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Wisconsin Groundwater Management Practice Monitoring Project No. 9

GROUNDWATER
Wisconsin's buried treasure

Wisconsin Department of Natural Resources

West Bend Area Road Salt Use Study

Prepared for the
Department of Natural Resources

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October 23, 1990

Southeast District
Milwaukee, Wisconsin

West Bend Area Road Salt Use Study

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INTRODUCTION

Chlorides in groundwater are of concern to private well owners. There is no health-related drinking water standard for chloride. However, chlorides present in concentrations above 250 milligrams per liter (250 mg/l) impart a salty taste to drinking water and make it undesirable for consumption.

A study was undertaken at three sites in southeastern Wisconsin to determine the effect of road salt application on the concentration of chloride in groundwater. Additional parameters were analyzed to determine whether concentrations of other groundwater constituents might correlate to the chloride concentration. Several different geological settings were selected to ascertain the movement of road salt through each.

BACKGROUND

The three study sites are located within 30 miles of Milwaukee. One site is in Pewaukee, in Waukesha County, and the other two are in Germantown and West Bend, in Washington County. (Fig. 1)

The study began at the Pewaukee and Germantown sites in the fall of 1985. The West Bend site became available in the fall of 1986, before the Highway 45 freeway bypass was completed and opened to traffic.

Because there was little change in the chloride concentrations at the Pewaukee and Germantown sites, but significant increases could be traced at West Bend, sampling was suspended at the other sites but continued at West Bend.

Five years of annual well sampling were completed at the West Bend site, and three calendar quarters of seasonal sampling at Pewaukee and Germantown. Four to five wells were sampled at each site. Three downgradient wells and one to two up gradient wells were selected at each site. Sampling began in August, 1986, and was conducted through May, 1990.

MATERIALS AND METHODS

Study Sites

Site selection was based on types of geological formations, depth to water table, and proximity to high-density traffic roads with a high rate of salt application. Areas of high water table, with shallow- to moderate-depth wells, were chosen because they are historically more responsive to local activities.

Wells

Well selection was based on availability of well construction reports, accessibility for surveying and measuring water levels, and the well owner's cooperation and permission. Existing, privately owned wells were used in Pewaukee and Germantown. In West Bend, two private wells, a municipally owned test well, and a driven point installed on private property by Department of Natural Resources personnel, were used.

Field Methods

Tops of well casings were surveyed by tying into a local benchmark and leveling for elevation. Surveyors tripod level and rod were used. Surface elevation maps were drawn on copies of air photographs. (Fig. 2,3,4)

Well water levels were measured with an electric probe or mechanical plopper every time the wells were sampled. Readings were consistently taken at the surveyor's chalk mark inside the well casing. A water table map was made from the initial water level readings to determine groundwater flow direction. (Fig. 5,6,7)

Prior to sampling for inorganic chemical parameters, all wells in the study were sampled for potability (presence of coliform bacteria). This was done for two reasons: 1) determine whether well is safe before introducing water level measuring device, and 2) eliminate external source of chlorides which could enter groundwater through a structurally unsound well.

Water samples were collected from untreated, cold water taps or from a pitcher-type pump threaded onto the top of a driven point. Samples were sent through the mail to the State Laboratory of Hygiene, Madison, Wisconsin.

On occasion, a softened water sample was collected in error (Wells PSG3 and PSG5 in Germantown; Well PSP4 in Pewaukee). The high sodium value and corresponding low calcium and magnesium values were indicators of soft water. Chloride levels were consistent when checked in hard and soft water from the same well (PSG3, PSG5, and PSP4). Therefore, chloride values were interpreted from soft water results and used as data in this report. (Table 1,2)

DATA

Parameters

Background analyses were made for 13 parameters:

- Total Alkalinity ($CaCO_3$)
- Calcium
- Chloride
- Total Hardness
- Iron
- Magnesium
- Manganese
- Lab pH
- Sodium
- Sulfate
- Total Residue
- Conductivity (25 C)
- Cyanide

The 13 parameters were requested for background analyses to determine whether there were influences between chloride and other groundwater constituents, both seasonally and annually. Chloride, sodium and conductivity values were compared for seasonal and annual fluctuations at each site. (Table 1,2,3)

Sodium and chloride were coupled because they constitute road salt, and conductivity is an indicator of salinity in water. If conductivity is not in line with chloride in a sample, other constituents (different salts) are adding to the conductivity of the groundwater and additional parameters such as calcium and potassium should be analyzed.

A charge-balance equation was figured for nine of the 13 parameters for each sample. Ion and cation charges balanced, which indicated that no other parameters were missed in the investigation.

Drinking Water Standards

The aesthetic drinking water standard for chloride, per Chapter NR109, Wisconsin Administrative Code, is 250 mg/l. Water with this concentration or higher of chloride can have a salty taste. The preventive action limit (PAL) for chloride in public drinking water supplies, per Chapter NR140, is 125 mg/l.

Sodium does not have a drinking water standard, however the

American Heart Association recommends a level less than 22 mg/l in water for patients on sodium-restricted diets (Field, 1974). Excessive sodium can affect persons with high blood pressure, and heart and kidney disease (Saleem, 1977).

<u>Results</u>

Chloride

PEWAUKEE - Chloride levels were high (120 to 250 mg/l) in one up-gradient well, PSP1, and in all three down-gradient wells, PSP3, PSP4 and PSP5. Well PSP4 had a chloride level of 250 mg/l, which is at the aesthetic drinking water standard. A slight seasonal increase in chloride levels was apparent in two down-gradient wells, PSP3 and PSP5. Levels decreased slightly in one down-gradient well, PSP4, and fluctuated slightly in the up-gradient wells, PSP1 and PSP2. (Table 4)

Background inorganic chemistry results from 1951 are available for well PSP1. The chloride level was 5 mg/l in November, 1951, and 130 mg/l in February, 1986. Chlorides increased 125 mg/l in 35 years. (Table 12,13)

GERMANTOWN - Chloride levels were moderate, from 12 to 78 mg/l, and increased slightly in all five wells during the summer. Wells PSG1 and PSG5 appeared to be downgradient from the main road. (Table 5)

WEST BEND - Chloride levels were low to moderate, from 4.1 to 31 mg/l. Chloride levels increased significantly in one down-gradient well, TSW2, from 1986 through 1990. Annual levels were relatively steady in wells PSW1 and PSW3, but decreased slightly in the up-gradient well, TSW4. (Table 6)

Conductivity

PEWAUKEE - Levels were between 890 and 1200 micromhos in up-gradient wells, and 1000 to 1600 micromhos in the down-gradient wells. All wells exhibited a slight increase in conductivity levels. (Table 7)

GERMANTOWN - Levels were between 830 to 1400 micromhos. All wells exhibited a slight increase in conductivity levels. (Table 8)

WEST BEND - Conductivity readings were not considered. Values were obtained in the field from a conductivity meter. Samples at other sites were measured for conductivity by the State Lab. Because field values were not in line with lab values, for water samples with similar chloride levels, conductivity values at West Bend are deleted from the data. Future conductivity readings will be made by the state lab for all water samples.

Sodium

PEWAUKEE - Levels ranged from 24 to 70 mg/l. The down-gradient wells had a slight increase in sodium. The up-gradient wells had decreases in sodium. Well PSP1 had a sodium level of zero in 1951. In 1986, the level was 70 mg/l. (Table 9)

GERMANTOWN - Levels ranged from 4.8 to 37 mg/l, and increased in well PSG1 and remained steady in wells PSG2 and PSG4. (Table 10)

WEST BEND - Levels ranged from 2 to 7 mg/l. Sodium increased in one down-gradient well, TSW2, fluctuated in the other two down-gradient wells, PSW1 and PSW3, and decreased in the background well, TSW4. (Table 11)

Combined Parameters

PEWAUKEE - Two down-gradient wells, PSP3 and PSP5, had slight increases in chlorides, conductivity, and sodium. One up-gradient well, PSP1 showed a slight decrease in sodium and chloride. The other up-gradient well, PSP2, had a slight decrease in chloride but a large decrease in sodium. (Table 14)

GERMANTOWN - Well PSG1 had a moderate increase in chloride and sodium which correlated more closely than the increase in conductivity. (Table 15)

WEST BEND - One down-gradient well, TSW2, had a significant increase in chloride and sodium. The up-gradient well, TSW4, had a decrease in these parameters. (Table 16)

Cyanide

Cyanide was tested for because it is a break-down product of a road salt additive, ferrocyanide, which prevents caking (Field, 1974). Cyanide was not detected in any of the samples.

DISCUSSION

Road Salting Practices

During the winter of 1983-1984, 11,000 tons of sodium were applied to roads in Waukesha County, and 5,000 tons in Washington County. From 27 to 50 percent of salt applied to roads can infiltrate soil (Jones, 1981; Huling, 1972). Jones suggests that more than a year is needed to remove most of the salt applied to a watershed. And over years, there is an accumulation of salt in the ecosystem of the watershed.

Road Salt Alternatives

The literature has a variety of alternatives to or moderations of current road salt application practices. Moyland, 1980, mentions abrasives such as sand, stone dust and kitty litter, although these cannot melt ice. Blackburn, 1979, describes release agents on pavement surface to lessen the bond between ice and road surface. He also discusses induced currents, microwave and other electromagnetic radiation, mechanical percussion, ultrasound, and others.

Some alternatives have safetey and environmental drawbacks. Municipalities are aware of the potential environmental damage resulting from road salt and public works departments support careful and prudent use of road salt. The state of New Hampshire has, up to 1965, replaced more than 200 roadside private wells contaminated by road salts, some concentrations in excess of 3,500 mg/l (Field, 1974).

<u>Chloride Interference</u>

When selecting the salt study sites, other sources of chlorides were considered. Examples of chloride sources, other than road salt, are water softener backwash discharges, private septic systems effluent, wastewater treatment plant effluent, sludge drying beds, landfill leachate, and animal waste storage or land spreading locations.

In West Bend, there are two potential outside sources of chlorides. One is septic systems. However, these are down-gradient from the study wells.

The other is the City of West Bend Schuster Drive landfill. It is located one mile southwest of the salt study site. Direction of groundwater flow from the landfill location is east-northeast (Warzyn, 1989). Some private wells east of the landfill had volatile organic chemical detects greater than NR140 drinking water standards. These wells are one-half mile southwest of the study site. The study wells might eventually be within the groundwater plume from the landfill.

Well Site Descriptions

PEWAUKEE (Waukesha County) - The study site, a rural subdivision, is 20 miles west of Milwaukee. Legal Description: SW 1/4, Section 19, T7N, R19E. Interstate Highway 94, constructed more than 25 years ago, bisects the study site. Topography is hilly, with a downslope north, toward Pewaukee Lake. Homes have their own wells, but have municipal sewer. (Fig. 8)

GERMANTOWN (Washington County) - The site is 17 miles northwest of Milwaukee. Legal Description: NE 1/4, Section 22, T9N, R20E. Highway 145, or Fond du Lac Avenue, is a major street in the Village of Germantown. Topography is nearly flat, with a slight upgrade to the north. Homes have their own wells, but have municipal sewer. (Fig. 9)

WEST BEND (Washington County) - A recently constructed freeway extension is in the study site, 31 miles north of Milwaukee. Legal Description: SW 1/4, SE 1/4, Section 3, T11N, R19E.

Located just outside of the City of West Bend, these rural homes have their own wells and septic systems. Topography is hilly. (Fig. 10)

Well Site Geology and Hydrogeology

Road runoff moves through non-native soils, usually compacted fill material, before infiltrating through native soils and geologic formations (Hofstra, 1984). Construction fill material adjacent to raodbeds is more like a non-stratified till with low permeability of 0.2 to 0.8 inches per hour (USGS Atlas HA-432, 1973).

PEWAUKEE - Unsorted ground moraine deposits of clay, silt, sand, gravel and boulders. Permeability is 0.8 to 2.5 inches per hour. (USGS Atlas HA-360, 1969). From available well logs, glacial drift is 32 to 83 feet thick, overlying the Niagara dolomite bedrock. All study wells terminate in the limestone. Static water levels range from 7 to 64 feet.

GERMANTOWN - Unstratified ground moraine is primarily a clayey, silty till. Permeability is 0.2 to 0.8 inches per hour. (USGS Atlas HA-432, 1973). Three to 46 feet of clay overlies the Niagara limestone bedrock in study wells, and the bedrock outcrops locally. Static water levels range from 0.5 (occasionally flows) to 26 feet.

WEST BEND - End moraine deposits of permeable stratified sediments and till. Permeability varies from 0.8 to 5 inches per hour. (USGS Atlas HA-432, 1973). The sand and gravel aquifer varies from 60 to 138 feet thick above the Niagara limestone. There are driven point and drilled wells in the glacial drift, and a limestone well at the study site. Static water levels range from 5 to 41 feet.

Interpretation of Results

Sodium and chloride concentrations did not correlate. The sodium ion is held up in the soil and taken up by vegetation, whereas the chloride ion can move readily through soils (Jones, 1981; Murray, 1976; Saleem, 1977).

High chloride levels in Pewaukee appear due to heavy salt loading along the freeway and on the hilly roads for the past 25 years. Chloride and sodium levels are moderate in Germantown, but both increased slightly and steadily during the summer. Chloride and sodium ions can travel easily through the few feet of clay overlying the bedrock. Background chloride levels are low in West Bend, probably due to the presence of only one rural road in the area prior to the freeway extension in 1986.

Chloride levels and conductivity readings at Pewaukee and Germantown did relate, indicating chlorides from road salt are the major contributor to salts in the groundwater. Results from the charge balance equations indicated no other paramters were missed in the analyses.

Other parameters, such as alkalinity, hardness, and sulfate, had levels that appeared to be consistent background levels.

CONCLUSION

1. Road salt application appears to affect chloride concentrations in groundwater. Evidence for this is the significant increase in chloride concentration over time in well TSW2 in West Bend and well PSP1 in Pewaukee.

   Chlorides from road salt appear to have negatively impacted well PSP3 in Pewaukee. Chloride levels are at the secondary inorganic chemical (aesthetic) standard of 250 mg/l, per Chapter NR 109 of the Wisconsin Administrative Code. Chloride levels at wells PSP1 and PSP4 are at and above the Preventive Action Limit, PAL, of 125 mg/l, per Chapter NR 140. There has been an unacceptable impact on groundwater at this site.

   Chloride levels increased significantly in well TSW2 in West Bend. The benefit of this site is that there is background data available for groundwater quality prior to freeway construction and road salting. Although chloride levels are below PAL and aesthetic drinking water standards at this site, and there is no adverse impact to groundwater at this time, indications from the data are that chlorides will continue to increase over time.

Judging from the increase in chlorides over 35 years at the Pewaukee site, it could take about 25 years for the chlorides to reach PAL concentrations at the West Bend site.

2. No pattern of similar concentrations was observed among other groundwater constituents and chloride. There was insufficient data available to say whether there might be relationships over time.

3. The sand and gravel sediments at the West Bend site appears to be the most permeable of the three geologic settings. The most significant and steady increase in chloride concentration over time was observed in one well at this site.

4. Permeability at the sites ranges from 0.2 to 5 inches per hour (USGS Atlases HA-360, 1969; HA-432, 1973). Taking average depths of the drift at each site, and average permeabilities, travel time of infiltrated road runoff would take from 17 to 26 days to reach the bedrock. Considering

that frost leaves the ground in mid-April, May and June appear good times to sample for chlorides.

RECOMMENDATIONS

1. Continue to sample annually at West Bend for chlorides, sodium, conductivity, for at least five more years.

2. Sample every five years for all 13 background parameters at all three sites.

3. Collect a background volatile organic water sample at West Bend and repeat every 5 years.

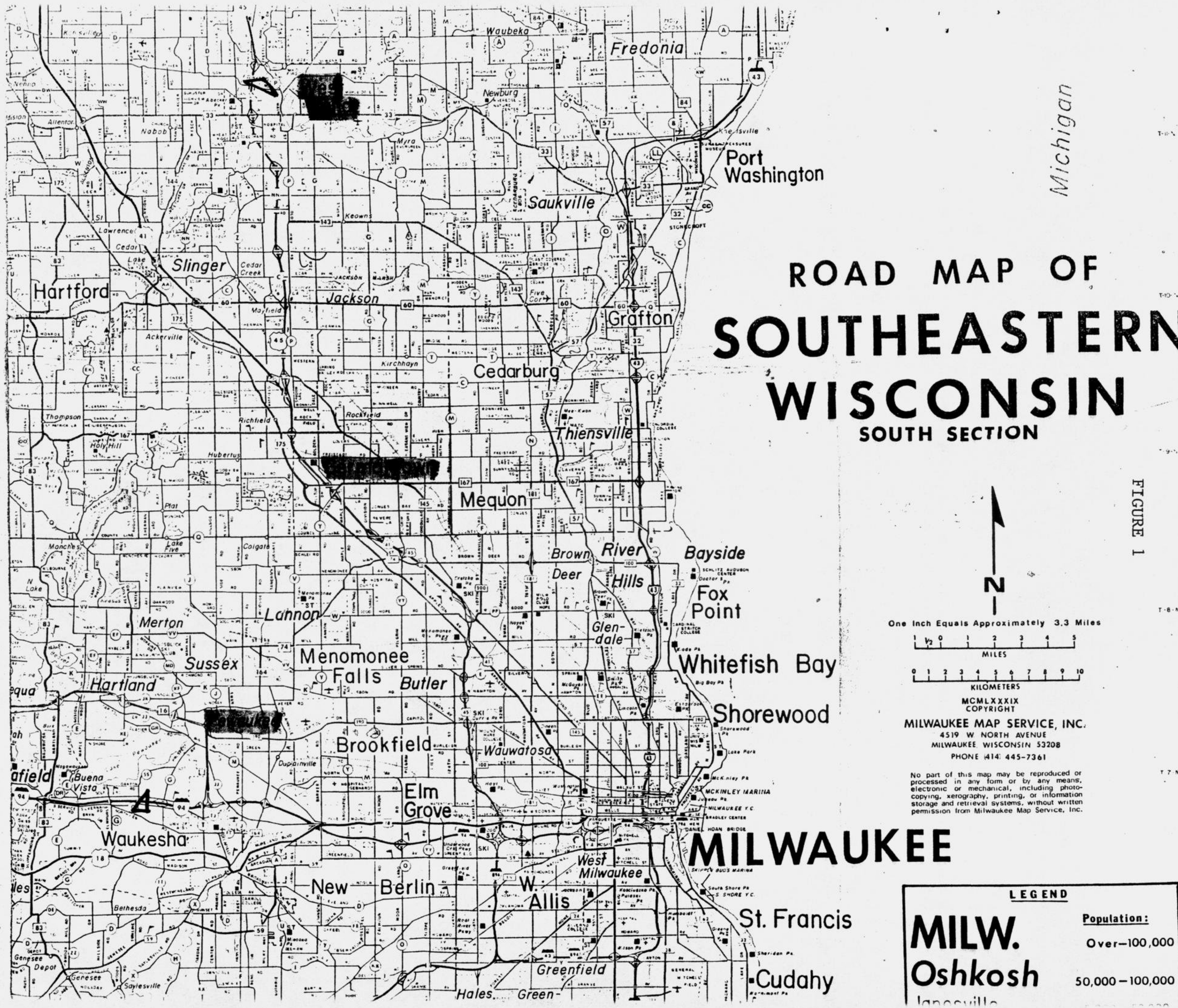
4. Investigate existing and potential additional chloride sources when selecting a road salt study site.

5. Consider that roadside construction fill could have different permeability than native soils.

6. Inform private well owners about chlorides in groundwater and suggest collection of an initial chloride sample, then repeat sampling every three to five years to establish a history.

7. State of Wisconsin should continue to investigate, develop and implement alternative methods of clearing roads of snow and ice which maintain public safety and environmental protection.

8. Advise the legislature of the possibility of future law suits against local governments from private well owners for chloride contamination of drinking water. Consider preparing a relief fund to assist homeowners to drill new wells or connect to city water where available.


ROAD MAP OF
SOUTHEASTERN
WISCONSIN
SOUTH SECTION
Michigan
N
One Inch Equals Approximately 3.3 Miles
MILES
KILOMETERS
MCMLXXXIX
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LEGEND
Population:
MILW. Over—100,000
Oshkosh 50,000—100,000
Fredonia
Port Washington
Saukville
Slinger
Hartford
Jackson
Grafton
Cedarburg
Thiensville
Mequon
Brown Deer
River Hills
Bayside
Fox Point
Glendale
Whitefish Bay
Shorewood
Merton
Lannon
Sussex
Menomonee Falls
Butler
Hartland
Brookfield
Wauwatosa
Elm Grove
Waukesha
MILWAUKEE
New Berlin
West Milwaukee
W. Allis
St. Francis
Cudahy
Greenfield
Hales
Green

FIGURE 1

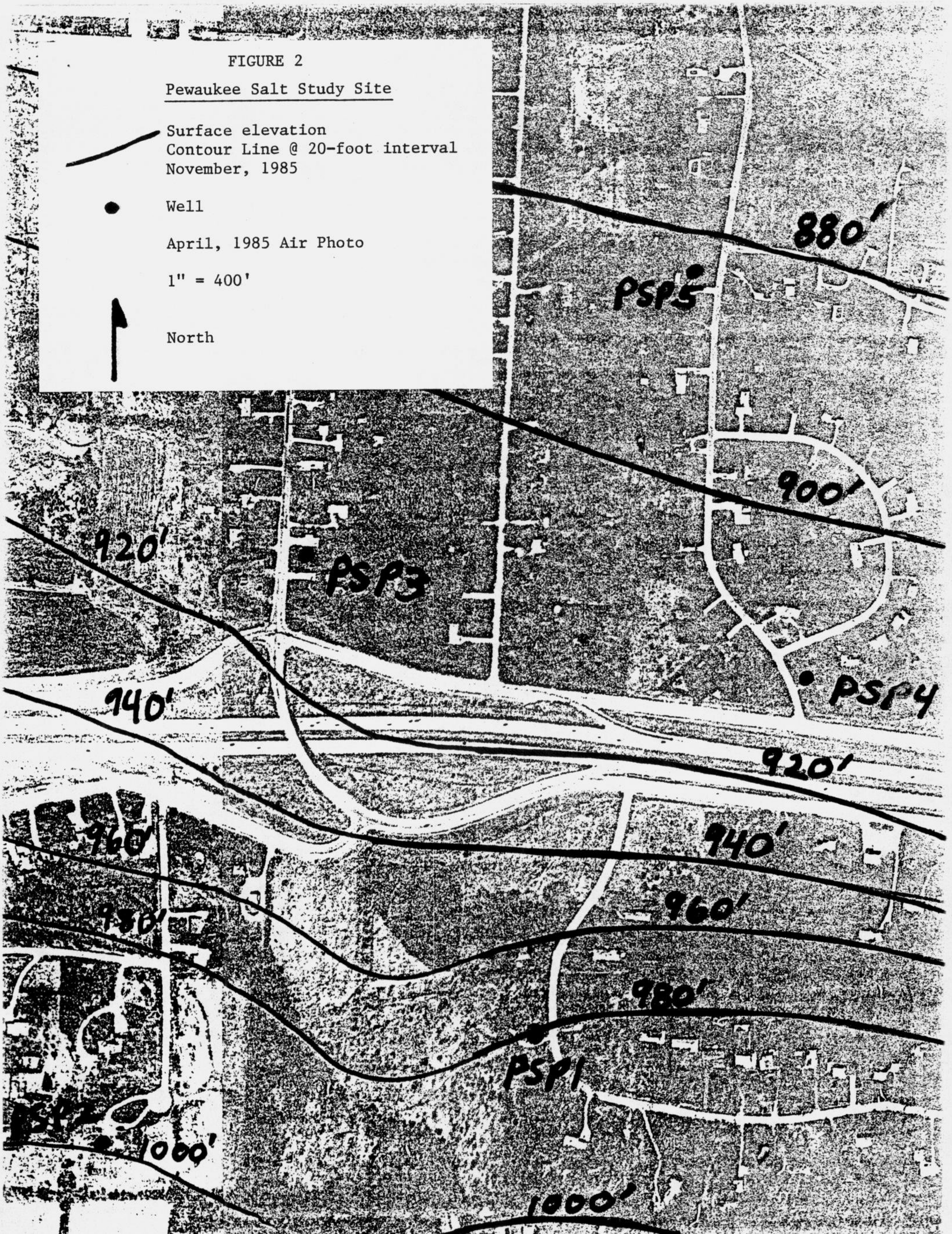


FIGURE 2

Pewaukee Salt Study Site

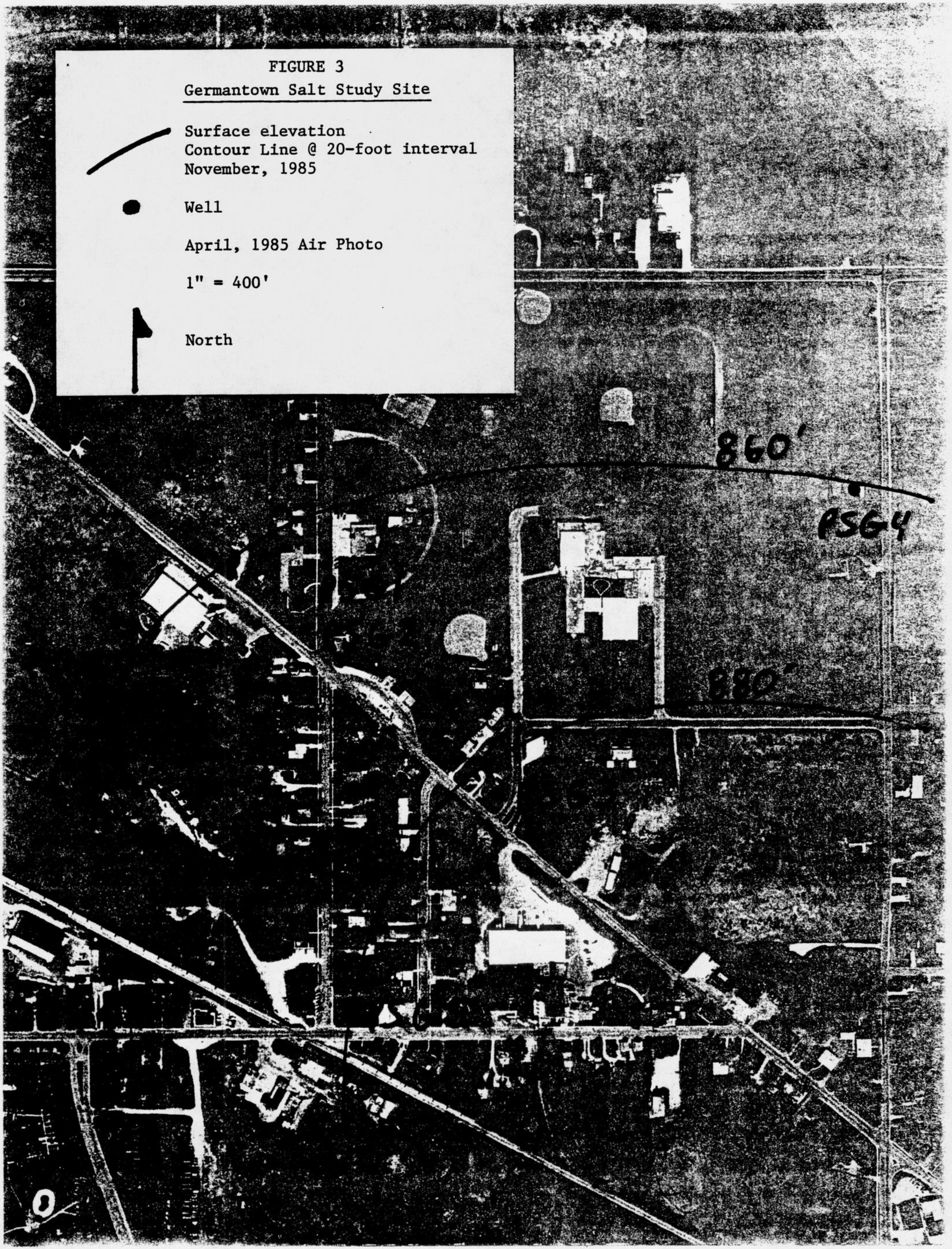


FIGURE 3
Germantown Salt Study Site

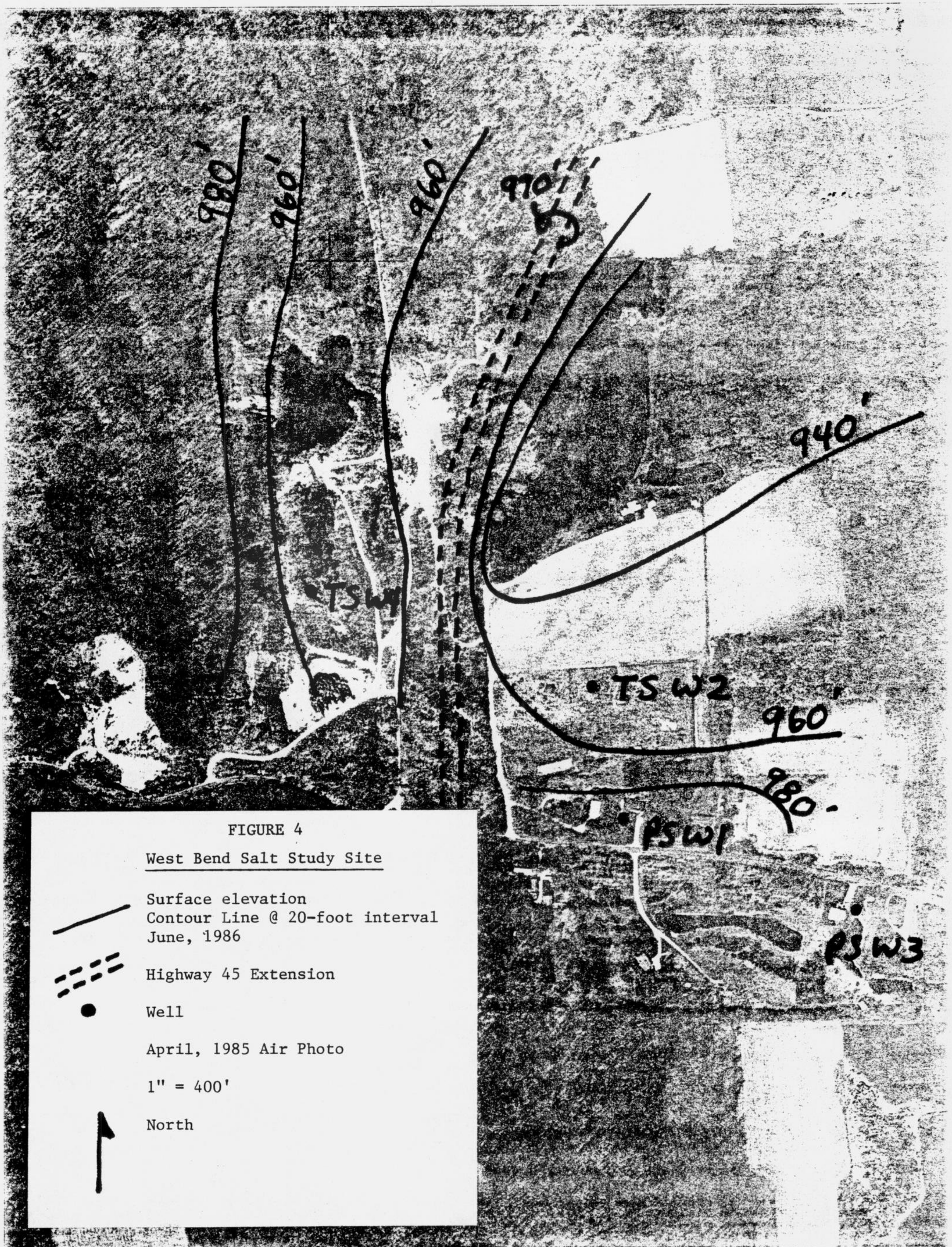


FIGURE 4

West Bend Salt Study Site

NOVEMBER 1985 GROUNDWATER ELEVATION PEWAUKEE

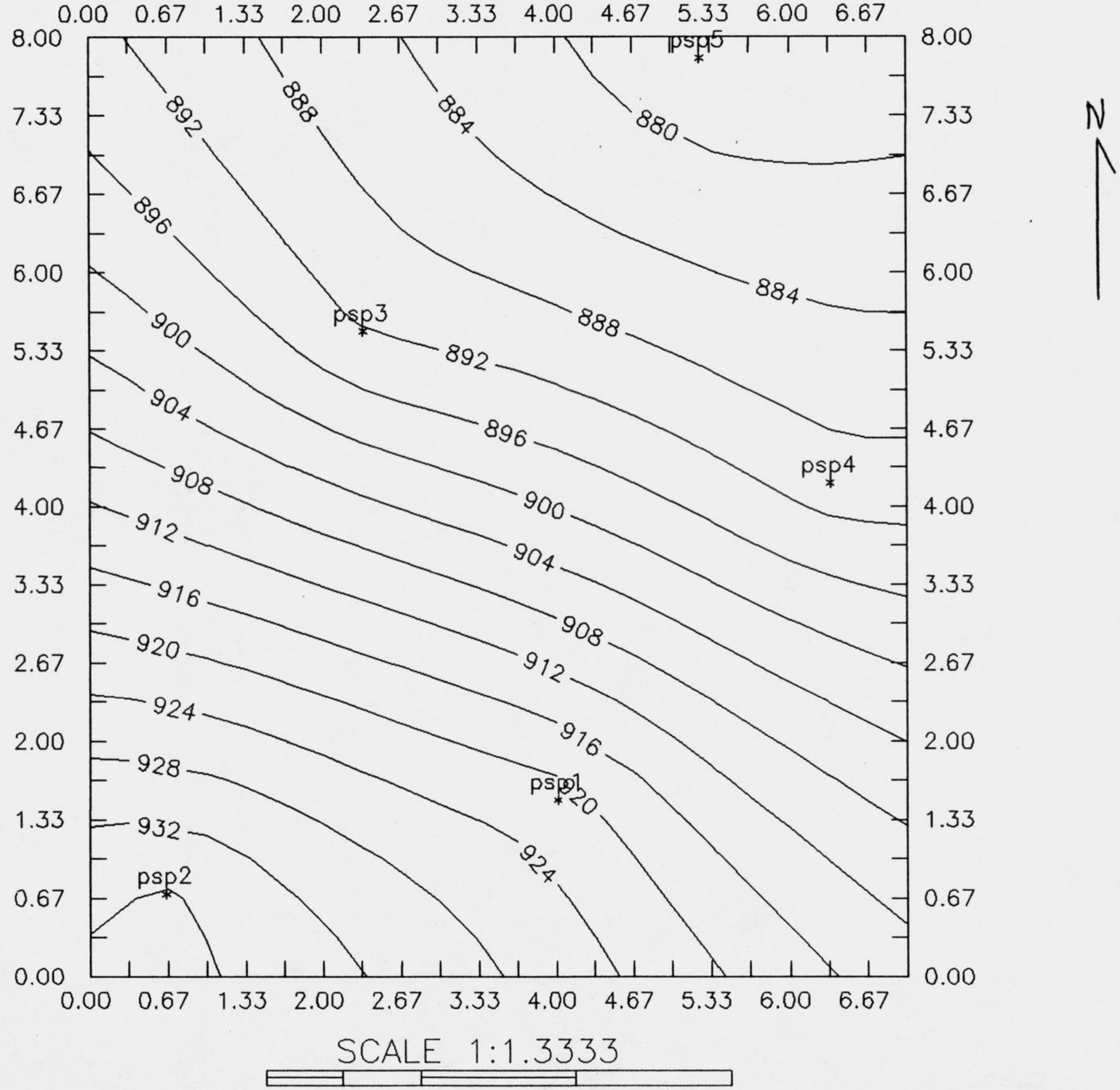


FIGURE 5

NOVEMBER 1985 GROUNDWATER ELEVATION GERMANTOWN

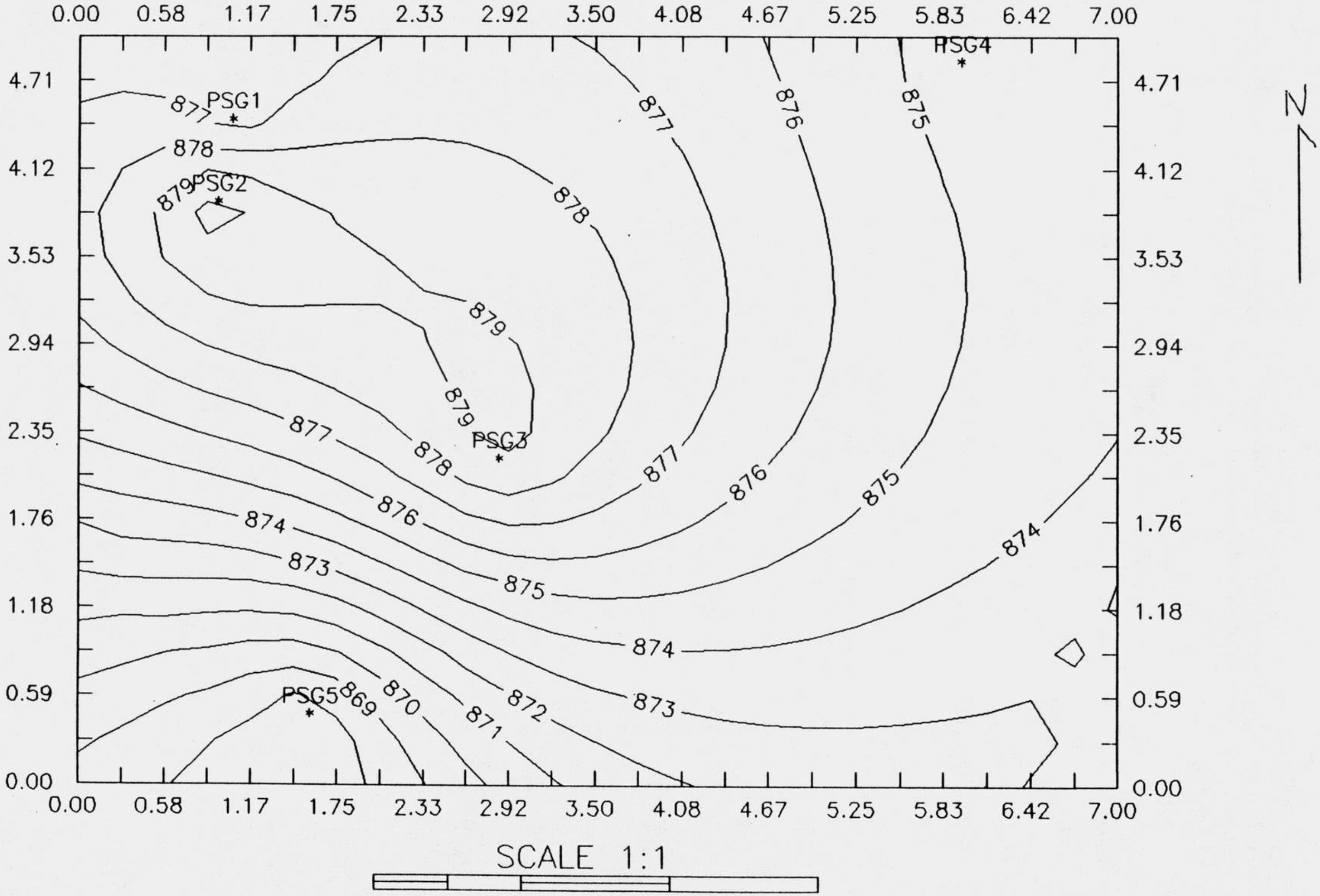


FIGURE 6

JUNE 1986 GROUNDWATER ELEVATION WEST BEND SITE

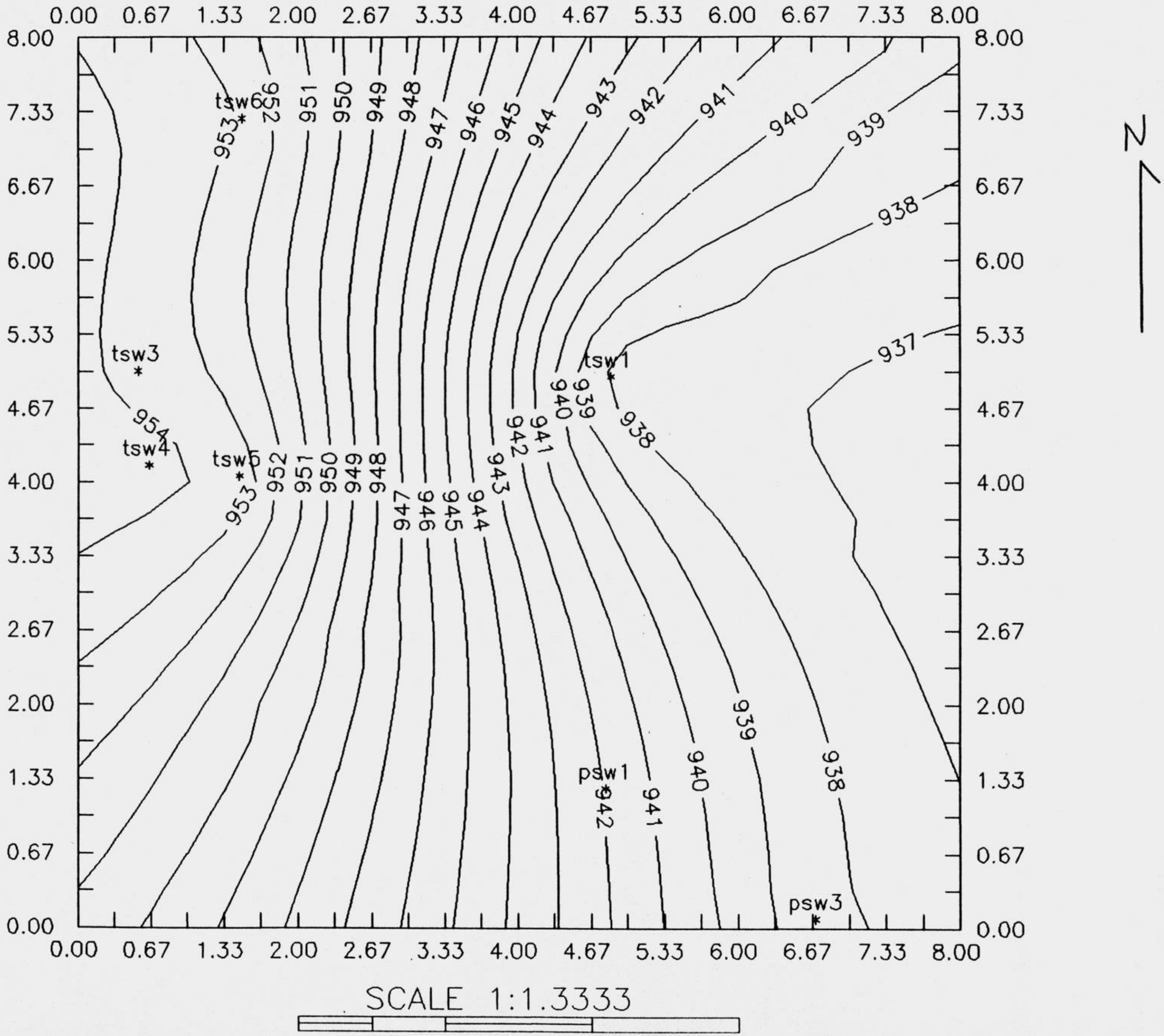
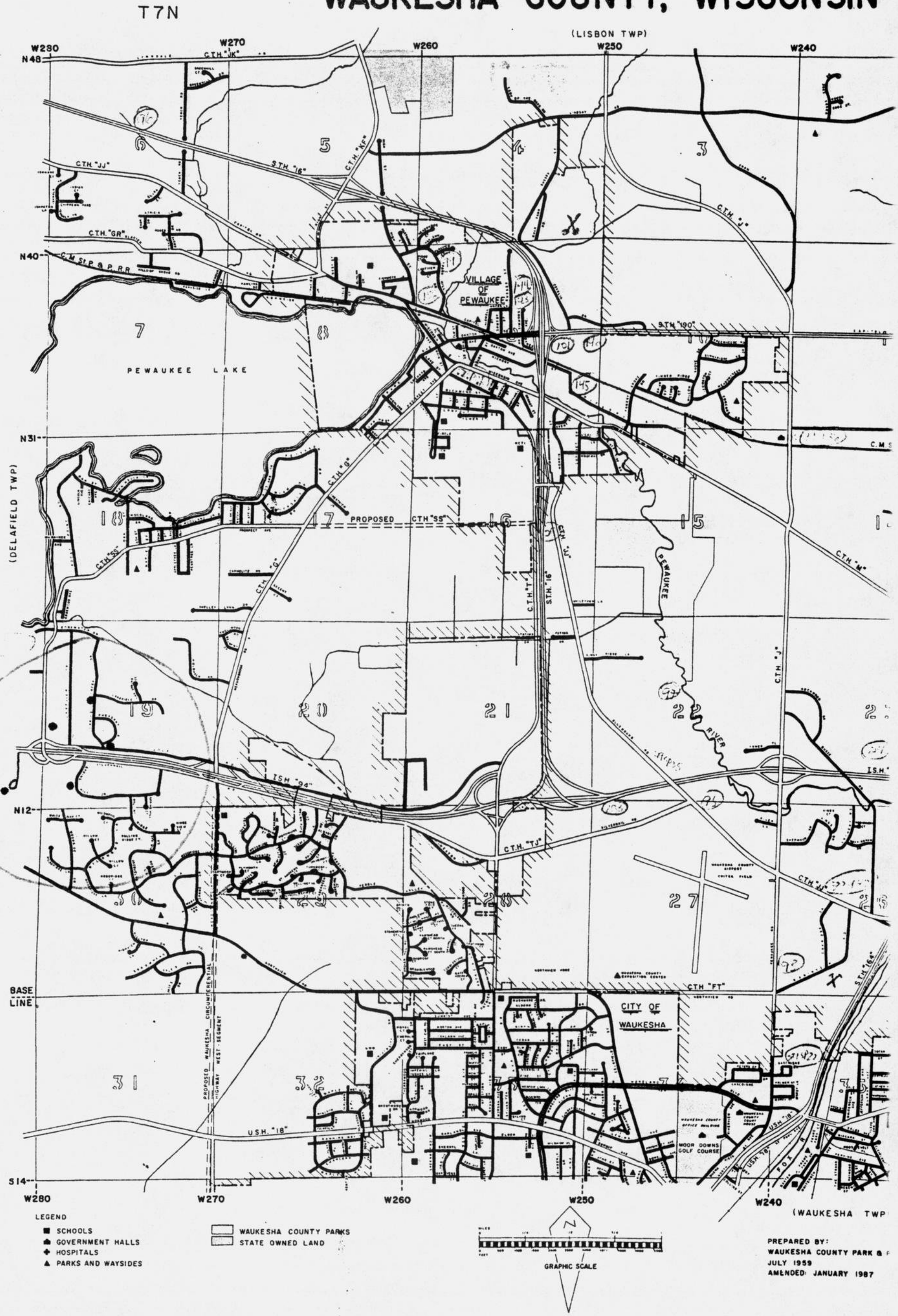


FIGURE 7

FIGURE 8

PEWAUKEE TOWNSHIP
WAUKESHA COUNTY, WISCONSIN



GERMANTOWN T. 9N.-R. 20E.

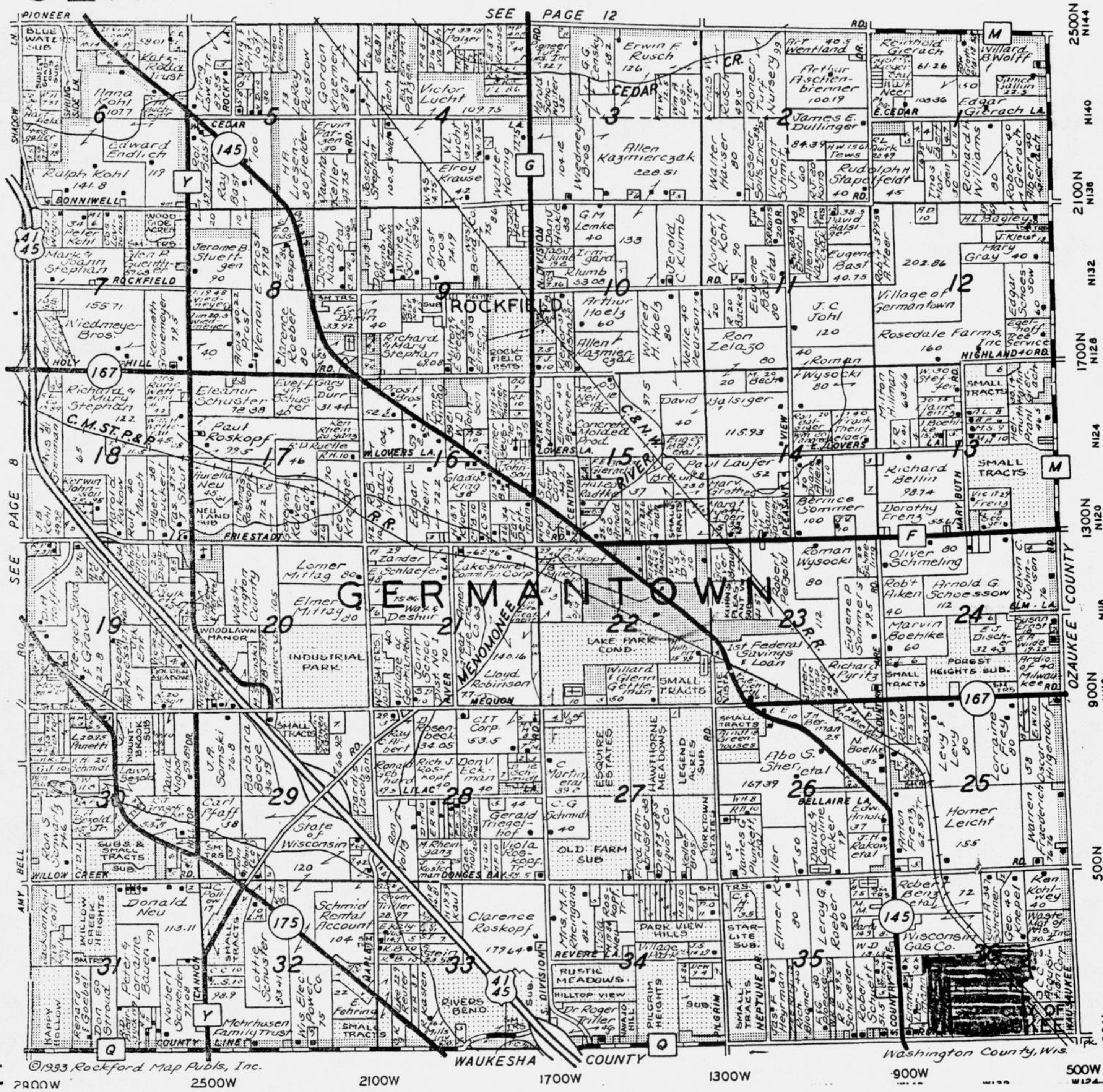


FIGURE 9

1983 Land Atlas and Plat Book
Washington-Ozaukee County, Wisconsin
Rockford Map Publishers, Inc.

16 BARTON T.11-12N.-R.19E.

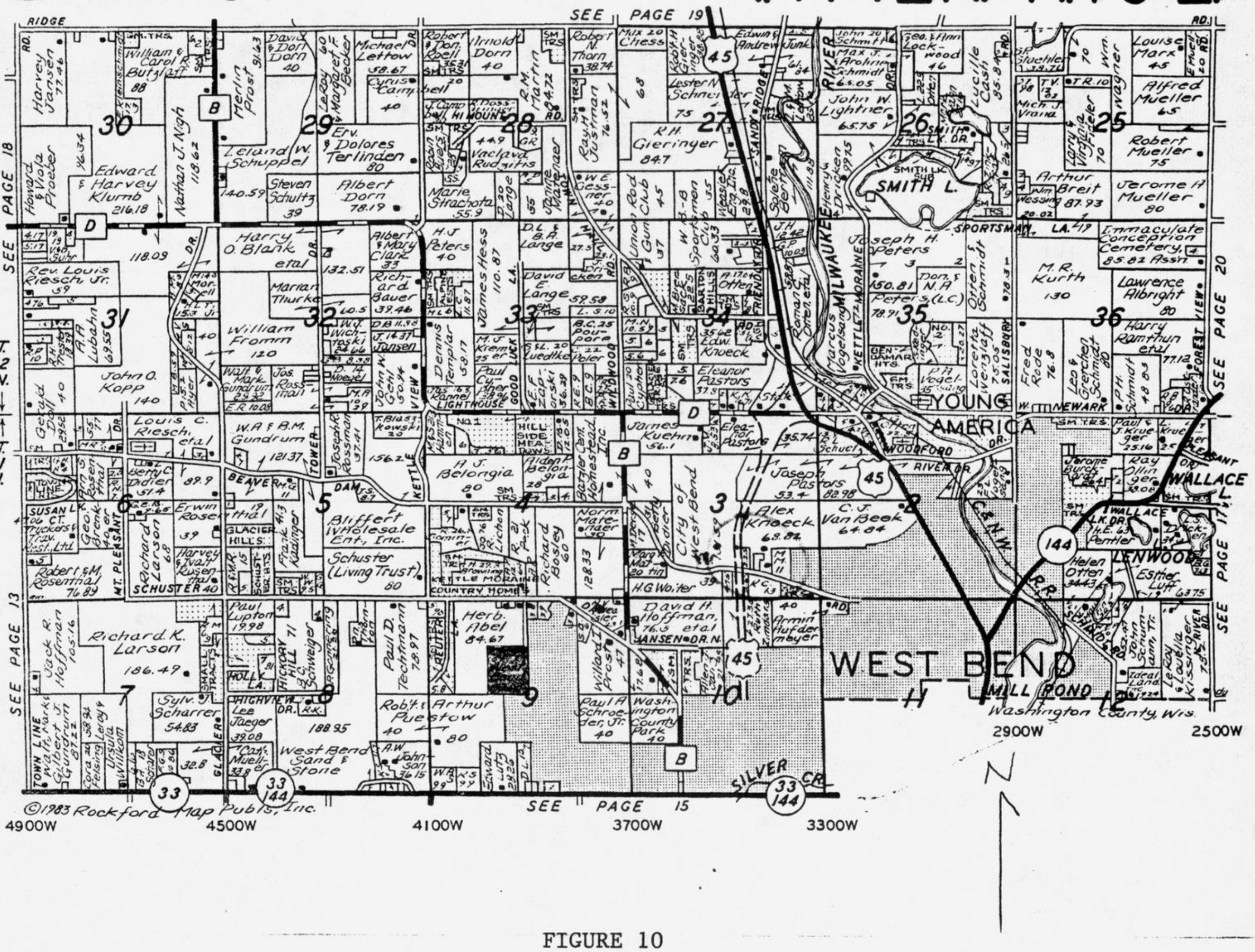


FIGURE 10

1983 Land Atlas and Plat Book
Washington-Ozaukee County Wisconsin
Rockford Map Publishers, Inc.

TABLE 1

PEWAUKEE SITE

([redacted])

PSP1 2/11/86

T ALK	CACO3	MG/L	365
CALCIUM	CA-TOT	MG/L	110
CHLORIDE	CL	MG/L	130
TOT HARD	CACO3	MG/L	480
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	50
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.8
SODIUM	NA,TOT	MG/L	70
SULFATE	SO4-TOT	MG/L	39
RESIDUE	TOTAL	MG/L	694
CNDUCTVY	AT 25C	MICROMHO	1100
CYANIDE	CN	MG/L	<0.01

PSP1 5/15/86

T ALK	CACO3	MG/L	360
CALCIUM	CA-TOT	MG/L	97
CHLORIDE	CL	MG/L	140
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	48
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.6
SODIUM	NA,TOT	MG/L	67
SULFATE	SO4-TOT	MG/L	39
RESIDUE	TOTAL	MG/L	708
CNDUCTVY	AT 25C	MICROMHO	1100
CYANIDE	CN	MG/L	<0.01

PSP1 8/13/86

T ALK	CACO3	MG/L	366
CALCIUM	CA-TOT	MG/L	98
CHLORIDE	CL	MG/L	130
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	48
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.6
SODIUM	NA,TOT	MG/L	68
SULFATE	SO4-TOT	MG/L	36
RESIDUE	TOTAL	MG/L	698
CNDUCTVY	AT 25C	MICROMHO	1200
CYANIDE	CN	MG/L	<0.01

PSP2 2/11/86

WATER	TEMP	CENT	14
T ALK	CACO3	MG/L	357
CALCIUM	CA-TOT	MG/L	84
CHLORIDE	CL	MG/L	58
TOT HARD	CACO3	MG/L	380
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	41
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.6
SODIUM	NA,TOT	MG/L	62
SULFATE	SO4-TOT	MG/L	39
RESIDUE	TOTAL	MG/L	554
CNDUCTVY	AT 25C	MICROMHO	910
CYANIDE	CN	MG/L	<0.01

PSP2 5/15/86

T ALK	CACO3	MG/L	352
CALCIUM	CA-TOT	MG/L	94
CHLORIDE	CL	MG/L	56
TOT HARD	CACO3	MG/L	430
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	48
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.3
SODIUM	NA,TOT	MG/L	24
SULFATE	SO4-TOT	MG/L	39
RESIDUE	TOTAL	MG/L	590
CNDUCTVY	AT 25C	MICROMHO	890
CYANIDE	CN	MG/L	<0.01

PSP2 8/13/86

T ALK	CACO3	MG/L	344
CALCIUM	CA-TOT	MG/L	94
CHLORIDE	CL	MG/L	56
TOT HARD	CACO3	MG/L	230
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	48
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.7
SODIUM	NA,TOT	MG/L	24
SULFATE	SO4-TOT	MG/L	37
RESIDUE	TOTAL	MG/L	572
CNDUCTVY	AT 25C	MICROMHO	940
CYANIDE	CN	MG/L	<0.01

PSP3 2/11/86

WATER	TEMP	CENT	11
T ALK	CACO3	MG/L	342
CALCIUM	CA-TOT	MG/L	100
CHLORIDE	CL	MG/L	130
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	0.1
MGNSIUM	MG,TOT	MG/L	47
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.4
SODIUM	NA,TOT	MG/L	67
SULFATE	SO4-TOT	MG/L	37
RESIDUE	TOTAL	MG/L	658
CNDUCTVY	AT 25C	MICROMHO	1000
CYANIDE	CN	MG/L	<0.01

PSP3 5/15/86

T ALK	CACO3	MG/L	337
CALCIUM	CA-TOT	MG/L	92
CHLORIDE	CL	MG/L	140
TOT HARD	CACO3	MG/L	410
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	44
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.2
SODIUM	NA,TOT	MG/L	67
SULFATE	SO4-TOT	MG/L	37
RESIDUE	TOTAL	MG/L	686
CNDUCTVY	AT 25C	MICROMHO	1100
CYANIDE	CN	MG/L	<0.01

PSP3 8/13/86

T ALK	CACO3	MG/L	330
CALCIUM	CA-TOT	MG/L	92
CHLORIDE	CL	MG/L	150
TOT HARD	CACO3	MG/L	420
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	46
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.7
SODIUM	NA,TOT	MG/L	73
SULFATE	SO4-TOT	MG/L	36
RESIDUE	TOTAL	MG/L	712
CNDUCTVY	AT 25C	MICROMHO	1200
CYANIDE	CN	MG/L	<0.01

PSP4 2/11/86

WATER	TEMP	CENT	13
T ALK	CACO3	MG/L	382
CALCIUM	CA-TOT	MG/L	1
CHLORIDE	CL	MG/L	250
TOT HARD	CACO3	MG/L	<6
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	<1
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.3
[redacted]			
SULFATE	SO4-TOT	MG/L	58
RESIDUE	TOTAL	MG/L	940
CNDUCTVY	AT 25C	MICROMHO	1500
CYANIDE	CN	MG/L	<0.01

PSP4 5/15/86

T ALK	CACO3	MG/L	386
CALCIUM	CA-TOT	MG/L	120
CHLORIDE	CL	MG/L	240
TOT HARD	CACO3	MG/L	580
IRON	FE	MG/L	0.3
MGNSIUM	MG,TOT	MG/L	67
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.0
SODIUM	NA,TOT	MG/L	54
SULFATE	SO4-TOT	MG/L	58
RESIDUE	TOTAL	MG/L	982
CNDUCTVY	AT 25C	MICROMHO	1500
CYANIDE	CN	MG/L	<0.01

PSP4 8/13/86

T ALK	CACO3	MG/L	380
CALCIUM	CA-TOT	MG/L	150
CHLORIDE	CL	MG/L	240
TOT HARD	CACO3	MG/L	710
IRON	FE	MG/L	0.2
MGNSIUM	MG,TOT	MG/L	82
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.5
SODIUM	NA,TOT	MG/L	56
SULFATE	SO4-TOT	MG/L	55
RESIDUE	TOTAL	MG/L	1150
CNDUCTVY	AT 25C	MICROMHO	1600
CYANIDE	CN	MG/L	<0.01

PSP5 2/11/86

WATER	TEMP	CENT	10
T ALK	CACO3	MG/L	348
CALCIUM	CA-TOT	MG/L	110
CHLORIDE	CL	MG/L	120
TOT HARD	CACO3	MG/L	530
IRON	FE	MG/L	1.9
MGNSIUM	MG,TOT	MG/L	63
MANGNESE	MN	UG/L	100
LAB	PH	SU	7.8
SODIUM	NA,TOT	MG/L	34
SULFATE	SO4-TOT	MG/L	72
RESIDUE	TOTAL	MG/L	718
CNDUCTVY	AT 25C	MICROMHO	1100
CYANIDE	CN	MG/L	<0.01

PSP5 5/15/86

T ALK	CACO3	MG/L	348
CALCIUM	CA-TOT	MG/L	96
CHLORIDE	CL	MG/L	130
TOT HARD	CACO3	MG/L	490
IRON	FE	MG/L	1.4
MGNSIUM	MG,TOT	MG/L	60
MANGNESE	MN	UG/L	90
LAB	PH	SU	8.2
SODIUM	NA,TOT	MG/L	37
SULFATE	SO4-TOT	MG/L	78
RESIDUE	TOTAL	MG/L	794
CNDUCTVY	AT 25C	MICROMHO	1100
CYANIDE	CN	MG/L	<0.01

PSP5 8/13/86

T ALK	CACO3	MG/L	340
CALCIUM	CA-TOT	MG/L	100
CHLORIDE	CL	MG/L	130
TOT HARD	CACO3	MG/L	520
IRON	FE	MG/L	1.9
MGNSIUM	MG,TOT	MG/L	65
MANGNESE	MN	UG/L	110
LAB	PH	SU	7.8
SODIUM	NA,TOT	MG/L	37
SULFATE	SO4-TOT	MG/L	76
RESIDUE	TOTAL	MG/L	796
CNDUCTVY	AT 25C	MICROMHO	1200
CYANIDE	CN	MG/L	<0.01

TABLE 2

GERMANTOWN SITE

[redacted]

PS81			2/12/86
WATER	TEMP	CENT	10
T ALK	CACO3	MG/L	304
CALCIUM	CA-TOT	MG/L	110
CHLORIDE	CL	MG/L	47
TOT HARD	CACO3	MG/L	480
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	51
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.4
SODIUM	NA,TOT	MG/L	21
SULFATE	SO4-TOT	MG/L	120
RESIDUE	TOTAL	MG/L	634
CNDUCTVY	AT 25C	MICROMHO	960
CYANIDE	CN	MG/L	<0.01

PS81			5/16/86
T ALK	CACO3	MG/L	308
CALCIUM	CA-TOT	MG/L	93
CHLORIDE	CL	MG/L	41
TOT HARD	CACO3	MG/L	430
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	48
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.2
SODIUM	NA,TOT	MG/L	17
SULFATE	SO4-TOT	MG/L	120
RESIDUE	TOTAL	MG/L	596
CNDUCTVY	AT 25C	MICROMHO	900
CYANIDE	CN	MG/L	<0.01

PS81			8/13/86
T ALK	CACO3	MG/L	310
CALCIUM	CA-TOT	MG/L	98
CHLORIDE	CL	MG/L	78
TOT HARD	CACO3	MG/L	530
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	70
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.7
SODIUM	NA,TOT	MG/L	37
SULFATE	SO4-TOT	MG/L	96
RESIDUE	TOTAL	MG/L	702
CNDUCTVY	AT 25C	MICROMHO	1100
CYANIDE	CN	MG/L	<0.01

PS82			2/12/86
WATER	TEMP	CENT	11
T ALK	CACO3	MG/L	324
CALCIUM	CA-TOT	MG/L	98
CHLORIDE	CL	MG/L	49
TOT HARD	CACO3	MG/L	430
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	44
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.6
SODIUM	NA,TOT	MG/L	12
SULFATE	SO4-TOT	MG/L	60
RESIDUE	TOTAL	MG/L	556
CNDUCTVY	AT 25C	MICROMHO	830
CYANIDE	CN	MG/L	<0.01

PS82			5/16/86
T ALK	CACO3	MG/L	327
CALCIUM	CA-TOT	MG/L	100
CHLORIDE	CL	MG/L	52
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	46
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.1
SODIUM	NA,TOT	MG/L	13
SULFATE	SO4-TOT	MG/L	63
RESIDUE	TOTAL	MG/L	548
CNDUCTVY	AT 25C	MICROMHO	840
CYANIDE	CN	MG/L	<0.01

PS82			8/13/86
T ALK	CACO3	MG/L	320
CALCIUM	CA-TOT	MG/L	95
CHLORIDE	CL	MG/L	54
TOT HARD	CACO3	MG/L	430
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	46
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.5
SODIUM	NA,TOT	MG/L	14
SULFATE	SO4-TOT	MG/L	58
RESIDUE	TOTAL	MG/L	626
CNDUCTVY	AT 25C	MICROMHO	910
CYANIDE	CN	MG/L	<0.01

PS83			2/12/86
WATER	TEMP	CENT	10
T ALK	CACO3	MG/L	313
CALCIUM	CA-TOT	MG/L	99
CHLORIDE	CL	MG/L	49
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	0.1
MGNSIUM	MG,TOT	MG/L	47
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.5
SODIUM	NA,TOT	MG/L	12
SULFATE	SO4-TOT	MG/L	72
RESIDUE	TOTAL	MG/L	548
CNDUCTVY	AT 25C	MICROMHO	831
CYANIDE	CN	MG/L	<0.01

PS83			5/16/86
T ALK	CACO3	MG/L	324
CALCIUM	CA-TOT	MG/L	9.0
CHLORIDE	CL	MG/L	50
TOT HARD	CACO3	MG/L	55
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	8
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.1
[redacted]			
SULFATE	SO4-TOT	MG/L	77
RESIDUE	TOTAL	MG/L	566
CNDUCTVY	AT 25C	MICROMHO	860
CYANIDE	CN	MG/L	<0.01

PS83			8/13/86
T ALK	CACO3	MG/L	324
CALCIUM	CA-TOT	MG/L	<1
CHLORIDE	CL	MG/L	61
TOT HARD	CACO3	MG/L	<6
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	<1
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.9
[redacted]			
SULFATE	SO4-TOT	MG/L	79
RESIDUE	TOTAL	MG/L	598
CNDUCTVY	AT 25C	MICROMHO	1000
CYANIDE	CN	MG/L	<0.01

PS84			2/12/86
T ALK	CACO3	MG/L	318
CALCIUM	CA-TOT	MG/L	96
CHLORIDE	CL	MG/L	46
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	49
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.4
SODIUM	NA,TOT	MG/L	12
SULFATE	SO4-TOT	MG/L	58
RESIDUE	TOTAL	MG/L	536
CNDUCTVY	AT 25C	MICROMHO	840
CYANIDE	CN	MG/L	<0.01

PS84			5/16/86
T ALK	CACO3	MG/L	327
CALCIUM	CA-TOT	MG/L	95
CHLORIDE	CL	MG/L	57
TOT HARD	CACO3	MG/L	440
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	48
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.2
SODIUM	NA,TOT	MG/L	15
SULFATE	SO4-TOT	MG/L	64
RESIDUE	TOTAL	MG/L	550
CNDUCTVY	AT 25C	MICROMHO	912
CYANIDE	CN	MG/L	<0.01

PS84			8/13/86
T ALK	CACO3	MG/L	312
CALCIUM	CA-TOT	MG/L	92
CHLORIDE	CL	MG/L	53
TOT HARD	CACO3	MG/L	420
IRON	FE	MG/L	<0.1
MGNSIUM	MG,TOT	MG/L	47
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.7
SODIUM	NA,TOT	MG/L	13
SULFATE	SO4-TOT	MG/L	59
RESIDUE	TOTAL	MG/L	598
CNDUCTVY	AT 25C	MICROMHO	900
CYANIDE	CN	MG/L	<0.01

PS85			2/12/86
WATER	TEMP	CENT	10
T ALK	CACO3	MG/L	262
CALCIUM	CA-TOT	MG/L	200
CHLORIDE	CL	MG/L	12
TOT HARD	CACO3	MG/L	730
IRON	FE	MG/L	0.4
MGNSIUM	MG,TOT	MG/L	54
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.4
SODIUM	NA,TOT	MG/L	5
SULFATE	SO4-TOT	MG/L	420
RESIDUE	TOTAL	MG/L	956
CNDUCTVY	AT 25C	MICROMHO	1200
CYANIDE	CN	MG/L	<0.01

PS85			5/16/86
T ALK	CACO3	MG/L	259
CALCIUM	CA-TOT	MG/L	180
CHLORIDE	CL	MG/L	13
TOT HARD	CACO3	MG/L	650
IRON	FE	MG/L	0.3
MGNSIUM	MG,TOT	MG/L	49
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.1
SODIUM	NA,TOT	MG/L	4.8
SULFATE	SO4-TOT	MG/L	410
RESIDUE	TOTAL	MG/L	924
CNDUCTVY	AT 25C	MICROMHO	1200
CYANIDE	CN	MG/L	<0.01

PS85			8/13/86
T ALK	CACO3	MG/L	262
CALCIUM	CA-TOT	MG/L	1
CHLORIDE	CL	MG/L	15
TOT HARD	CACO3	MG/L	<6
IRON	FE	MG/L	0.1
MGNSIUM	MG,TOT	MG/L	<1
MANGNESE	MN	UG/L	<40
LAB	PH	SU	7.5
[redacted]			
SULFATE	SO4-TOT	MG/L	380
RESIDUE	TOTAL	MG/L	884
CNDUCTVY	AT 25C	MICROMHO	1400
CYANIDE	CN	MG/L	<0.01

TABLE 3

WEST BEND SITE

PSW1 — 8/14/86

T ALK	CACO3	MG/L	334
CALCIUM	CA-TOT	MG/L	93
CHLORIDE	CL	MG/L	11
TOT HARD	CACO3	MG/L	400
IRON	FE	MG/L	9.6
MGNSIUM	MG,TOT	MG/L	42
MANGNESE	MN	UG/L	50
LAB	PH	SU	7.8
SODIUM	NA,TOT	MG/L	7
SULFATE	SO4-TOT	MG/L	19
RESIDUE	TOTAL	MG/L	490
CNDUCTVY	AT 25C	MICROMHO	660
CYANIDE	CN	MG/L	<0.01

TSW2 — 9/12/86

T ALK	CACO3	MG/L	310
CALCIUM	CA-TOT	MG/L	80
CHLORIDE	CL	MG/L	5.2
IRON	FE	MG/L	0.2
MGNSIUM	MG,TOT	MG/L	41
MANGNESE	MN	UG/L	<40
LAB	PH	SU	8.2
SODIUM	NA,TOT	MG/L	2
SULFATE	SO4-TOT	MG/L	23
RESIDUE	TOTAL	MG/L	430
CNDUCTVY	AT 25C	MICROMHO	650
CYANIDE	CN	MG/L	<0.01

PSW3 — 8/14/86

T ALK	CACO3	MG/L	298
CALCIUM	CA-TOT	MG/L	71
CHLORIDE	CL	MG/L	4.1
TOT HARD	CACO3	MG/L	320
IRON	FE	MG/L	1.6
MGNSIUM	MG,TOT	MG/L	36
MANGNESE	MN	UG/L	50
LAB	PH	SU	7.8
SODIUM	NA,TOT	MG/L	3
SULFATE	SO4-TOT	MG/L	32
RESIDUE	TOTAL	MG/L	374
CNDUCTVY	AT 25C	MICROMHO	570
CYANIDE	CN	MG/L	<0.01

TSW4 — 8/14/86

T ALK	CACO3	MG/L	42
CALCIUM	CA-TOT	MG/L	16
CHLORIDE	CL	MG/L	20
TOT HARD	CACO3	MG/L	69
IRON	FE	MG/L	4.6
MGNSIUM	MG,TOT	MG/L	7
MANGNESE	MN	UG/L	100
LAB	PH	SU	10.1
SODIUM	NA,TOT	MG/L	8
SULFATE	SO4-TOT	MG/L	14
RESIDUE	TOTAL	MG/L	788
CNDUCTVY	AT 25C	MICROMHO	160
CYANIDE	CN	MG/L	0.10

TABLE 4

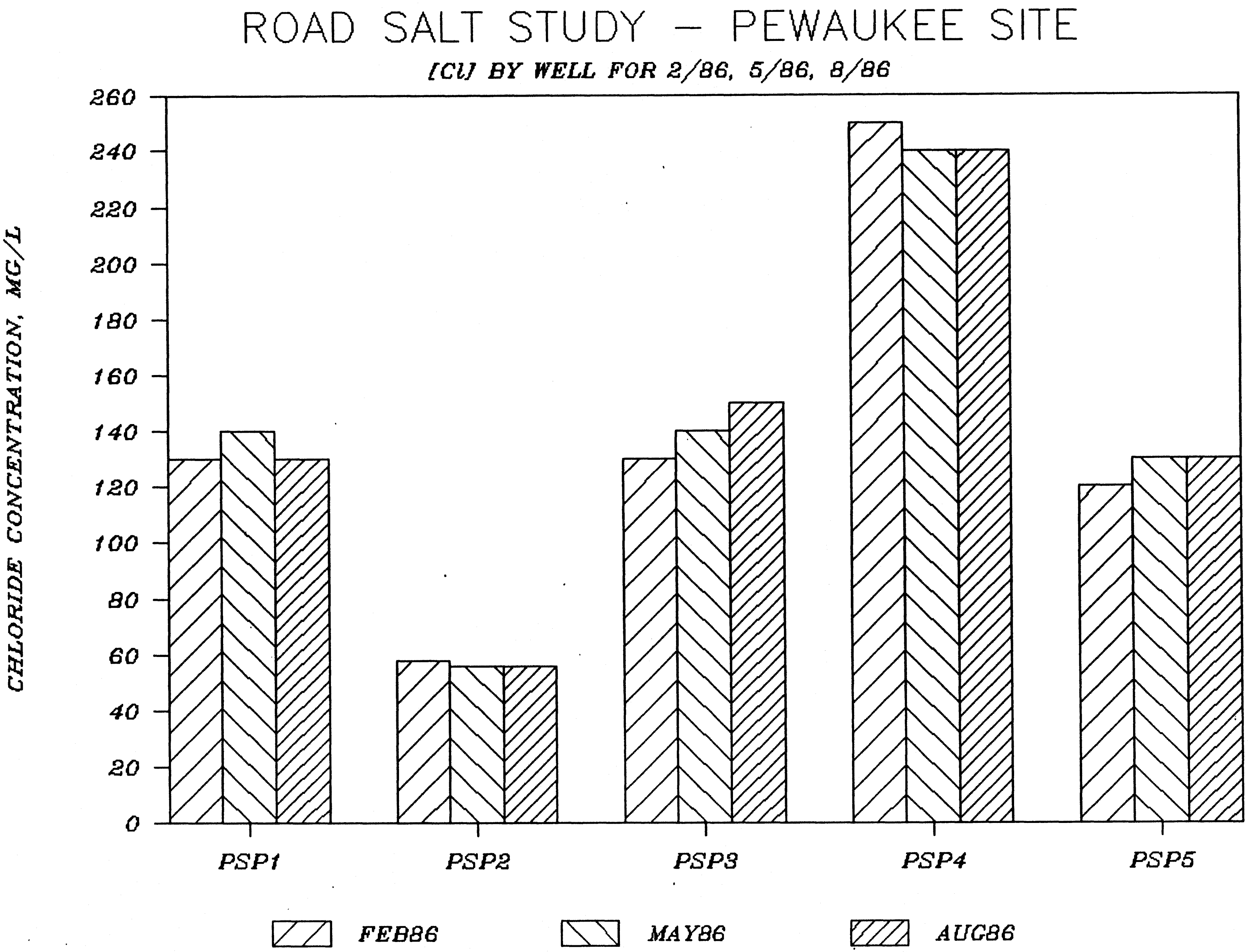

ROAD SALT STUDY - PEWAUKEE SITE
[Cl] BY WELL FOR 2/86, 5/86, 8/86
CHLORIDE CONCENTRATION, MG/L
260
240
220
200
180
160
140
120
100
80
60
40
20
0
PSP1
PSP2
PSP3
PSP4
PSP5
FEB86
MAY86
AUG86

TABLE 5

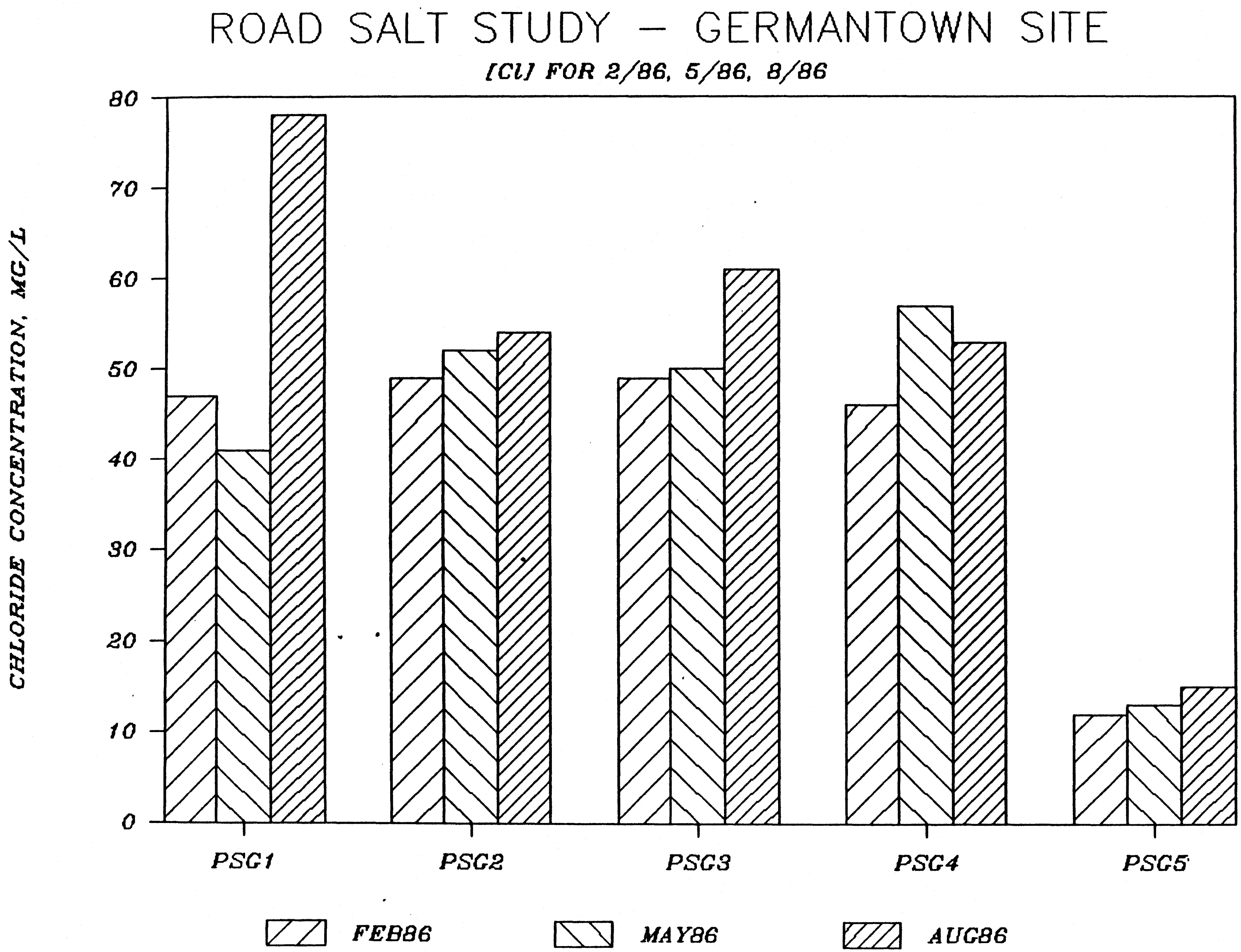

ROAD SALT STUDY — GERMANTOWN SITE
[Cl] FOR 2/86, 5/86, 8/86
CHLORIDE CONCENTRATION, MG/L
80
70
60
50
40
30
20
10
0
PSG1
PSG2
PSG3
PSG4
PSG5
FEB86
MAY86
AUG86

TABLE 6

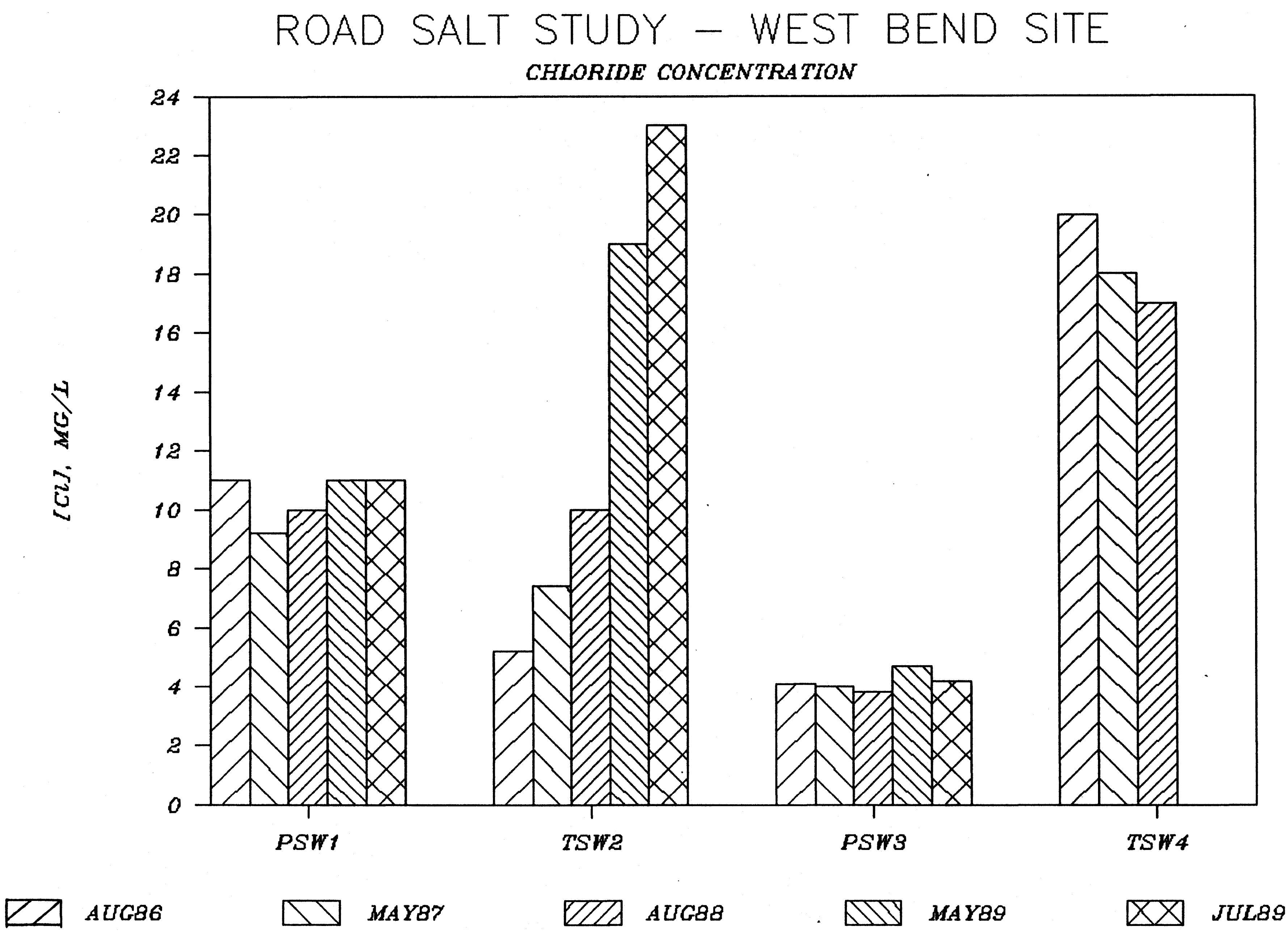

ROAD SALT STUDY - WEST BEND SITE
CHLORIDE CONCENTRATION
[Cl], MG/L
24
22
20
18
16
14
12
10
8
6
4
2
0
PSW1
TSW2
PSW3
TSW4
AUG86
MAY87
AUG88
MAY89
JUL89

TABLE 7

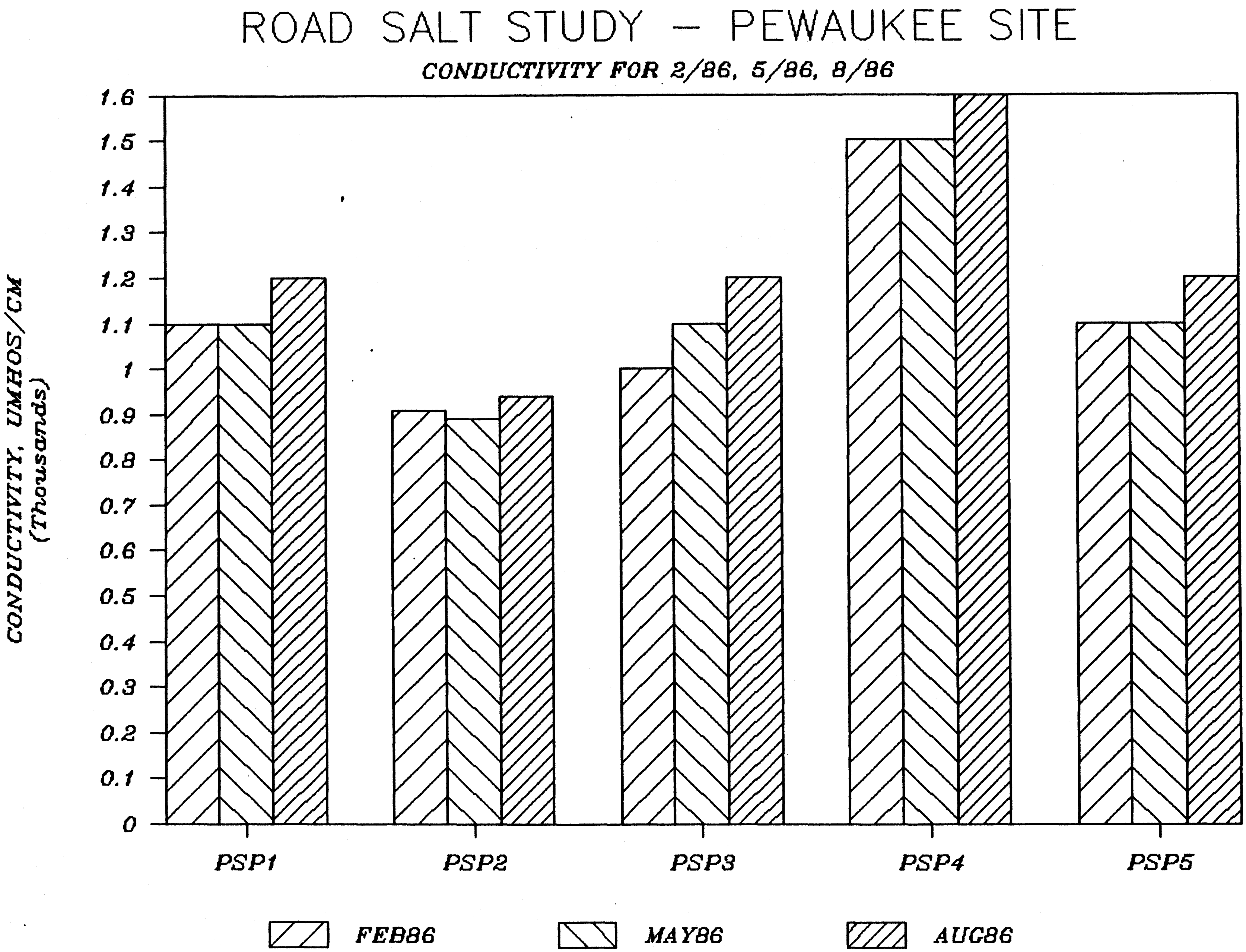

ROAD SALT STUDY – PEWAUKEE SITE
CONDUCTIVITY FOR 2/86, 5/86, 8/86
CONDUCTIVITY, UMHOS/CM
(Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PSP1
PSP2
PSP3
PSP4
PSP5
FEB86
MAY86
AUG86

TABLE 8

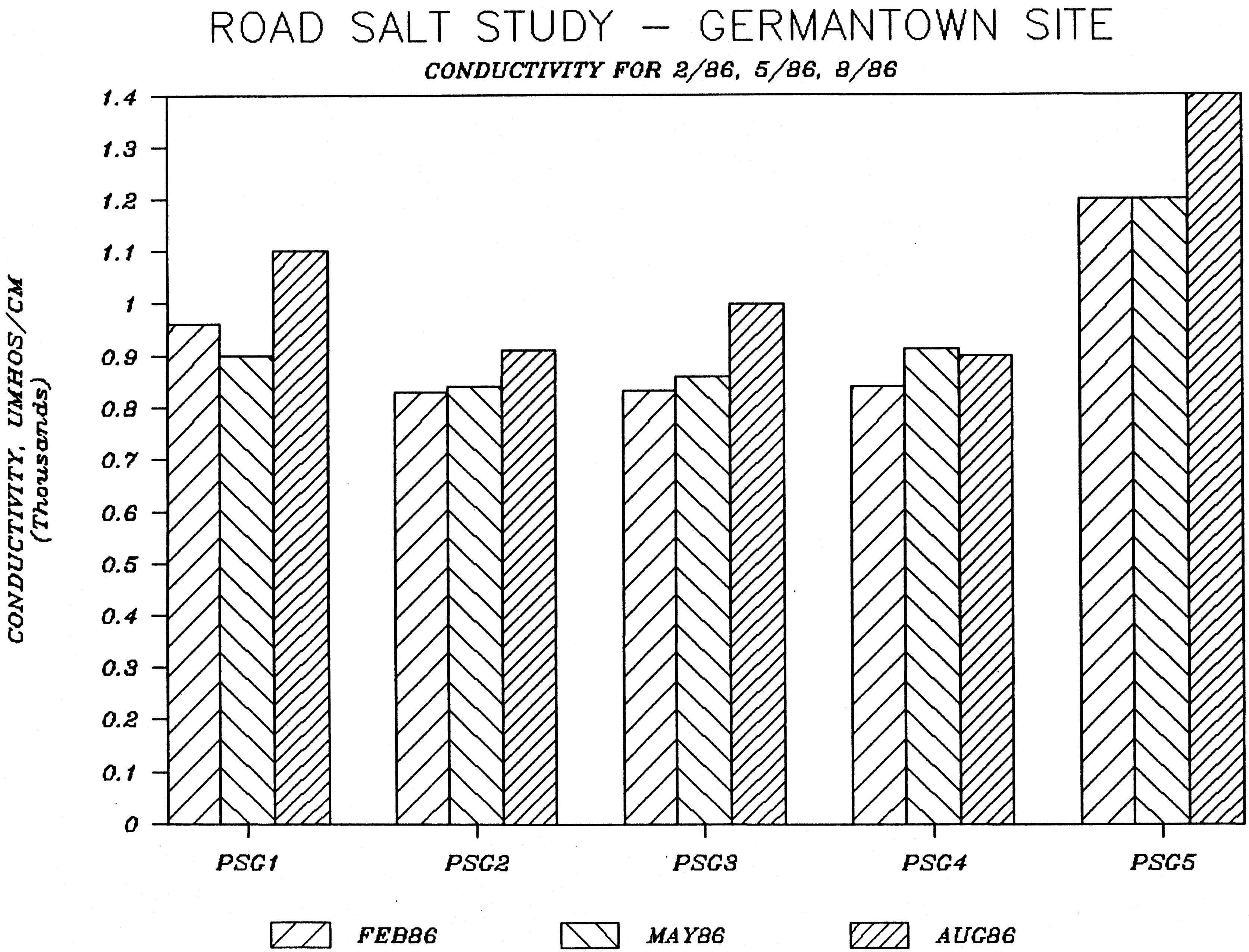

ROAD SALT STUDY - GERMANTOWN SITE
CONDUCTIVITY FOR 2/86, 5/86, 8/86
CONDUCTIVITY, UMHOS/CM
(Thousands)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PSG1
PSG2
PSG3
PSG4
PSG5
FEB86
MAY86
AUG86

TABLE 9

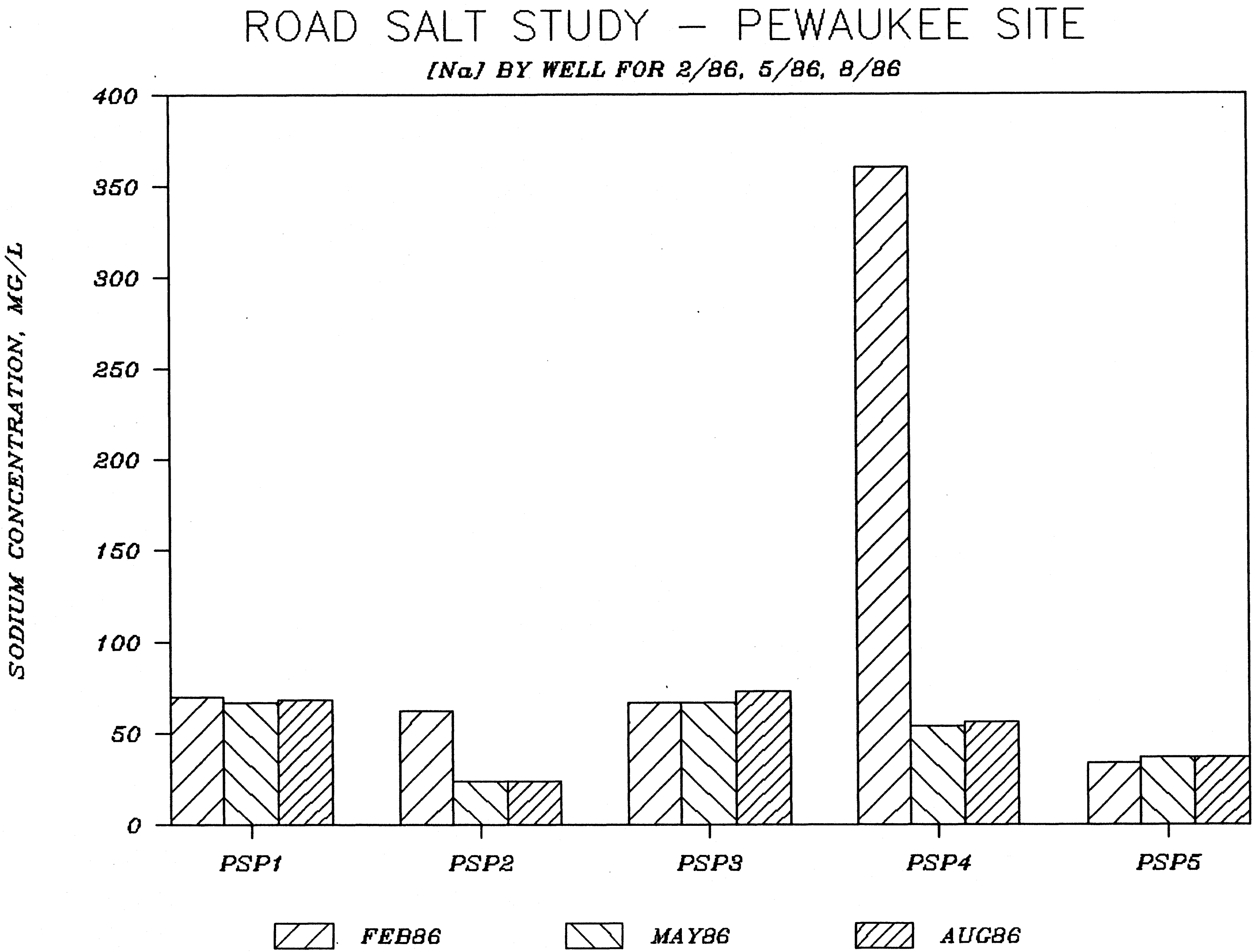
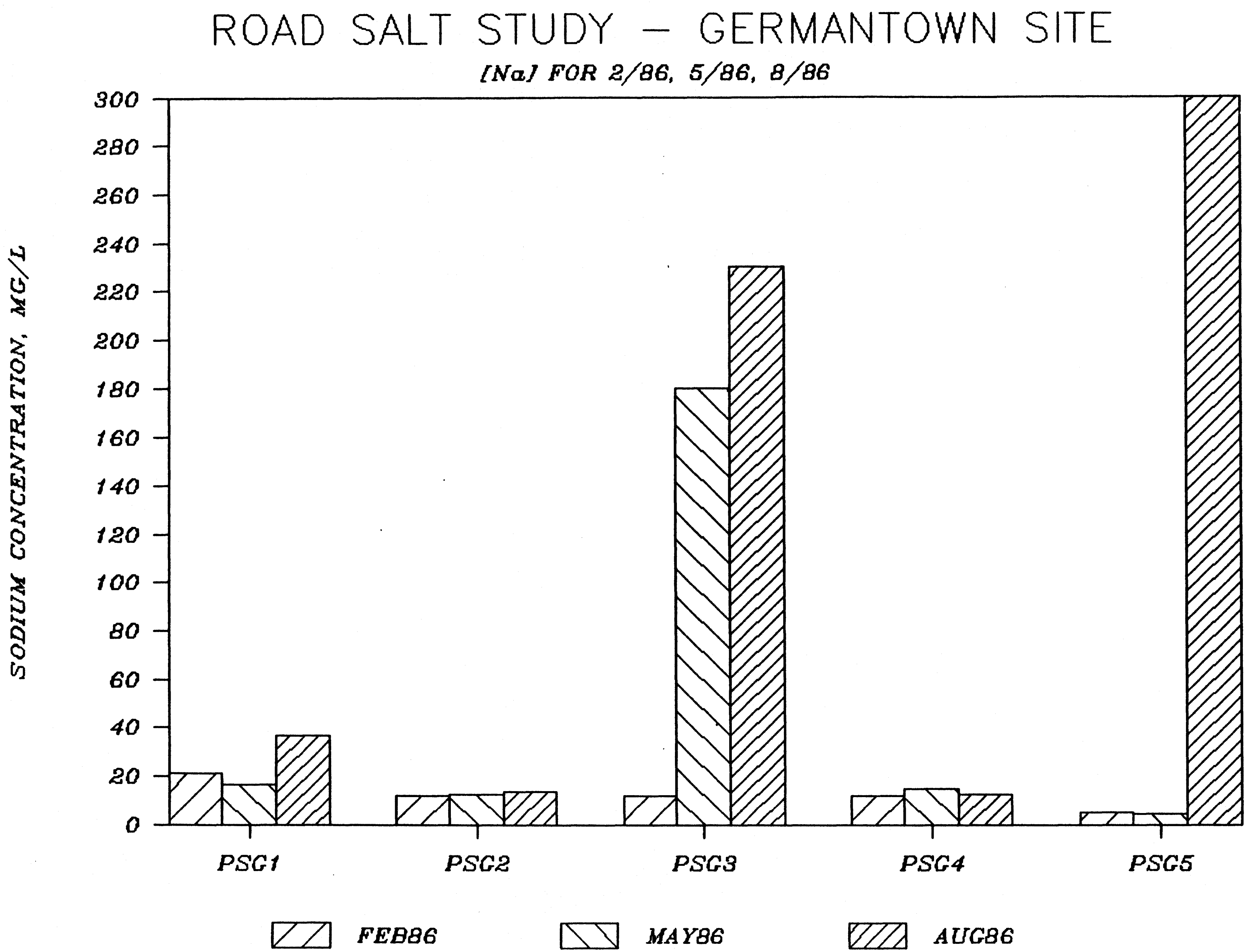

ROAD SALT STUDY – PEWAUKEE SITE
[Na] BY WELL FOR 2/86, 5/86, 8/86
SODIUM CONCENTRATION, MG/L
400
350
300
250
200
150
100
50
0
PSP1
PSP2
PSP3
PSP4
PSP5
FEB86
MAY86
AUG86

TABLE 10



ROAD SALT STUDY — GERMANTOWN SITE
[Na] FOR 2/86, 5/86, 8/86
SODIUM CONCENTRATION, MG/L
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
PSG1
PSG2
PSG3
PSG4
PSG5
FEB86
MAY86
AUG86

TABLE 11

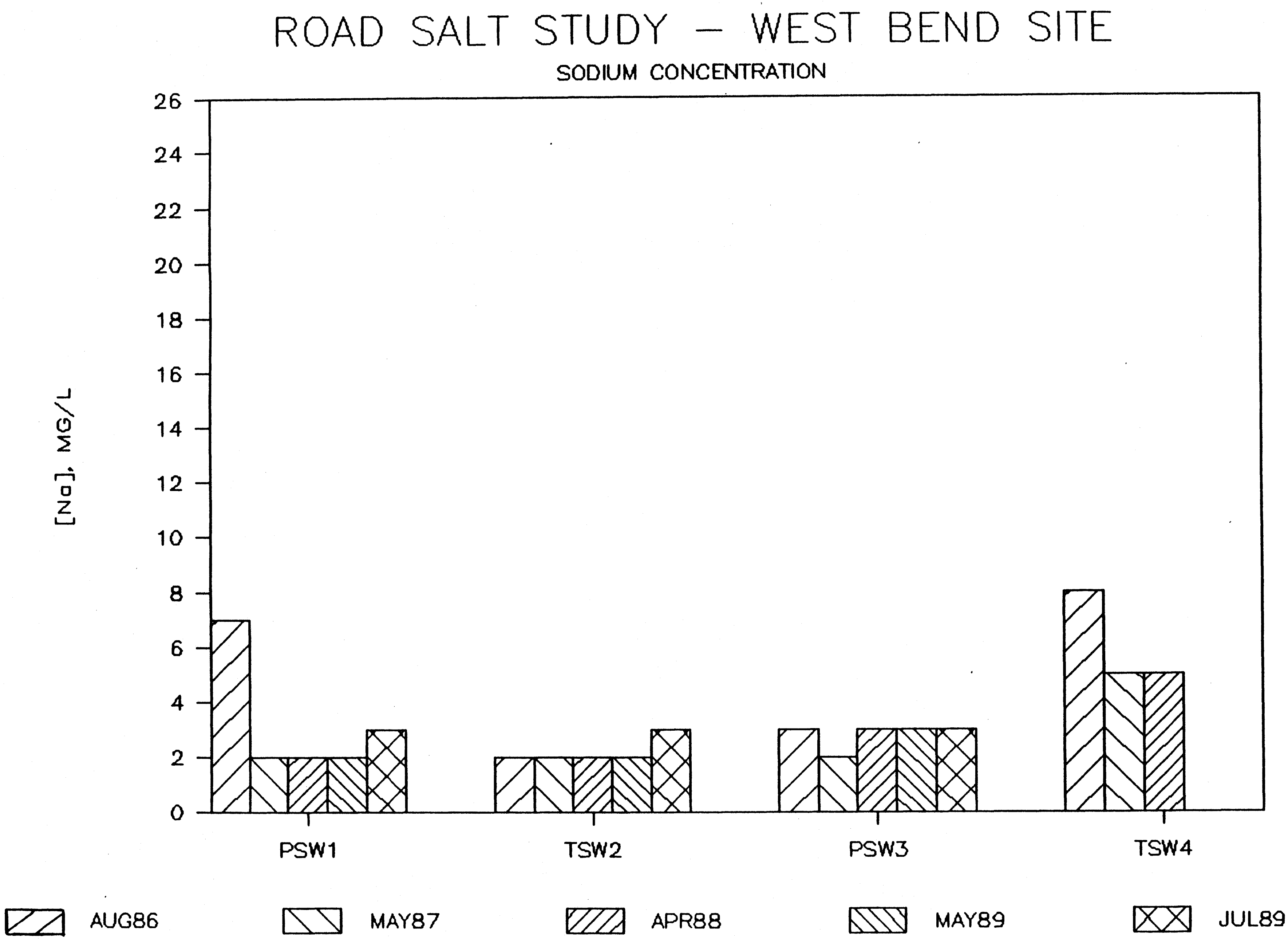

ROAD SALT STUDY – WEST BEND SITE
SODIUM CONCENTRATION
[Na], MG/L
0
2
4
6
8
10
12
14
16
18
20
22
24
26
PSW1
TSW2
PSW3
TSW4
AUG86
MAY87
APR88
MAY89
JUL89

TABLE 12

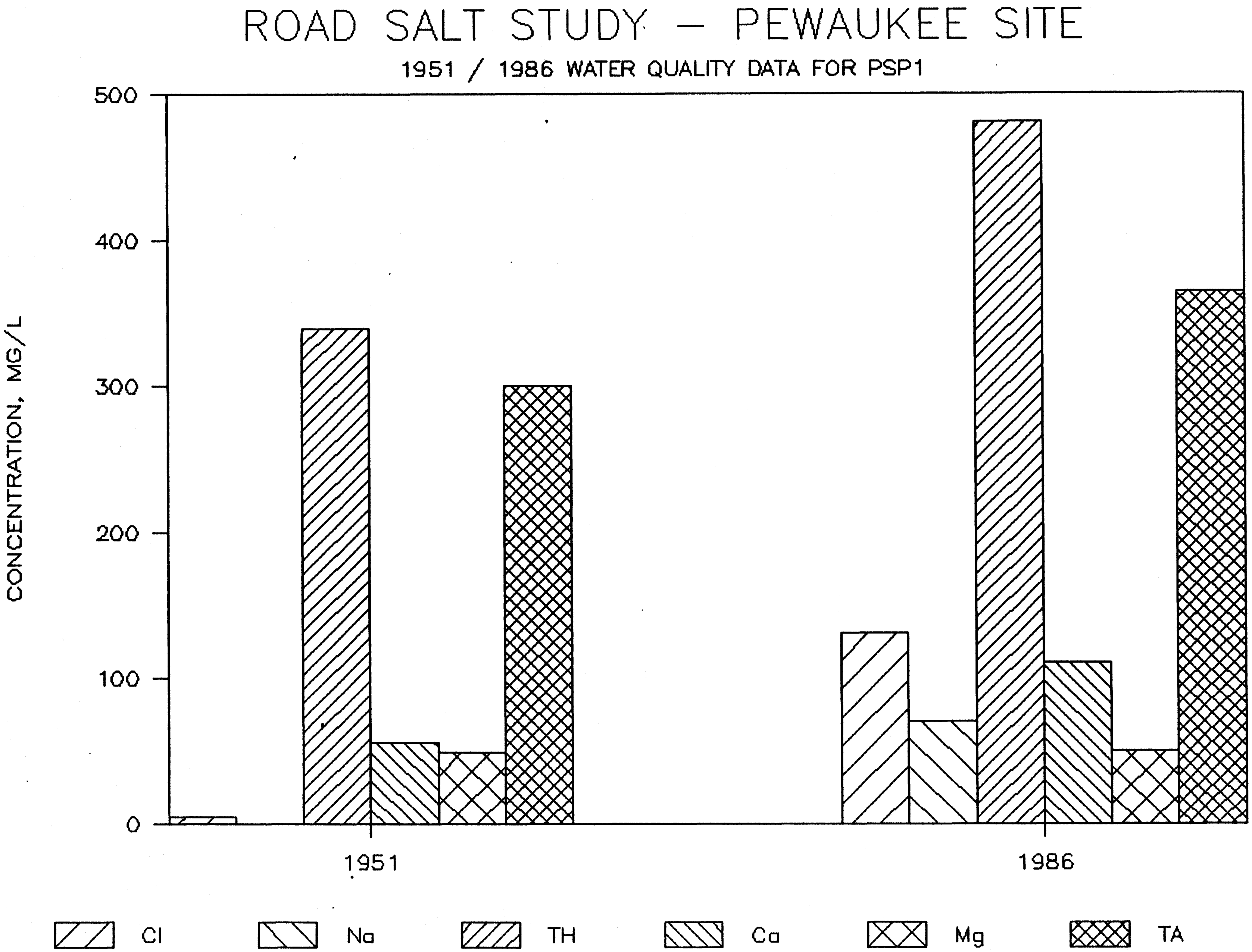

ROAD SALT STUDY – PEWAUKEE SITE
1951 / 1986 WATER QUALITY DATA FOR PSP1
CONCENTRATION, MG/L
500
400
300
200
100
0
1951
1986
Cl
Na
TH
Ca
Mg
TA

TABLE 13

PEWAUKEE SITE

Well PSP1

Parameter (mg/l)	November, 1951	February, 1986
Total Alkalinity (CaCO3)	300	365
Calcium	56	110
Chloride	5	130
Total Hardness (CaCO3)	340	480
Iron	0.24	less than 0.1
Magnesium	49	50
pH (standard units)	7.3	7.8
Sodium	0	70
Sulfate	29	39
Total Dissolved Solids	366	--
Total Residue	--	694

TABLE 14

PEWAUKEE SITE

Well # Owner Name	Parameter (mg/l)	1st Q 2/11/86	2nd Q 5/15/86	3rd Q 8/13/86	4thQ n/a
PSP1	Chloride	130	140	130	
Pettersen	Sodium	70	67	68	
	Conductivity (umhos)	1100	1100	1200	
PSP2	Chloride	58	94	56	
Wilde	Sodium	62	24	24	
	Conductivity	910	890	940	
PSP3	Chloride	130	140	150	
Wiedmeyer	Sodium	67	67	73	
	Conductivity	1000	1100	1200	
PSP4	Chloride	250*	240	240	
Kaulbach	Sodium	360*	54	56	
	Conductivity	1500*	1500	1600	
PSP5	Chloride	120	130	130	
Jerabek	Sodium	34	37	37	
	Conductivity	1100	1100	1200	

PSP = Private Well - Salt Study - Pewaukee
* = Soft water sample

TABLE 15

GERMANTOWN SITE

Well # Owner Name	Parameter (mg/l)	1st Q 2/12/86	2nd Q 5/16/86	3rd Q 8/13/86	4thQ n/a
PSG1	Chloride	47	41	78	
Wilegus	Sodium	21	17	37	
	Conductivity (umhos)	960	900	1100	
PSG2	Chloride	49	52	54	
Carriage Hills	Sodium	12	13	14	
Apartments	Conductivity	830	840	910	
PSG3	Chloride	49	50*	61*	
Guzzanato	Sodium	12	180*	230*	
(Otto)	Conductivity	831	860*	1000*	
PSG4	Chloride	46	57	53	
Gronemeyer	Sodium	12	15	13	
	Conductivity	840	912	900	
PSG5	Chloride	12	13	15*	
Germantown	Sodium	5	4.8	300*	
Mutual Ins.	Conductivity	1200	1200	1400*	

PSG = Private Well - Salt Study - Germantown
* = Soft water sample

TABLE 16

WEST BEND SITE

Well #	Parameter (mg/l)	8/86	5/87	4/88	5/89	7/89	5/90
(upgradient)							
TSW4	Chloride	20	18	17	--	--	--
	Sodium	8	5	5	--	--	--
(upgradient)							
TSW6	Chloride	--	--	--	--	20	--
	Sodium	--	--	--	--	7	--
(downgradient)							
PSW1	Chloride	11	9.2	10	11	11	12
	Sodium	7	2	2	2	3	3
(downgradient)							
TSW2	Chloride	5.2	7.2	10	19	23	31
	Sodium	2	2	2	2	3	4
(downgradient)							
PSW3	Chloride	4.1	4	3.8	4.7	4.2	6.2
	Sodium	3	2	3	3	3	2

PSW = Private Well - Salt Study - West Bend
TSW = Test Well - Salt Study - West Bend

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REFERENCES

Blackburn, R.R., and St. John, A.D., Physical alternatives to chemicals for highway deicing, National Research Council, Transportation Research Board Special Report No. 185, p.176-184, National Academy of Science, Washington, D.C., 1979.

Field, R., Struzeski, Jr., E.J., Masters, H.E., and Tafuri, A.N., Water pollution and associated effects from street salting, Journal of the Environmental Engineering Division, v.100, p.459-475, April, 1974.

Hofstra, G. and Smith, D.W., The effects of road deicing salt on the levels of ions in roadside soils in southern Ontario, Journal of Environmental Management, v.19, n.3, p.261-271, October, 1984

Huling, E.E., and Hollocher, T.C., Groundwater contamination by road salt: steady-state concentrations in east central Massachusetts, Science, v.176, n.4032, p.288-290, 1972.

Jones, P.H., Snow and ice control and the transport environment, Environmental Conservation, v.8, n.1, p.33-38, Spring, 1981.

Moyland, R.L., City examines effects of road salting on its water supply, Public Works, p.59-60, August, 1980.

Murray, D.M., and Ernst, U.F.W., An ecomonic analysis of the environmental impact of highway deicing, Environmental Protection Technology Series, Municipal Environmental Research Laboratory, Office of Research and Development, p.2-15, U.S. EPA, May, 1976.

Saleem, Z.A., Road salts and quality of ground-water from a dolomite aquifer in the Chicago area, In: Hydrologic Problems in Karst Regions; proceedings of symposium held at Western Kentucky University, Bowling Green, Kentucky, p.364-368, 1977.

USGS Hydrologic Investigations Atlas HA-360, Water Resources of Wisconsin Rock-Fox River Basin, Cotter, R.D., Hutchinson, R.D., Skinner, E.L., and Wentz, D.A., Washington, D.C., 1969.

USGS Hydrologic Investigations Atlas HA-432, Water Resources of Wisconsin--Lake Michigan Basin, Skinner, E.L., and Borman, R.G., Washington, D.C., 1973.

Warzyn Engineering Inc., Report No. 13480, Phase I Remedial Investigation, Schuster Drive Landfill, Town of Barton, Washington County, Madison, Wisconsin, November, 1989.

Wisconsin Administrative Code, Chapter NR109, Register August, 1989, No. 404; Chapter NR140, Register October, 1988, No. 394, Wisconsin Department of Natural Resources, P.O. Box 7921, Madison, Wisconsin, 53707.

Wisconsin Department of Transportation, 3502 Kinsman Boulevard, Madison, Wiscosin, 53704, Road salt tonnage data by county, 1986.

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