-3) 40'-0"	STL.
1 EACH	REIN. MATS (B-1) 11'-0" (B-2) 13'-10"	STL.
11½ CU. YDS.	CONCRETE	
30	1/2" x 12" DOWELS	STL.
	WIRE MESH 10'-0" x 6'-0" (6 x 6 - 6 GAUGE)	STL.
VAULT U-318 D		
3	8"x 6½" W.F. 24# 7'-0" LONG	STL.
2	REIN. MATS (A-1) 38'-8"	STL.
1	REIN. MAT (B) 30'-10"	STL.
1 EACH	REIN. MATS (B-1) 11'-0" (B-2) 13'-10"	STL.
12½ CU. YDS.	CONCRETE	
32	1/2" x 12" DOWELS	STL.
	WIRE MESH 11'-0" x 6'-0" (6 x 6 - 6 GAUGE	STL.
1	3 RING ROADWAY MANHOLE COVER	C. I.
1	VAULT LADDER 6'-0" LONG	STL.
VAULTS U-318 E		
3	8"x 6½" W.F. 24# 7'-0" LONG	STL.
2	REIN. MATS (A-1) 38'-8"	STL.
1	REIN. MAT (C) 49'-4"	STL.
1 EACH	REIN. MATS (C-1) 15'-4" (C-2) 19'-3"	STL.
12½ CU. YDS.	CONCRETE	
36	1/2" x 12" DOWELS	STL.
	WIRE MESH 13'-0" x 6'-0" (6 x 6 - 6 GAUGE	STL.
1	VAULT LADDER	STL.
2	3 RING ROADWAY MANHOLE COVERS	C. I.
AMT.	ITEM	MAT.

BILL OF MATERIAL

WORKED IN AROUND BEAMS AND REINFORCING

BE USED.

ES ON VAULTS 1, 2 AND 3 MAY BE
ANEL BY SHIFTING MATS.

CENTER. ALL (B) MATS 6" ON CENTER.

ø BARS.

COVERS OVER THE FOLLOWING REGULATORS
SHER 880 CLASS.

CONSTRUCTION, GROUT PIPE INTO THE WALL.

REFERENCE DRAWINGS	DRAWN ______	DATE ______
	TRACED ______	DATE ______
	CHECKED ______	DATE ______
	O. K. ______	DATE ______
	O. K. ______	DATE ______
JOB NO	APPROVED ______	DATE ______
	USE DIMENSIONS ONLY	

FIG. 28

STANDARD VAULTS FOR EMCO AND FISHER REGULATORS

MICHIGAN CONSOLIDATED GAS COMPANY

DETROIT DISTRICT

Damage is light until elastic limit (35,000 psi) is exceeded. Stresses above that value progressively produce more damage. Severe damage is taken to occur when I beam stress reaches 55,000 psi. Overpressure for severe damage:

1. **Weight carried by beam**

   $= 6.167 \times 3.21 \times 150 \qquad = 2{,}970$ lbs

2. **Load due to overpressure**

   $= 6.167 \times 3.21 \times 144\,p \qquad = 2{,}850\,p$

3. **Section modulus**

   $= 20.8\ \text{in}^3$

4. **Moment at failure (55,000 X 20.8)**

   $= 1{,}144{,}000$ in-lbs

5. **Bending moment**

   $$= \frac{Wl \times 12}{10} = \frac{2{,}850p \times 2{,}970 \times 6.167 \times 12}{10}$$

6. **Overpressure at failure**

   $p = 53$ psi

7. **Overpressure for light damage**

   $= 34$ psi where $fs = 35{,}000$ psi

In addition to stress induced by soil transmitted overpressure, vaults are subject to the undulating motion of ground shock. Because of their thinness, floor slabs are more vulnerable to damage therefrom than other elements of the structure. It is then reasonable to base limiting overpressure on the premise that floors will fail. These overpressures are:

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Vault Size	Light Damage Limiting Overpressure psi
U 318 B	34*
U 318 C	29
U 318 D	23
U 318 E	16

*Roof light damage overpressure is controlling for this vault.

DISCUSSION OF BELL AND SPIGOT JOINTS

No usable data exists to predict the amount of ground motion that unclamped, cement packed, bell and spigot joints in the Michigan Consolidated Detroit grid system can absorb before damage to the sealant materials results in significant leakage.

The purpose of this consideration is to see if, in general, it can be concluded that these joints will withstand the ground motion generated by 16 psi surface overpressure—the light damage limit established for regulator vaults. If so, the amount of cast iron grid system piping in Detroit returnable to postattack operation will more than service the area having repairable and ultimately usable aboveground buildings.

A test in Nevada of buried steel and cast iron pipe and an unclamped, lead caulked, bell and spigot joint reports nothing more than an insignificant leak in the joint after subjection to a 30 psi overpressure (Reference 5). It appears, though, that the pipe lengths containing the test joint lay parallel to the blast front, thereby enabling the joint to largely escape flexural stress. Furthermore, it would appear that the soil encasing the newly layed pipe in Nevada would be less compact and permit the pipe to adjust itself with less flexural stress than the compact, cohesive soil surrounding pipe for years in Detroit.

Jute packing is the main sealant against leakage in both cement packed and lead caulked joints. No significant difference is considered to exist between the two types in ability to resist development of leakage under normal conditions.

A later report (Reference 9, part 3, page 15) prepared for the Five City Study concludes, as a general observation, that ground motions generated by surface overpressures of less than 10–15 psi are unlikely to damage underground facilities of utilities, but cast iron pipe and bell and spigot joints are not specifically mentioned. It concludes further that a definite determination of an overpressure limiting value is not possible at this stage of the art because of differences in physical properties, degrees of deterioration of like items installed at equal distances from ground zero, dissimilar regional installation standards and other local influences.

In view of the absence of data applicable to cement packed, bell and spigot joints, the only course at this time for gauging damage to such joints in Detroit is to base a judgement on reasonable assumptions.

The front part of the blast wave where overpressure builds up from ambient to its peak value produces the most damaging ground motion because of its short length of about 2 feet.* The balance of the wave cycle is relatively long declining to ambient pressure in several thousand feet. A length of pipe normal to the blast front would experience maximum deflection over its length.

In Detroit, cast iron grid piping and bell and spigot joints generally are under 3-1/2 feet of 6 to 8 inch concrete paving. Pavement acts to distribute and project a concentrated force, such as a blast front, to underlying soil ahead of the front, but at decreasing intensities. It is assumed that this projection is at least 5 feet, a reasonable distance for concrete in view of 3 feet often used for earth cover to distribute loading from a concentrated force on the surface to underground gas piping. Two (2) feet more can be added, this being the distance required for overpressure to build up from ambient to its peak value.

Thus, seven feet of a ten foot length moves with ground depression developing ahead of the front and can be assumed to be unstressed. Assuming further that pipe rigidity resists bending,

*Calculated from an overpressure rise time of 1.2 milliseconds and a shock front velocity of 1600 ft./second at 4 Km from G.Z.

the remaining three feet is required to compress or shear surrounding soil using the joint as fulcrum point. The soil to be compressed by the three foot length varies from a maximum of 3/8 inches to zero over the remaining 3 feet of a 10 foot length. Since soil under a pipe is the least compacted, it is believed that pipe and soil will adjust accordingly without excessive strain on the joint.

Assuming that the foregoing adjustment between pipe and soil takes place, the transient angularity between companion parts of the joint is about 1/2 degree. This misalignment is not considered large enough to significantly damage the joint sealing materials.

The actions described are an over simplification of what may develop in the diverse piping configurations in the field. It disregards paving expansion joints and locations where the pipe is not under concrete or where the joint or piping is already highly stressed. The absence of concrete covering, however, does not change the angularity developed in the joints; it merely increases the amount of soil under the pipe requiring compaction to remain straight and rigid.

This consideration indicates that deflection taking place in joints under an applied 16 psi surface overpressure is small. It is felt that the cast iron grid system in Detroit will not be systematically damaged at the 16 psi overpressure radius and can be returned to operation as needed after reasonable amounts of repair for isolated fractures and other leakage.

The Company has expressed an interest in making a test to determine the effect of pipe deflection on the gas tightness of a joint. Pipe in place and about to be replaced or abandoned is considered best suited for a test. No test site materialized during the progress of the study. It is hoped that the Company can perform the test when the opportunity develops and will make known the results.

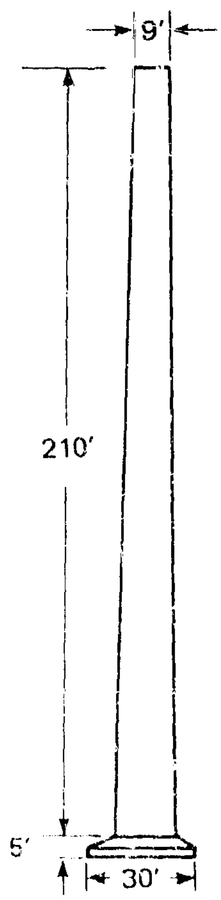
The tentative boundary of 16 psi overpressure radius is developed as a matter of interest only, it has little postattack significance in Detroit since it is within the area where residences and most buildings are totally destroyed and need for gas service no longer exists.

ANALYSIS OF CHIMNEY AT COOLIDGE STATION‡

Comparison of overturn and resisting forces indicates that the reinforced concrete chimney will continue to stand.

The bearing pressure of 3.6 tons/ft^2 under the toe of the base is less than the accepted 4–5 tons for Detroit soil at foundation depth, indicating continuance of chimney stability.

Analysis



Weight:
1,460,000 lbs.

1. **Attack Data:**

overpressure	P	=	6.2 psi
reflected overpressure	P_r	=	13.6 psi
dynamic pressure	q	=	1.0 psi
duration of positive phase	t_+	=	6.8 sec.
peak wind speed		=	200 mph.

2. **Overturn Resisting Moment:**

1,460,000 X 15 = 21,900,000 lbs-ft.

3. **Loading from Blast Wave:***

(a) from overpressure, $\text{psi} = P \frac{D}{U} A$

(b) from dynamic pressure, $\text{psi} = C_d \; q(t) \; A$†

where
D = average diameter of chimney = 12.67 ft.
U = shock front velocity = 1300 ft/sec.
A = projected area of chimney = 2555 sq. ft.
$q(t)$ = dynamic press, at time (t) where t = D/U

(c) $q(t) = q\left(1 - \frac{t}{t_+}\right)^2 e^{\frac{-2t}{t_+}}$ $\qquad t = \frac{12.67}{1300} = 0.00935$

$$= q\left(1 - \frac{0.00935}{6.8}\right)^2 e^{\frac{-2 \times 0.00936}{6.8}}$$

*Reference 1, page 202.
†C_d = drag coefficient = 0.34 @ 1.5 × 10^6 Reynolds Number.
‡Subsequent to writing this report this chimney has been razed.

(d) overpressure loading $= 13.6 \times \frac{12.67}{1300} = 0.133$ psi

(e) dynamic pressure loading $= 0.34 \times 1.0 \times 0.997 = 0.340$

total net loading $= 0.473$ psi

4. **Overturn Moment:**

(a) center of gravity of chimney projected area $= \frac{h(2a+b)}{3(a+b)}$

where:

a = top diameter

b = bottom diameter

$$= \frac{210\ (18+15.33)}{3\ (9+15.33)}$$

$= 95.9$ ft.

(b) moment

$2555 \times 0.473 \times 144 \times (95.9 + 5.0) = 17{,}600{,}000$ lbs-ft.

5. **Pressure under toe of base:**

(a) area of hexagonal base $= 8.66 \times 15 \times 6 = 779.5\ ft.^2$

(b) soil pressure $\frac{1{,}460.000}{779.5} = 1873\ lbs/ft.^2$

(c) load per lineal foot of cross section $Rv = 1873 \times 30 = 56190$ lbs.

(d) horizontal wind force acting on chimney:

$0.473 \times 144 \times 210 = 14300$ lbs.

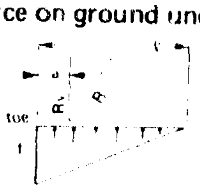
(e) tangent of angle of resultant force acting on chimney:

$14300/1{,}460{,}000 = 0.0979$

(f) distance resultant force intersects base from toe:

$a = 15 - (95.9 + 5.0) \times 0.0979 = 5.12$ ft.

(g) force on ground under toe, $f = \frac{2\ Rv}{3a}$ where $a < \frac{w}{3}$



$$= \frac{2 \times 56190}{3 \times 5.12 \times 2000} = 3.65\ tons/ft.^2$$

6. The safe bearing pressure of medium clay soil in Detroit is 4 to 5 tons per square foot. Considering that wind force is short in duration, it is concluded that chimney will not overturn or be significantly tilted.

ANALYSIS LOW PRESSURE HOLDER AT COOLIDGE STATION

This 10 MMcf, low pressure waterless holder is 218 feet in diameter by 320 feet in height. It is empty and the piston is landed. Its early dismantlement is planned.*

The steel top and sides are designed for a maximum stress of 13,500 psi at a lateral pressure of 30 $lbs/ft.^2$

$$\text{Pressure for failure} = \frac{65{,}000}{13{,}500} \times 30 = 144\ lbs/ft^2$$

The combination of 893 lbs/ft^2 (6.2 psi overpressure) and a coincident lateral impulse of 380 lbs/ft^2 (Reference 1, page 202) acting when the blast wave just envelopes the holder will crush and bend over the structure, but it will remain bolted to the foundation.

*Subsequent to writing this report this holder has been razed.

Table XIII—Gas Main Overcrossings Where Overpressure is Greater Than 2.5 PSI
Detroit District—Michigan Consolidated Gas Company

Location	Description of Facility	Attack Environmental Data			
		Distance from G.Z. km	Over-Pressure psi	Dynamic Pressure psi	Angle of Incidence - degrees
Freeways					
Southfield & McNichols	127'-12" Stl. Pipe On Hangers Under Bridge	10.9	2.7	0.22	35
Puritan	155'-12" Stl. Pipe On Hangers Under Bridge	10.2	3.1	0.27	37
Grand River	121'-12" Stl. Pipe On Hangers Under Bridge	9.7	3.3	0.32	70
Fulletron	166'- 8" Stl. Pipe On Hangers Under Bridge	8.0	4.6	0.60	50
Plymouth	105'-12" Stl. Pipe On Hangers Under Bridge	7.6	5.0	0.70	55
W. Chicago	108'-12" Stl. Pipe On Hangers Under Bridge	7.1	5.7	0.85	61
Joy Road	107'-12" Stl. Pipe On Hangers Under Bridge	6.7	6.3	1.05	66
Tireman	151'- 8" Stl. Pipe On Hangers Under Bridge	6.5	6.7	1.15	73
Warren	107'-12" Stl. Pipe On Hangers Under Bridge	6.3	7.0	1.30	81
Paul	155'- 8" Stl. Pipe On Hangers Under Bridge	6.2	7.2	1.35	88
Ford	400'-12" Stl. Pipe On Hangers Under Bridge	6.3	7.0	1.30	85
Gildow	176'- 8" Stl. Pipe On Hangers Under Bridge	6.4	6.8	1.20	77
Rotunda	176'- 6" Stl. Pipe On Hangers Under Bridge	6.9	6.0	0.93	81
Oakwood	166'- 8" Stl. Pipe On Hangers Under Bridge	7.5	5.1	0.72	19
Outer Drive	106'-12" Stl. Pipe On Hangers Under Bridge	9.0	3.8	0.40	12
Outer Drive	106'- 6" Stl. Pipe On Hangers Under Bridge	9.0	3.8	0.40	12
Fisher & Springwells	303'-12" Stl. Pipe On Hangers Under Bridge	4.2	15.5	4.7	73
Green	288'-12" Stl. Pipe On Hangers Under Bridge	4.4	14.0	4.0	86
Livernois	229'-12" Stl. Pipe On Hangers Under Bridge	4.3	15.0	4.3	73
Clark	148'-16" Stl. Pipe On Hangers Under Bridge	4.8	12.0	3.0	59
Lafayette	175'-16" Stl. Pipe On Hangers Under Bridge	5.2	10.0	2.4	68
Fisher & Porter	300'-26" Stl. Pipe On Hangers Under Bridge	5.1	10.5	2.5	50
Second	153'-12" Stl. Pipe On Hangers Under Bridge	6.8	8.2	0.97	24
Cass	170'-12" Stl. Pipe On Hangers Under Bridge	7.0	5.8	0.90	21
Woodward	167'-12" Stl. Pipe On Hangers Under Bridge	7.2	5.5	0.83	24
Brush	205'-12" Stl. Pipe On Hangers Under Bridge	6.7	6.3	1.05	22

Lodge & 7 Mile Road	134'-12" Stl. Pipe On Hangers Under Bridge	11.3	2.6	0.20	19
Schaefer	174'- 8" Stl. Pipe On Hangers Under Bridge	10.5	2.9	0.25	74
Schaefer	174'-22" Stl. Pipe On Hangers Under Bridge	10.5	2.9	0.25	74
McNichols	130'-12" Stl. Pipe On Hangers Under Bridge	9.4	3.5	0.35	15
Puritan	138'-12" Stl. Pipe On Hangers Under Bridge	8.5	4.2	0.50	12
Livernois	118'- 8" Stl. Pipe On Hangers Under Bridge	7.7	4.9	0.67	88
Livernois	118'-16" Stl. Pipe On Hangers Under Bridge	7.7	4.9	0.67	88
12th Street	134'- 8" Stl. Pipe On Hangers Under Bridge	7.7	4.9	0.67	85
Oakman	242'-24" Stl. Pipe On Hangers Under Bridge	7.6	5.1	0.70	42
Oakman	242'- 8" Stl. Pipe On Hangers Under Bridge	7.6	5.1	0.70	42
Glendale	168'- 6" Stl. Pipe On Hangers Under Bridge	7.1	5.7	0.84	49
Chicago Boulevard	244'-12" Stl. Pipe On Hangers Under Bridge	6.4	6.8	1.20	73
Forest W.	108'-12" Stl. Pipe On Hangers Under Bridge	5.9	7.9	1.55	79
Stimson	108'-12" Stl. Pipe On Hangers Under Bridge	6.1	7.5	1.40	75
Michigan Avenue	134'-12" Stl. Pipe On Hangers Under Bridge	6.6	6.5	1.15	85
Howard	123'- 8" Stl. Pipe On Hangers Under Bridge	6.9	6.0	0.93	56
Lafayette	174'-16" Stl. Pipe On Hangers Under Bridge	6.9	6.0	0.93	54
Lodge & Fort Street	117'- 6" Stl. Pipe On Hangers Under Bridge	7.1	5.7	0.85	53
Fort Street	117'-22" Stl. Pipe On Hangers Under Bridge	7.1	5.7	0.85	53
Edsel Ford & Second	202'-12" Stl. Pipe On Hangers Under Bridge	6.4	6.8	1.20	6
Woodward	237'-12" Stl. Pipe On Hangers Under Bridge	6.7	6.3	1.05	2
Livernois	206'-12" Stl. Pipe On Hangers Under Bridge	1.3	21.5	2.90	17
Brush	177'-16" Stl. Pipe On Hangers Under Bridge	7.2	5.7	0.83	2
E. Grand	162'- 8" Stl. Pipe On Hangers Under Bridge	9.3	3.6	0.37	2
Van Dyke	167'- 6" Stl. Pipe On Hangers Under Bridge	11.5	2.5	0.19	5
Chrysler & Holbrook	153'- 8" Stl. Pipe On Hangers Under Bridge	8.2	4.4	0.54	2
Milwaukee	237'-12" Stl. Pipe On Hangers Under Bridge	7.9	4.7	0.61	6
Ferry	104'- 8" Stl. Pipe On Hangers Under Bridge	7.5	5.1	0.72	1
Ferry	238'- 8" Stl. Pipe On Hangers Under Bridge	7.7	4.9	0.67	1
Warren	204'- 8" Stl. Pipe On Hangers Under Bridge	7.7	4.9	0.67	85
Mack	204'- 6" Stl. Pipe On Hangers Under Bridge	7.9	4.7	0.61	15
Wilkins	227'- 6" Stl. Pipe On Hangers Under Bridge	8.0	4.6	0.59	72
Gratiot	295'-12" Stl. Pipe On Hangers Under Bridge	8.3	4.3	0.52	30
Larned	165'-20" Stl. Pipe On Hangers Under Bridge	8.6	4.0	0.48	58

*Angle of incidence is 90° when direction of blast front is parallel to longitudinal axis of overcrossing, when blast front strikes head on angle of incidence is 0°.

Table XIII–(Continued)

Location	Description of Facility	Attack Environmental Data			
		Distance from G.Z. km	Over-Pressure psi	Dynamic Pressure psi	Angle of Incidence* degrees
Rivers					
River Rouge & Southfield	374′- 8″ Stl. Pipe On Hangers Under Bridge	6.6	6.5	1.15	17
Southfield	374′- 6″ Stl. Pipe On Hangers Under Bridge	6.6	6.5	1.15	17
So. of Mich. Ave.	2″ Stl. Pipe On Hangers Under Bridge	6.8	6.1	0.94	76
Lamphere	100′-12″ Stl. Pipe On Hangers Under Bridge	11.2	2.6	0.21	29
So. of Ann Arbor Tr.	95′-12″ Stl. Pipe On Hangers Under Bridge	9.8	3.3	0.31	31
So. of Ann Arbor Tr.	95′- 4″ Stl. Pipe On Hangers Under Bridge	9.8	3.3	0.31	31
West of Southfield	120′-12″ Stl. Pipe On Hangers Under Bridge	7.3	5.3	0.78	79
Rotunda	374′- 6″ Stl. Pipe On Hangers Under Bridge	6.6	6.5	1.15	80
Rotunda	374′- 8″ Stl. Pipe On Hangers Under Bridge	6.6	6.5	1.15	80
Rotunda Drive	143′- 8″ Stl. Pipe On Hangers Under Bridge	6.2	7.2	1.35	79
Warren	80′- 6″ Stl. Pipe On Hangers Under Bridge	10.2	3.1	0.27	85
Ecorse & Jefferson	120′-16″ Stl. Pipe On Hangers Under Bridge	11.2	2.6	0.20	84
Southfield	75′-12″ Stl. Pipe On Hangers Under Bridge	10.1	3.1	0.28	13
Streets					
Brady So. of Cherry Hill	140′- 4″ Stl. Pipe On Hangers Under Bridge	7.5	5.1	0.72	6
So. of Cherry Hill	140′-12″ Stl. Pipe On Hangers Under Bridge	7.5	5.1	0.72	6
Wyoming & Southern	167′-12″ Stl. Pipe In Cradle On Sidewalk	2.4	46.0	47.0	47
Railroads					
GTWRR & Larned	84′-22″ Stl. Pipe On Hangers Under Bridge	9.3	3.5	0.47	67
NYCRR & Bagley	477′-24″ Stl. Pipe On Hangers Under Bridge	5.5	9.0	2.0	13
& Porter	491′- 6″ Stl. Pipe On Hangers Under Bridge	5.9	8.0	1.55	55

*Angle of incidence is 90° when direction of blast front is parallel to longitudinal axis of overcrossing, when blast front strikes head on angle of incidence is 0°.

APPENDIX B

TABLE XIV—NORMAL DISTRIBUTION OF MOBILE EQUIPMENT DEPARTMENT OF P.T.&S.
Michigan Consolidated Gas Company

Description	Big Rapids	Six Lakes	Belle River	Milford Jct. Willow Station
Air Compressor 105—125 cfm trailer	2	2	1	
Back Hoe—Tractor w/front end loader		1		1
Beveling Machine 4"—20"		1		
Crane, Motor w/Back Hoe 7—15 ton	1	1		
Crane, Swamp Cat, Insley	1			
Extinguisher, 1000# skid mounted		1		
Extinguisher, 900# trailer mounted		1		
Generator 1000—2400 watts	1	1		1
Lowboy, Lawrence FD	1			1
Oxy-acetylene Cutting Outfit		1		
Pipe Layer w/Blade & Sideboom, TD 15		1		1
Pump, Water 1-1/2—3 inch	1	1	1	2
Pump, Water, Plunger, Engine Driven	1			
Pump, Water, Centrifigal, Engine Driven	1			
Pump, Hydrostatic Fill, 6" Engine Driven	1			
Pump, Water, Trash		1		
Side Boom, Crawler, TD 9	1			
Side Boom, Crawler, TD 18	1	1		
Tractor, w/Accessories	1			
Tractor, w/Bucket			1	1
Tractor, w/Winch	1			
Trailer, Pipe and Pole	2	1		
Trailer, Triole Axle	1			
Trailer, Enclosed Equipment	2			
Trailer, Low Boy		1		
Trencher, #140 Cleveland	1			
Truck, Flat Rack 1—3 tons, Winch		4		1
Truck, 1-1/2 ton Utility w/Compressor	1			
Truck, Platform 2—3 tons	2			
Truck, Dump & Blade 3 tons		1		
Truck, w/Fifth Wheel & Blade 5 ton		1		1
Welder, Micro Wire	1	1		
Welder, 200—350 Amp, Mobile	2	1		

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APPENDIX C

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GAS SYSTEM RESTORATION PERSONNEL AT ATTACK WARNING TIME

The locations of operating personnel possessing the skills needed for restoration of the gas system in the immediate postattack period are shown in Figure 29.

Off-duty Personnel

Plotted locations (residences) of off-duty personnel are uncircled. Categories 3 and 8 represent groups of ten employees. The location of a ten employee group is chosen by taking the residence address of each tenth off-duty employee of that category from the Company list. Other off-duty category locations indicate individual employees.

On-duty Personnel

On-duty employee employment locations are circled. Category 3 plot points represent two or three man distribution maintenance crews working out of the Service and Maintenance stations. Locations of the crews are determined by dividing the service area of each station into five equal parts. The specific subdivision is then selected by use of random numbers, and its centroid is assumed to be the job site.

Category 8 plot points represent 38 individual servicemen in the field plus 9 dispatchers at One Woodward. Locations of servicemen are determined by approximate equidistant spacing in the areas served by the stations. This method of job location selection is in keeping with operating practice of working servicemen in specific areas.

The remaining on-duty employees (categories 10, 11, 12 and 15) have established work locations in the Service and Maintenance, Regulating or City Gate Stations and are presumed to be at them at attack warning time.

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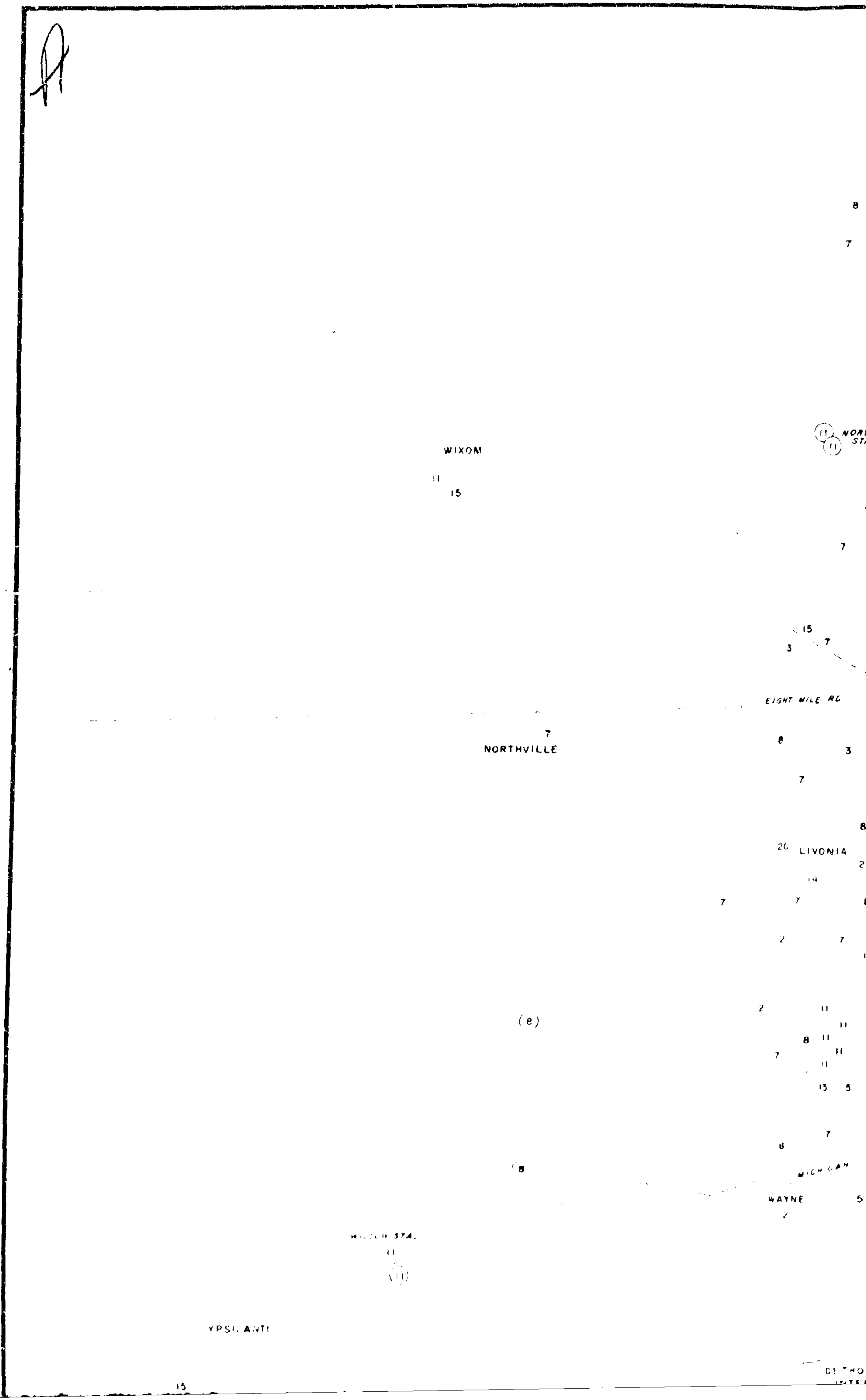
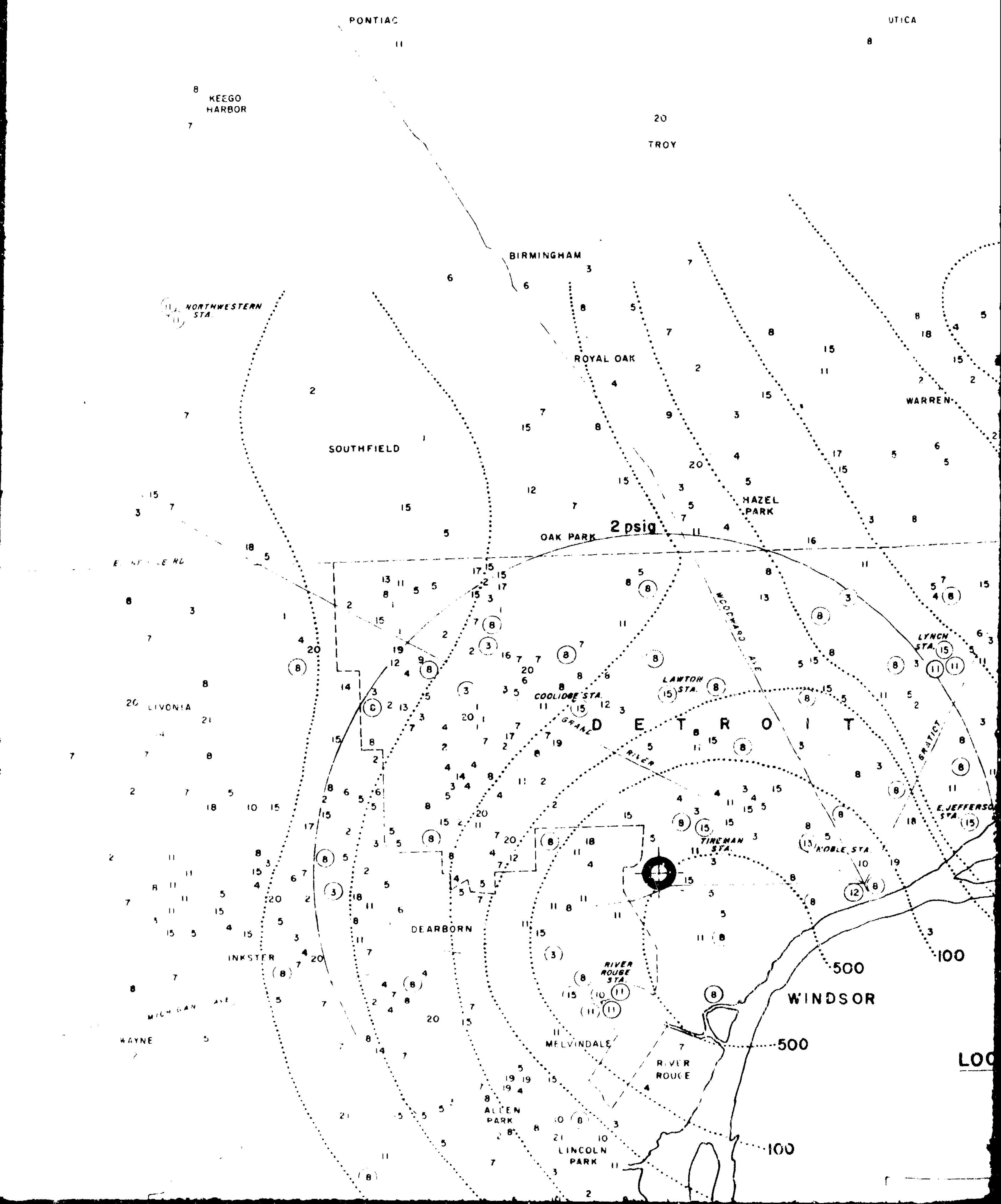

WIXOM
EIGHT MILE RD
NORTHVILLE
LIVONIA
(e)
WAYNE
YPSILANTI


PONTIAC
UTICA
KEEGO HARBOR
TROY
BIRMINGHAM
NORTHWESTERN STA.
ROYAL OAK
WARREN
SOUTHFIELD
HAZEL PARK
OAK PARK
2 psig
WOODWARD AVE
LYNCH STA.
LAWTON STA.
COOLIDGE STA.
LIVONIA
DETROIT
GRAND RIVER
GRATIOT
E. JEFFERSON STA.
TIREMAN STA.
NOBLE STA.
DEARBORN
INKSTER
RIVER ROUGE STA.
WINDSOR
MICHIGAN AVE.
WAYNE
MELVINDALE
RIVER ROUGE
ALLEN PARK
LINCOLN PARK
500
100

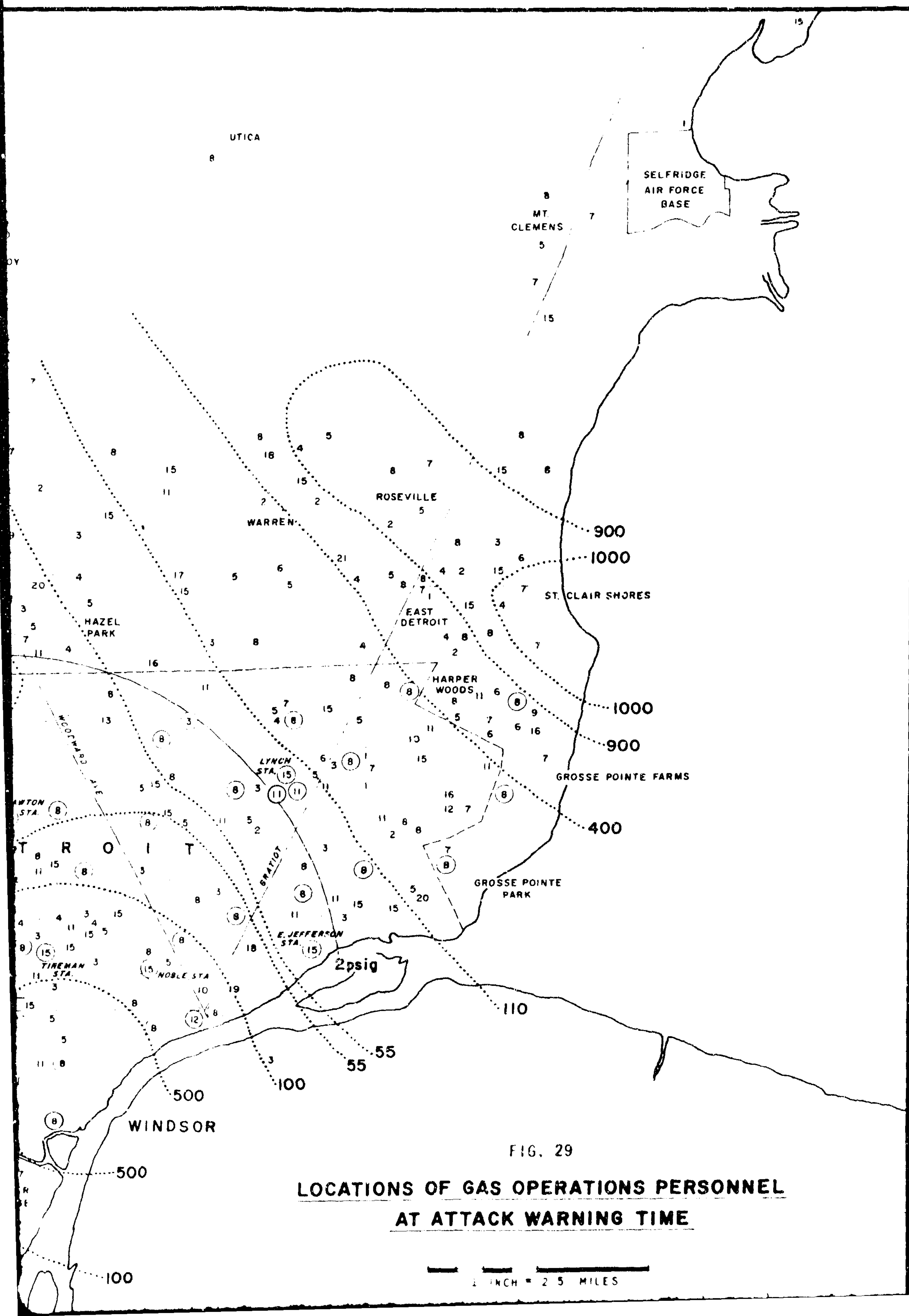
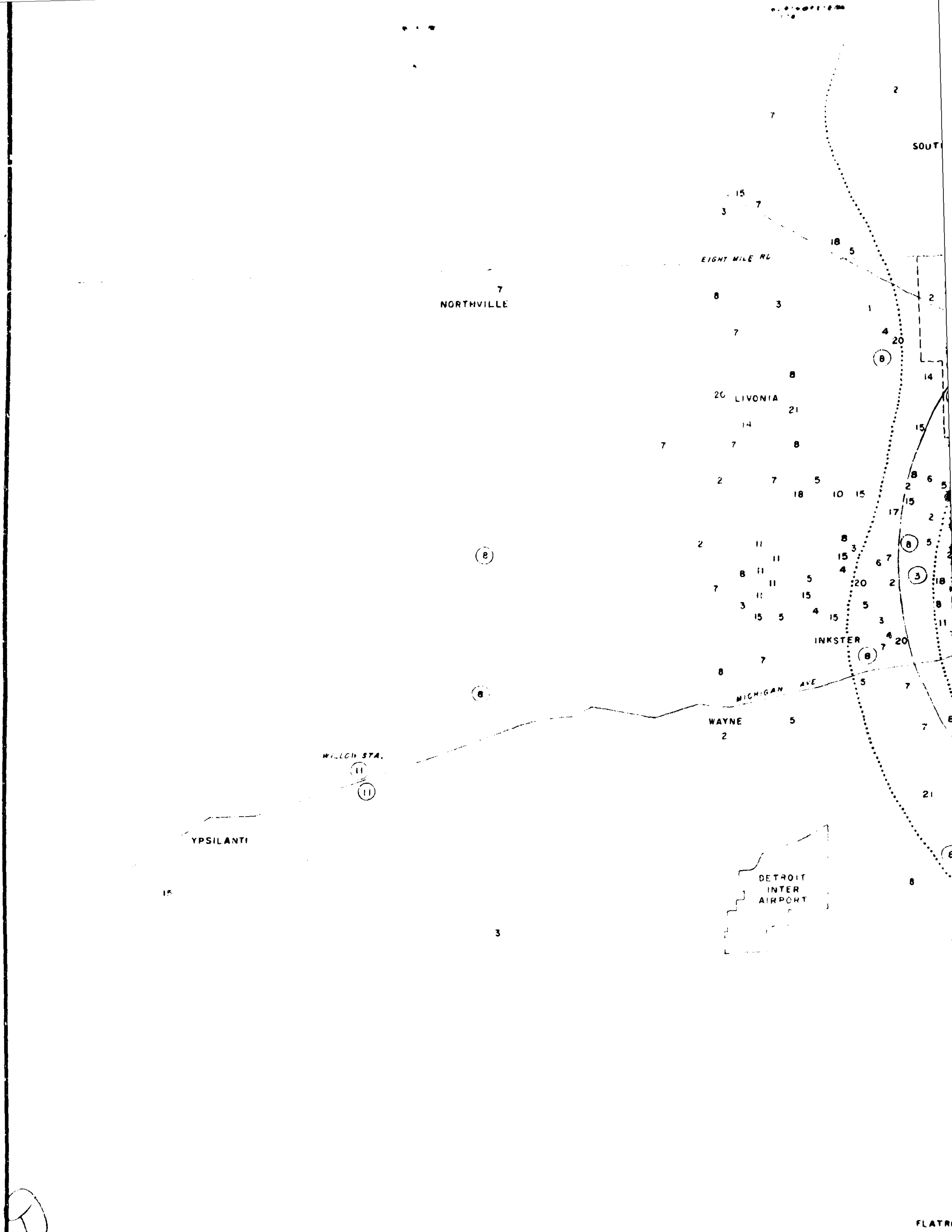
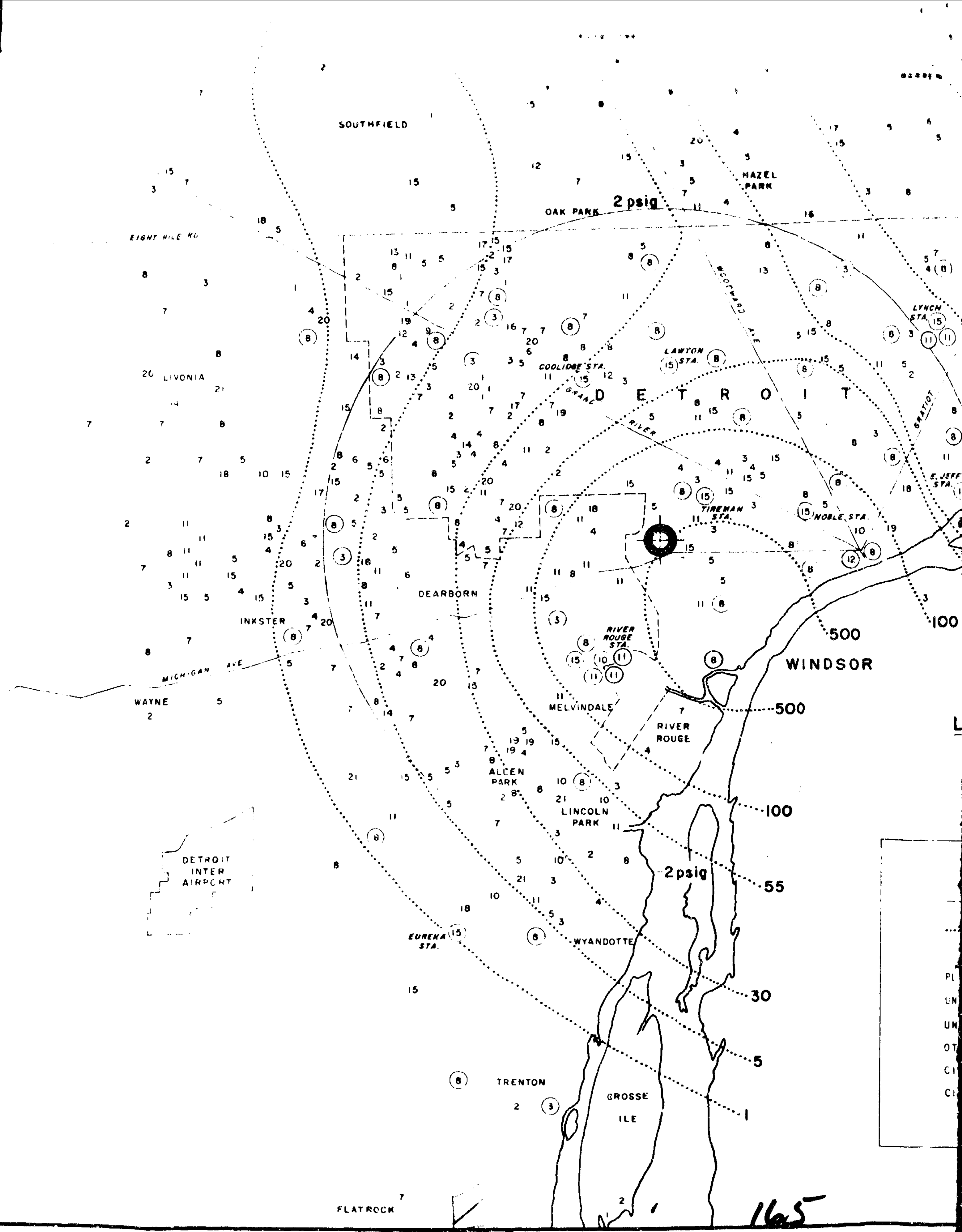


FIG. 29

LOCATIONS OF GAS OPERATIONS PERSONNEL AT ATTACK WARNING TIME


NORTHVILLE
LIVONIA
INKSTER
MICHIGAN AVE
WAYNE
YPSILANTI
DETROIT
INTER
AIRPORT


SOUTHFIELD
HAZEL PARK
OAK PARK
2 psig
EIGHT MILE RD
WOODWARD AVE
LYNCH STA.
LAWTON STA.
COOLIDGE STA.
GRAND RIVER
D E T R O I T
GRATIOT
LIVONIA
TIREMAN STA.
NOBLE STA.
DEARBORN
INKSTER
MICHIGAN AVE
WAYNE
RIVER ROUGE STA.
500
100
WINDSOR
MELVINDALE
RIVER ROUGE
ALLEN PARK
LINCOLN PARK
2 psig
55
DETROIT INTER AIRPORT
EUREKA STA.
WYANDOTTE
30
5
TRENTON
GROSSE ILE
1
FLATROCK

165

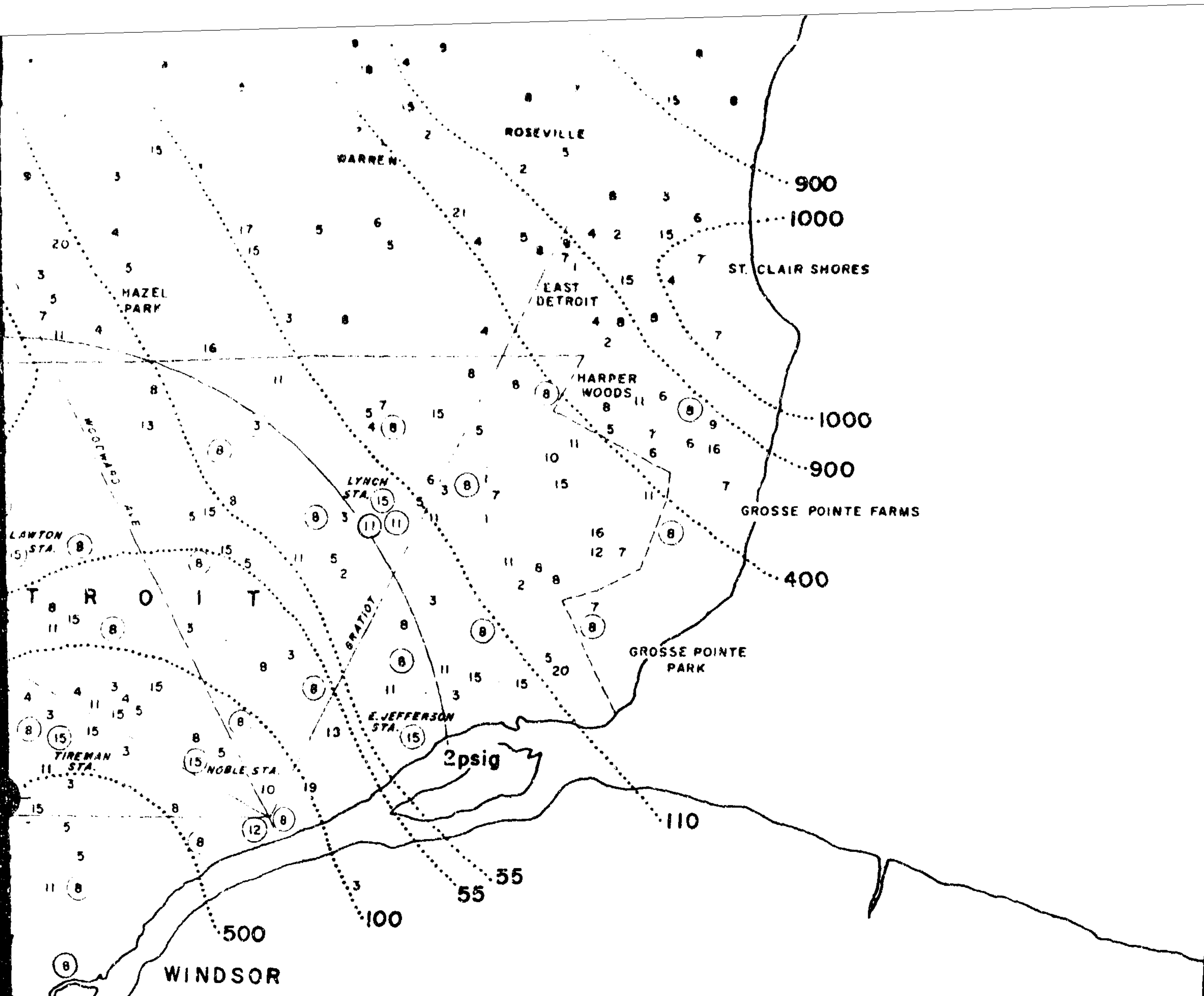


FIG. 29

LOCATIONS OF GAS OPERATIONS PERSONNEL AT ATTACK WARNING TIME

1 INCH = 2.5 MILES

·LEGEND·

DETROIT CITY LIMITS

RESIDUAL RADIATION INTENSITY ROENTGENS PER HOUR AFTER ONE HOUR

PLOT NUMBER INDICATES JOB CATEGORY OF EMPLOYEE. SEE TABLE. IX

UNCIRCLED PLOT NUMBER IS LOCATION OF OFF-DUTY EMPLOYEE.

UNCIRCLED PLOT NUMBERS 3 AND 8 REPRESENT GROUPS OF 10 EMPLOYEES:

OTHER CATEGORY NUMBERS REPRESENT INDIVIDUAL EMPLOYEES.

CIRCLED NUMBERS ARE ON-DUTY EMPLOYEES AND PLACES OF EMPLOYMENT.

CIRCLED NUMBERS (3) AND (15) REPRESENT GROUPS OF 2 TO 5 EMPLOYEES, SEE TEXT.

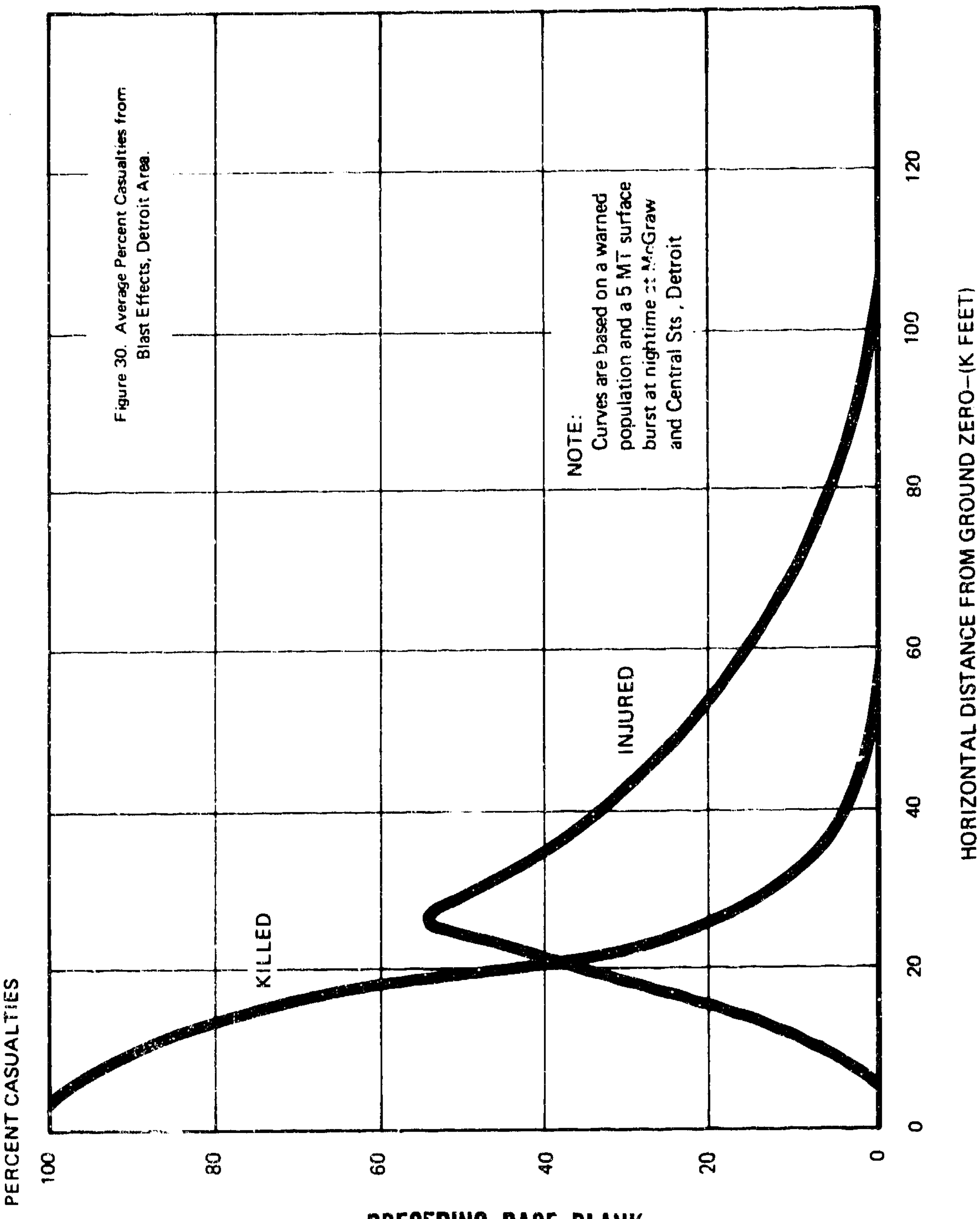


Figure 30. Average Percent Casualties from Blast Effects, Detroit Area.

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Table XV—Details of Casualty Distribution Among Gas System Restoration Personnel
Detroit District—Michigan Consolidated Gas Company

Category No.	Number of Personnel		Inside of Detroit City Limits										Outside of Detroit City Limi			
			Number of Personnel	Blast Effects				Fallout Effects				Number of Personnel	Blast Effects		
				At Home		On Duty		At Home		On Duty			At Home		On
	At Home	On Duty		Deaths	Injuries	Deaths	Injuries	Death	Injuries	Death	Injuries		Deaths	Injuries	Deaths
1	14		9		3				1			5		1	
2	32		12	1	6							20	2	4	
3	320	18	160	50	30	3	7		20			178		40	3
4	32		11	3	4							21	1	7	
5	51		21	6	7							30	1	11	
6	13		2	1	1				1			11		2	
7	49		14	2	4				3			35	2	7	
8	526	47	230	50	80	5	14		20		10	343	10	40	2
9	3		1									2		1	
10	7	1	2									6	1	2	
11	37	9	18	3	6		1	1	1			28	5	3	2
12	4	2	6	1	2		2		1			0			
13	3		3		1							0			
14	4		4		1							3		1	
15	41	20	35	6	4	6	8		1		2	26	1	5	2
16	4		1		1							3		1	
17	5		3		1							2			
18	7		1									6		1	
19	6		2		2							4		3	
20	12		5		2							7		1	
21	5		0									5		2	
Totals	1,175	97	537	123	155	14	32	1	48	0	12	735	23	132	9

*Fallout casualties among outside of Detroit personnel not determined or adjusted for in this table, see text.

PR

XV–Details of Casualty Distribution Among Gas System Restoration Personnel
Detroit District–Michigan Consolidated Gas Company

side of Detroit City Limits						Outside of Detroit City Limits*					Uninjured		
Effects		Fallout Effects				Number of Personnel	Blast Effects				At Home or On Duty	Evacuees	Total
On Duty		At Home		On Duty			At Home		On Duty				
Deaths	Injuries	Death	Injuries	Death	Injuries		Deaths	Injuries	Deaths	Injuries	Number	Number	Number
			1			5		1			[illegible]	1	10
						20	2	4			19	6	25
3	7		20			178		40	3		185	37	222
						21	1	7			17	3	20
						30	1	11			26	6	32
			1			11		2			8	3	11
			3			35	2	7			31	3	34
5	14		20		10	343	10	40	2	2	340	60	400
						2		1			2	1	3
						6	1	2		1	4	2	6
	1	1	1			28	5	3	2	1	23	3	26
	2		1			0					0	2	2
						0					2	1	3
						3		1			2	1	3
6	8		1		2	26	1	5	2		26	6	32
						3		1			2	1	3
						2					4	0	4
						6		1			6	1	7
						4		3			1	2	3
						7		1			9	1	10
						5		2			3	0	3
14	32	1	48	0	12	735	23	132	9	4	719	140	859

or adjusted for in this table, see text.

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APPENDIX D

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DERIVATION OF PRESSURE DECLINE EQUATION

Computation has established that at the moment of system shutdown at Northwestern Station:

1. The volume of pack in the 300 psig Transfer system is 10.1 MMCFH under an average pressure of 87 psig.

2. The flow rate from Northwestern to River Rouge and Coolidge Stations under open flow conditions is 16 MMCFH with 150 psig head pressure[1] at Northwestern.

The derivation of an equation to predict pressure decline assumes that the 300 psig Transfer main complex is acting as a reservoir with gas being withdrawn therefrom through 6, 8 and 10 inch Fisher and Emco regulators for delivery to intermediate Transfer system mains[2] at a starting rate of 16 MMCFH.

Gas flow at high pressure through an orifice is expressed by the general equation:[3]

$$Q\,hr. = 40{,}700\ C_d\ Y\ D^2 \sqrt{\frac{P_1 - P_2}{ST}}^{\,*} \qquad (1)$$

For critical flow:

$$\frac{P_2}{P_1} = \left(\frac{2}{K+1}\right)^{\frac{K}{K-1}}$$

$$\Delta P = 0.453P_1$$

[1]Nuclear Emergency Plan reduced operating pressure.
[2]Pressure has dropped to 0.1 psig at moment of shutdown.
[3]Derived from the basic flow equation in Reference 11:

$$Q\ min. = 181.6 \sqrt{\frac{D^5 (P_1^2 - P_2)^2}{S\,f\,L}} \times \sqrt{\frac{520}{T}}\ Y\dagger$$

*Symbol definitions are at end of this appendix.
†See footnote on following page.

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Orifice flow in Detroit is at critical velocity when pressure is above:

$$14.4/0.547 = 26.3 \text{ psia}$$

Substituting for S, T and Δ P equation (1) reduces to:

$$\begin{aligned} Q \text{ hr.} &= 1083\ C_d\ D^2\ P_1 \\ Q \text{ min.} &= 18.05\ C_d\ D^2\ P_1 \end{aligned} \qquad (2)$$

where P_1 is upstream pressure of 101.4 psia.

Orifice Discharge Coefficient

Regulator coefficients in terms of nominal regulator sizes listed for "K" and "KB" bodies in fisher Catalog #10 are determined by equating (2) with Fisher Controls formula for determining regulator capacity:

$$1083\ C_d\ D^2\ P_1 = \frac{520}{ST}\ P_1\ C_g\ \sin\left[\frac{3417}{C_1}\sqrt{\frac{\Delta P}{P}}\right]$$

where C_g = Fisher gas sizing coefficient

C_1 = Fisher catalog values

Where the bracketed expression exceeds 90 degrees or more, critical flow is indicated. Since the left hand part of the equation requires critical flow, the bracketed portion equals 1.00 and the simplified relation is:

$$1083\ C_d\ D^2 = \sqrt{\frac{1}{S}}\ C_g$$

$$C_d = 0.00119\ \frac{C_g}{D^2}$$

*Y = 0.7 and is derived from:

$$\sqrt{\frac{\frac{K}{K-1}\left(\frac{P_2}{P_1}\right)^{2K}\left[\left(1-\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right]}{1-\frac{P_2}{P_1}}}$$

Regulator nominal size inches	D^2	C_g @ 100% travel Fisher Cat. #10	$0.00119\ C_g$	$C_d = \frac{0.00119\ C_g}{D^2}$
6	36	15,100	18.0	0.50
8	64	24,200	28.8	0.45
10	100	42,700	50.8	0.51
			Average	0.49

Similarly, the average coefficient for Emco regulators is 0.29 giving an overall average of 0.39 for district regulators in the system.

Equation (2) reduces to:

$$Q\ \text{min.} = (18.05)\ (0.39)\ (D^2)\ (P_1)$$

$$= 7.04\ D^2\ P_1$$

Internal Volume of Pipe:

$$\text{Volume} = V_1\ \frac{P_1}{14.4}$$

$$\text{Differential of Volume} = dv = \frac{V_1\ dP}{14.4}$$

$$\text{Differential of Time} = dt = \frac{V_1\ dP}{(14.4)\ (7.04)\ (D^2)\ P_1}$$

Time Duration of Critical Flow, t_c:

$$t_c = \frac{V_1}{(14.4)\ (7.04)\ (D^2)} \int_{26.3}^{P_1} \frac{dP}{P_1}$$

$$= \frac{2.3\ V_1}{(14.4)\ (7.04)\ (D^2)} \log_{10} \frac{P_1}{26.3}$$

$$t_c = 0.0227\ \frac{V_1}{D^2} \log_{10} \frac{P_1}{26.3}$$

Time Duration of Subsonic Flow, t_s:

After pressure drops to 26.3 psia, flow will be sonic and then decline to subsonic velocities. The expansion factor (Y) varies almost linearly from 0.7 to 1.0.* Using an average of 0.85 for Y and 0.39 for C_d equation (1) becomes:

$$Q \text{ min.} = \frac{(40700)\ (0.85)\ (0.39)\ (D^2)}{(60)\ (17.67)} \quad \sqrt{P_1^2 - 14.4\,P_1}$$

$$= 12.7\ D^2 \quad \sqrt{P_1^2 - 14.4\,P_1}$$

where P_1 = 26.3 psia.

Time for Pressure Decline at Subsonic Flow:

$$dts = \frac{V_1\ dP}{(14.4)\ (12.7)\ D^2 \quad \sqrt{P_1^2 - 14.4\,P_1}} = \frac{0.00545\ V_1\ dP}{D^2 \quad \sqrt{P_1^2 - 14.4\,P_1}}$$

The integral of this expression has the form:

$$\int \frac{dx}{a \pm 2bx + cx^2} = \frac{1}{\sqrt{C}} \log_e \quad (\pm b + cx + \quad \sqrt{c} \quad \sqrt{a \pm 2bx + cx^2}$$

letting a = 0 C = 1.0 and 2b = 14.4

$$= \log_e \quad x - b + \quad \sqrt{X^2 - 2bx}$$

Time for Pressure to Decline from 26.3 psia to Zero Gauge:

$$t_s = \frac{(2.3)\ (0.00545)\ V_1}{D_2} \left[\log_{10} \quad \frac{26.3 - 7.2}{14.4 - 7.2} \quad \frac{\sqrt{(26.3)^2 - (14.4)\ (26.3)}}{\sqrt{(14.4)^2 - (14.4)\ (14.4)}} \right]$$

$$= 0.00896\ \frac{V_1}{D^2}$$

*seats are "O" rings and rounded.

Total Time for Pressure to Decline to Zero Gauge:

$$t_{total} = 0.0227 \frac{V_1}{D^2} \log_{10} \frac{P_1}{26.3} + 0.00896 \frac{V_1}{D^2}$$

$$\text{simplifying and substituting } D^2 = \frac{Q}{7.04\ V_1}$$

$$t_{total} = \frac{0.0632\ V_1\ P_1}{Q \text{ min.}} \left[2.53 \log_{10} \frac{P_1}{26.3} + 1 \right] \qquad (3)$$

where P_1 = initial average pressure = 101.4 psia

Q min. = initial flow rate @ Northwestern = 2.67×10^5 MMCF

V_1 = pipe volume containing 10.1 MMCF at standard conditions = $\frac{14.4}{101.4} (10.1 \times 10^6)$

V_1 = 1.426×10^6 cf.

Time for System Pressure to Decline to Zero Gauge:

substituting in equation (3)

$$t = \frac{(0.0632)\ (101.4)\ (1.426 \times 10^6)}{2.67 \times 10^5} \left[2.53 \log_{10} \frac{101.4}{26.3} + 1 \right]$$

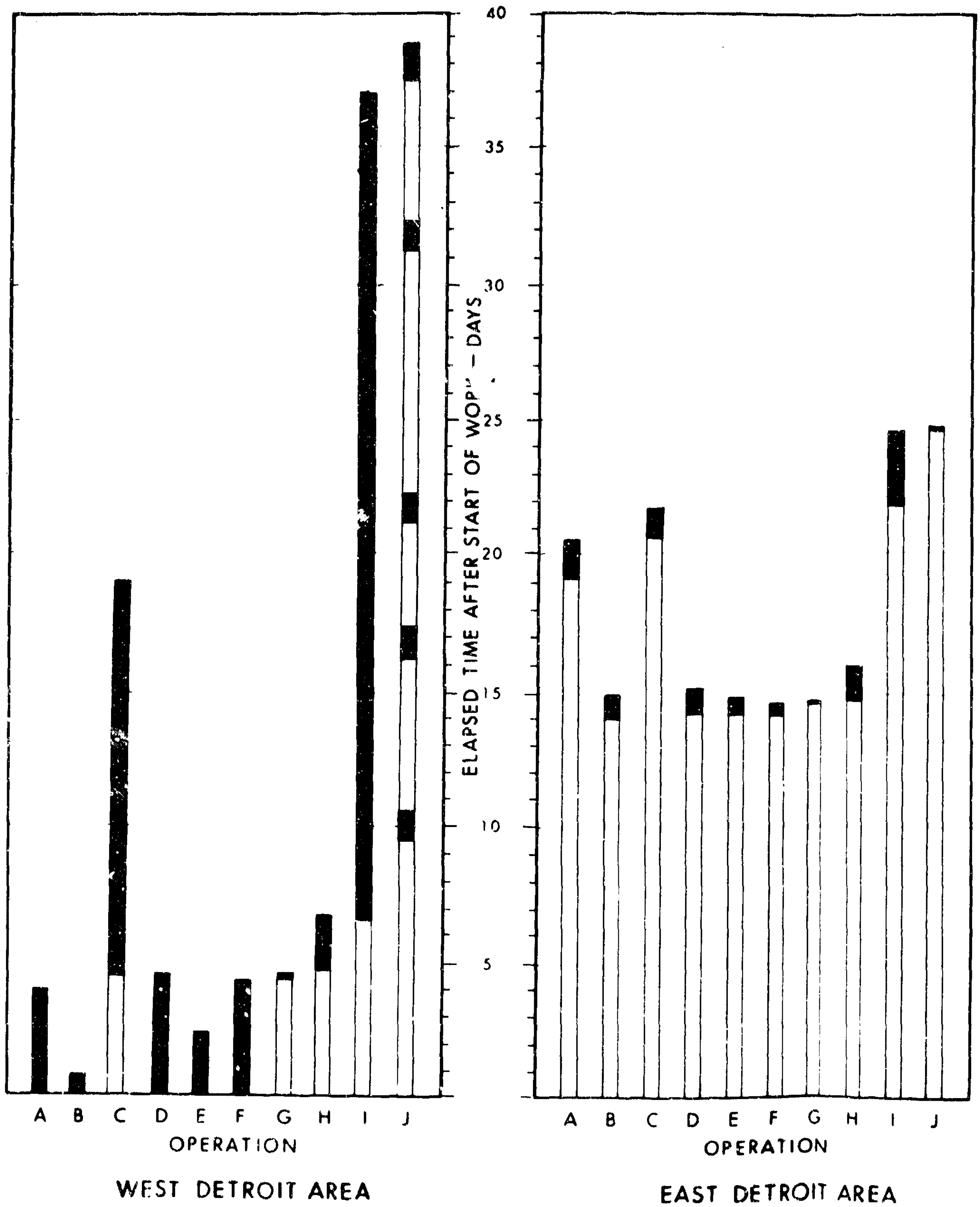
= 85 minutes

10 inch slide rule accuracy.

SYMBOLS

C_d	=	orifice coefficient of discharge
D	=	diameter of orifice, inches
K	=	ratio of specific heats of Detroit natural gas = 1.3
P_1	=	upstream pressure, psia
P_2	=	downstream pressure, psia
ΔP	=	$P_1 - P_2$
Q hr.	=	cubic feet of gas per hour at atmospheric pressure (14.73 psia, 60°F)
Q min.	=	cubic feet of gas per minute at atmospheric pressure (14.73 psia, 60°F)
S	=	specific gravity of Detroit gas = 0.6
T	=	upstream temperature in degrees Rankin
V_1	=	internal volume of piping, cu. ft.
Y	=	expansion factor
f	=	pipeline friction factor

APPENDIX E



Time
Distr

A Close

B. Excav

C. Purge

D. Excav

E. Excav

F. Shut

G. Inves

H. Cut d

I. Purge

J. Turn

G H I J

ON

IT AREA

FIG. 31

Time Required to Restore Immediate Postattack Distribution Grid System · In Detroit District

MICHIGAN CONSOLIDATED GAS COMPANY

LEGEND

RESTORATION OPERATIONS

A Close valves of transfer mains and shut off district regulators.

B. Excavate, cut and cap for distribution system separation.

C. Purge transfer mains.

D. Excavate, cut, cap and reconnect for purging distribution system.

E. Excavate purge points in distribution system.

F. Shut off all service valves on customer premises.

G. Investigate "No Gas" buildings for service pipes.

H. Cut and cap service pipes to damaged homes and buildings.

I. Purge distribution mains.

J. Turn on service valves, purge and relight appliances.

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Table XVI—Requirements to Restore Gas Service to Eight Hospitals in Shutdown Area

Hospital	Area	Blast Over-Pressure psi	Field Operations						
			Valves Opened or Closed	Regulators Shut off or Turned on	Cut and Cap		Mains Purged	Crew Hours Required[2]	Elapsed Time to Restore[3] Service-Days
					Mains	Services			
1 – Sinai[1]	W/o Detroit	3.1							
2 – Mt. Carmel	W/o Detroit	3.2	12	7	–	–	9 mi. total of 22"-24"-26"	10.8	20
3 – New Grace	W/o Detroit	2.9							
4 – Oakwood	W/o Detroit	1.6							
5 – Veterans[1]	W/o Detroit	4.8	11	8	6 –	35	6 mi. total of 8" and 12"	13.2	22
6 – Holy Cross	E/o Detroit	4.0	1	1	–	–	1/2 mile, 12"	5.8	23
7 – Saratoga	E/o Detroit	1.2	–	3	6	–	1 mi., 6" 1/4 mi., 4"	8.8	24
8 – St. John	E/o Detroit	1.1	1	6	–	–	4 mi. total of 12"-16"-24"	7.7	25
			Total Time in Net Working Hours					46.3[4]	XXXXX

[1]Hospitals 1 through 5 are handled in two field operations.
[2]Work is coordinated with repressuring of 300 psi Transfer mains, see Figure 31.
[3]Days after start of restoration operations in West Detroit area.
[4]Inclusion of these hospitals in restoration operations of Figure 31 will delay completion of East and West Detroit areas by 46 working hours.

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APPENDIX F

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DISCUSSION OF PROPOSAL THAT HOUSEHOLDERS TURN OFF GAS SUPPLY TO THEIR PREMISES

Appendix F considers a proposed countermeasure that service valves be turned off by householders when a nuclear attack is imminent. The purpose of this countermeasure is reduction of fire spread. The Office of Oil and Gas, Department of the Interior, recommends that this proposal be given additional study (possibly, with simulated or experimental housing units, provided with typical underground service piping) before a "pre-attack shutoff" of "service valves by householders" be adopted as a national program.

It has been proposed as national policy for civil defense that householders be instructed to turn off gas supplies to their premises at service valves in the case of an imminent nuclear attack. The intended turn-off is to be made by the householder after being warned that an attack has started but before he seeks shelter. At the completion of this report, the matter had not been fully resolved—accordingly, the various opinions are herewith noted:

The need for the proposed countermeasures is based on the premise that expansion of secondary fire can be materially reduced by preventing leakage of flammable gas from damaged, household gas equipment, (Reference 12). Ignition is considered to occur in two principal ways:

1. From flaming articles set on fire by fireball radiation and scrattered in the premises by the blast wave.

2. From pilot light flames of gas appliances in the premises.

Service valve closure, it is felt, will reduce ignitions by eliminating the downstream meter set components, houseline, appliances and their connectors as sources of gas leakage, leaving only the service valve and a few feet of exposed pipe still containing gas under pressure.

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The American Gas Association, representing the gas industry, feels that the measure is not only undesirable for one principal reason but cites a number of other objections questioning its need and effectiveness:

1. The stated undesirable feature is that the measure cannot avoid including service areas unaffected by the attack. As a result, if householders follow instructions gas utilities in the postattack period must divert diminished resources to restore gas appliance operation in the unaffected areas, which work would not have developed except for the turn-off measure. Completion of postattack emergency repairs would not only be delayed but, in large metropolitan areas, weeks could be required to return appliances to operation in the unaffected sections.

2. If need develops to eliminate leaking gas because it may aid fire development, the industry feels that it is a more effective alternate by being able to shut off supply and do it completely, whereas turn-off will only be partial if the public is relied on. At the same time, the utility can exercise selectivity in valving and avoid interrupting service in the undamaged areas and the unnecessary buildup of work load.

This substitute action by the utility, however, has the weakness that gas will continue to flow from leaks in the damaged area until pressure in the system is depleted. During this time, which can amount to several hours or more, gas continues to be potential fuel for fire.

3. It is further contended that there is no documented proof that pressurized gas facilities in households necessarily initiate or aid secondary fires in a significant degree. The generally light damage to piping and appliances and the absence of fire in the Nevada Tests are cited as evidence that gas is not a prime initiator of fire.

This conclusion, however, is largely invalidated by the exclusion of ignitable materials, such as window drapes, upholstered furniture, paper, etc. or pressurized gas piping and lighted pilots in the tests. In addition, the house piping systems lacked a reserve gas supply which would not be the case if served from an operating system where leakage and fire potential would be prolonged.

On the other hand, neither is there proof that a significant reduction in secondary fires will not follow the proposed mass turn-off of service valves. If leaking gas is not present, it would seem more difficult for flaming remnants of window coverings, paper and other room materials set on fire by fireball radiation and scattered in the premises by the blast to initiate sustained fires in the premises.

Other stated objections to the program by the Association are householders' unfamiliarity with service valve locations, difficulty of handling hard-to-turn service valves and the probability that valve closure will be overlooked in many instances because of stress of the moment. In addition, the delay imposed on the householder at a critical time when seeking shelter cannot be ignored, or the possibility of exposure of the householder to accident if he feels an obligation to turn it back on after the attack or does not wait for a utility unable to respond promptly because of the work load.

These objections are not necessarily or entirely accepted by this study. Preparing the public to turn off the valves could be merely a matter of issuing illustrated instructions by means of the news media or postcard mailing prior to the attack. The matter of exposing a householder to accident if he turns gas back on in the postattack period when his equipment may leak from damage could be minimized by: (1) postattack broadcast of street boundaries determined by utility survey wherein gas should not be turned on until the premises are checked and (2) by instructing householders to limit appliance turn-on to top burners of ranges where there is unfamiliarity with lighting procedure for other burners. This latter precaution, whose use would satisfy minimum cooking needs in the household in the immediate postattack period, would ease the need for a "crash" program by the utility to restore appliance operation and, instead, permit concentration on emergency repairs.

Available data indicate that the measure would not have curtailed fire spread in the Detroit area, since expected primary fires, initiated by fireball radiation, possessed capability to spread without participation of gas. The absence of gas, at the best, would be to delay fire spread in some degree, but not to limit its expansion.

No substantive field data evolved from the study to either confirm or absolve gas in damaged buildings as a significant contributor to development of fire. The study, however, supported one criticism of the proposal, namely, that if householder turn-off policy had been observed in the Detroit attack, the adjoining Ann Arbor District of Michigan Consolidated with its 43,775 customers would have been added to the postattack work load. The resulting work, however, will require less than two and one-half days for the combined Detroit District and Ann Arbor servicemen. Some space heating appliances may have to be deferred in order that these servicemen can be used to verify that all service valves have been turned off in the Detroit area to be returned to service. This check will take about two days and allow time to complete Ann Arbor without delaying Detroit operations, see Item I, Fig. 31. It is obvious that if there were more households in Ann Arbor some would have had to wait at least a week for Company service.

Figure 32, which shows the time duration of gas loss from the Detroit area gas distribution system and the development of concurrent fire, provides a basis for some general assumptions.

Values for the plot of gas volume inventory in Figure 32 are taken from Table XVII using two reference points: (1) the emergency shutdown one hour after the attack and (2) the 85 minutes taken by the system to lose pressure. The solid line portion of the curve is obtained by means of equation (3) in Appendix D; the dashed portion represents approximate intermediate values between the two known terminal values.

Values for the plot of the buildings burned or burning at intervals up to 28 hours postattack are taken from Reference 7.

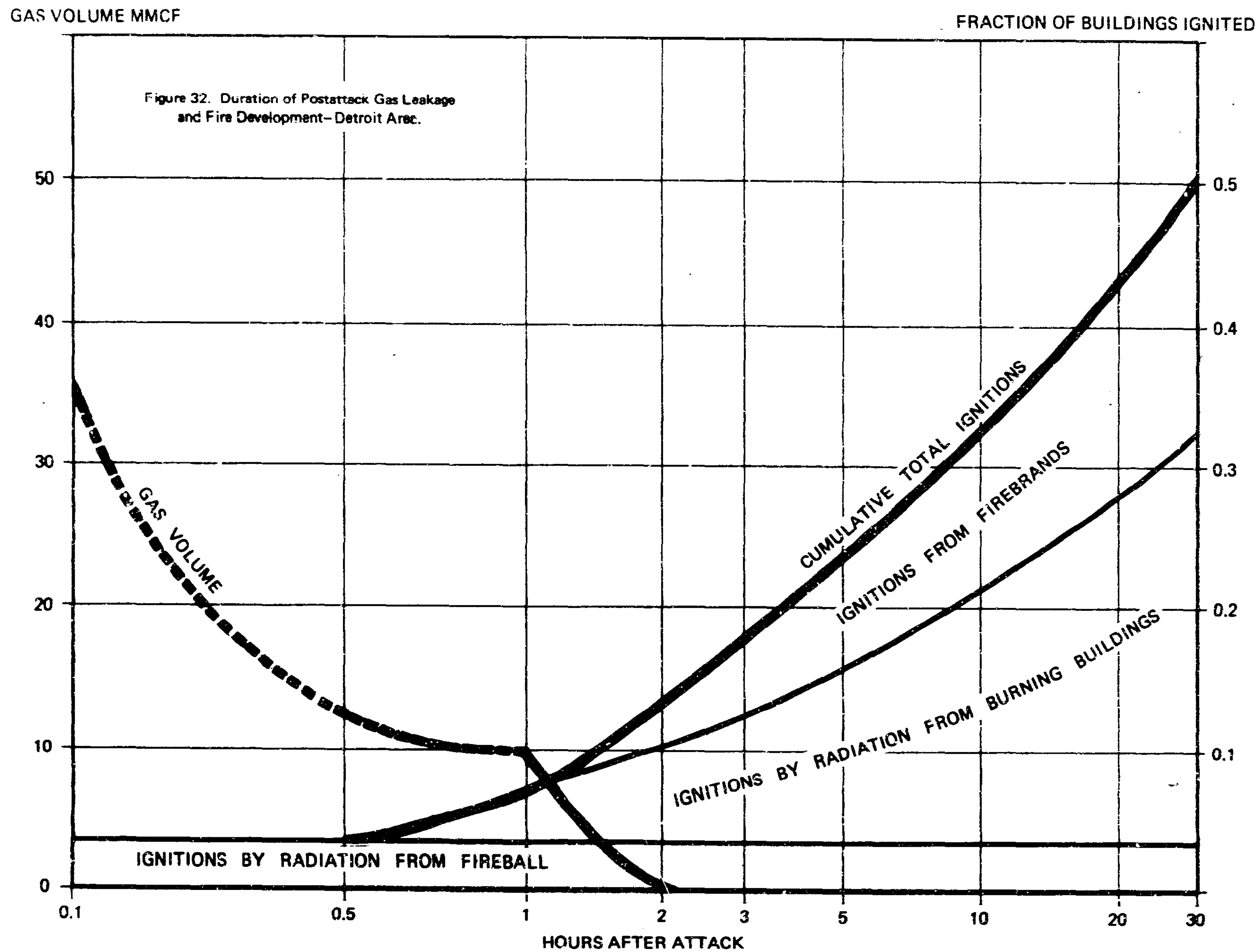

Figure 32. Duration of Postattack Gas Leakage and Fire Development–Detroit Area.

The graph indicates that leaking gas is not a participant in the major phase of fire expansion in Detroit beginning about 1-1/2 hours after the attack; gas volume in the system is almost depleted and is issuing from damaged household gas equipment at low pressure, see Table XVII.

Neither is leaking gas in the preceding hour, i.e. beginning about one-half hour after the attack likely to enter significantly into secondary fire initiation or spread. The chances of ignition of leaks by the two fire spread mechanisms of Figure 32 are considered to be small: *

1. The leaks, being within buildings, are shielded and unlikely to be ignited by firebrands. Ignitions, if they occur, are probably from building fires already in progress.

2. Radiant heat from burning buildings cannot, by itself, directly ignite free gas in a room or the atmosphere.

Thus, the period in which leaking gas in a building can be an important participant in fire initiation in the Detroit attack is limited the first one-half hour after the attack. During this time, the leak volume rate is not only the greatest but ignition liability from flaming matter scattered in the premises by the blast is the highest. Responsibility of gas in fire initiation, however, is restricted to those individual cases where the flaming articles which, otherwise, would have burned out harmlessly, cause gas ignition which, in turn, sets fire to the building. Unfortunately, factual data to predict the relative numbers of building fires started by gas flame as distinguished from those developing from sustained primary fires have yet to be determined.

Although decisive data as to whether service valve turn-off would have diminished fire spread in Detroit are lacking, it is felt that two general observations with respect to implication of gas in ignitions of fires are valid:

*Within the 2 to 5 psi overpressure radii in the Detroit area where fire prevention in still habitable buildings is meaningful, an estimated 91% of gas equipped buildings have basements wherein most of the gas equipment, except ranges and an occasional room circulator, are located. With overpressures in excess of 5 psi required to extensively damage basements (Reference 1, page 202), it is concluded that damage to gas equipment is light and probability of fire therefrom is of small order.

1. Service valve turn-off by householders would not have prevented nor reduced the extent of fire spread in the Detroit attack.

The predicted percentage of buildings ignited by fireball radiation is a calculated value based on a formula in which are assembled pertinent parameters involved in the mechanism of igniting fuels arrays in a room to ultimately produce a sustained fire (Reference 7, Vol. 1). The possible presence of gas or probability of its ignition, if present, are not discussed in the formula derivation. It is concluded, therefore, that the predicted ignitions are solely, or nearly, the product of fireball radiation and fuel arrays. They are unaided by gas and would have happened irrespective of turned-off service valves.

2. The assumption that pilot flames are likely to ignite gas leaking from damaged equipment in an excessive number of instances is questionable. Consideration of pilot operation in an environment, violently altered by the blast, casts doubt that a pilot flame can remain lighted. To remain an ignition source, it must survive two effects of the blast:

(a) *Turbulent air conditions leading to flame extinguishment.* Where gas equipment is damaged to the extent that significant volumes of gas are released, air movement in the vicinity of the pilot will be violent from overpressures in excess of 2 psi and 70 mph wind entering the premises through blown in doors and windows. In contrast, laboratory test approval for pilot flame stability employs a 7 mph air stream directed at the appliance.

(b) *Reversal of flow through the pilot orifice and interruption of pilot flame fuel supply.* This action is definitely possible as blast overpressure, measured in psi., seeks to equalize the 4 oz. houseline pressure by back flow through the pilot orifice. Transient interruption of fuel flow will extinguish the pilot flame.

Although overpressure will affect the service regulator too, the device's response is relatively slow. In indoor sets (amounting to more than 90% in Detroit) time is required for overpressure to travel through 5 to 6 feet of vent tubing and build up pressure in the diaphragm chamber before the regulator can react fully and raise pressure in the entire houseline. Air entering the houseline at a point of damage can also equalize pressure tending to offset back flow through the pilot orifice. But again, it is a slower action since perceptible time is required to fracture flexible pipe. In the meantime, peak overpressure is present at the orifice to interrupt fuel flow.

Although there are many configurations of house piping and locations of regulators with respect to a blast front, it appears that only where the device is subject to reflected overpressure can it respond fast enough to offset overpressure at the orifice and prevent back flow through the pilot orifice.

This study does not have laboratory or field data on this aspect of pilot performance under nuclear attack conditions. The theorized actions seem reason and distinctly probable. It is recommended that detailed study be considered.

Gas System Volumes Immediately Prior to Attack and Prior to System Shutdown at Northwestern Station

The gas volumes contained in the distribution system parts are given in Table XVII.

The line pack volumes existing immediately prior to the attack are calculated from known diameters and mileages of mains and pressures maintained therein by regulators for the "pilot light" load of 4.5 MMCFH.

The 0.445 MMCF Volume of pack in the cast iron grid is depleted in a short time by an estimated demand of 155 MMCFH resulting from leakage from damaged distribution facilities and customer utilization equipment. Grid pressure declines concurrently and has stabilized at less than 0.1 psig prior to shutdown at Northwestern. At the moment of shutdown, the cast iron grid is losing gas to the atmosphere at a rate of 15.3 MMCFH, its proportionate part of the 16 MMCFH being delivered by the 300 psig Transfer system. Similarly, the 0.322 MMCF in the steel grid

Table XVII—System Pressures and Volumes Immediately Prior to Attack and to Shutdown at Northwestern

System Component	Immediately Prior to Attack		Immediately Prior to Shutdown at Northwestern Station	
	Average Pressure psig	Volume MMCF	Average Pressure psig	Volume MMCF
Grid:				
cast iron	1.5	0.445	< 0.1*	Negligible
steel	10	0.322	< 0.2	Negligible
Intermediate Transfer supplying:				
cast iron grid	75	13.91	< 0.2	Negligible
steel grid	75	3.95	< 0.3	Negligible
300 psig Transfer	150	17.70	87	10.1
Total system		36.33		10.1

*Calculated from the expression:

$$\frac{p^2 - 14.4p}{(15.9)^2 - (14.4)(15.9)} = \left(\frac{15.3}{155}\right)^2$$

where p is the pressure to discharge 15.3 MMCFH to the atmosphere.

declines rapidly in response to an estimated 7 MMCFH loss from damaged facilities and equipment in its service area.

The 13.91 MMCF Volume in the portion of the intermediate pressure Transfer system feeding the cast iron grid, plus 7.3 MMCF of its proportionate part of the 7.67 delivered by the 300 psig Transfer system, declines to a negligible volume as the 358 district regulators with 370 MMCFH capacity try to hold the 1.5 psig pressure in the grid.

The 10.1 MMCF is the calculated volume remaining in the 300 psig Transfer system prior to shutdown at Northwestern. At shutdown, it is delivering gas to the intermediate system at a rate of 16 MMCFH.

PROPOSAL THAT HOUSEHOLDERS TURN OFF GAS SUPPLIES TO PREMISES

DISCUSSION AND COMMENT BY OFFICE OF CIVIL DEFENSE RESEARCH DIVISION

1. The danger from ignitions from pilot lights is probably not of major importance but is nevertheless real. A more important source of ignition of gas issuing from broken connections is as follows. First, most homes would not survive at overpressures above 2 or 3 psi. However, since we do not know which homes will be in those regions we must assume that *every* home *may* survive. At overpressures of one to three psi, for homes which survive, the following sequence of events occurs. (Discussion for the present is confined to homes with basements.) The blast enters the first story through windows and doors. It loads the floor over the basement which very rapidly (even before the blast overpressure can fill the basements) deflects from one to six inches depending on the joist spacing and spans. For these kinds of houses the gas service commonly is firmly attached to the under side of the joist and the service drops to furnaces, hot water heaters, and dryers often entering vertically into a connection to the appliance burner.

Deflections of one to six inches would surely break a vast percentage of these connections and gas (even at a pressure of 1/4 psi) will flow freely for a short time before the basement fills with pressure. If the appliance is burning at the time, there is a high probability that the gas will ignite thus increasing the probability of a fire initiation. This low overpressure in which the houses survive is the very region where the probability of ignition from the thermal pulse is low. (There is also a finite probability that the gas would be ignited by the pilot light alone.)

2. Pg. 187—Refers to the absence of fire in the Nevada tests. Gas was piped to an appliance in the house at 5 psi but was *turned off* prior to the test. There was no fire. Gas was not available to the houses at 2.4 and 4 psi and of course there was no fire. Gas was piped to the house (especially strengthened for this test) located at 1.7 psi and the pilot was left burning.

In addition to the fact that the house was strengthened and a small weapon was used, the house had no basement. The blast blew the pilot out and there was no fire. In other words the most common condition of greatest occurrence was never simulated in *any* full scale field test.

APPENDIX G

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GLOSSARY OF TERMS

1. *City Gate Station*—A station, generally at the terminus of a transmission system, which receives and meters the incoming supply and delivers pressure regulated volumes to outgoing Transfer Main System.

2. *Gas Main*—A general term denoting a pipeline transporting fuel gas within the distribution system.

3. *Grid System*—A network of interconnected mains in built-up areas from which gas service lines are supplied street by street.

4. *Meter Set*—An assembly of equipment, usually located on the customer's premises, but owned by the utility. The order of equipment items proceeding downstream from the service line termination are: service valve, service regulator and meter. The equipment functions to meter and deliver gas at standard pressure to the inlet of the customer's houseline.

5. *Gas Service Line*—The gas piping which conveys gas from the grid main in the street to the meter set on the customer's premises.

6. *Transfer Main System*—A local term denoting a network of major and secondary mains located in city streets or public thoroughfares and operating in the range of 10 to 300 psig. The mains function to take gas from City Gate Stations at pressures up to 300 psig and del ver volumes at 2 and 10 psig, after several or more stages of pressure reduction, to the cast iron and steel grid systems.

7. *Transmission System*—A single pipeline, or several or more in parallel, generally of large diameter, operating a high pressure and located on a private right-of-way, used for transporting gas from the area of origin (Interstate pipeline supplier, producing field, processing plant, compressor station) to a City Gate Station.

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